Volume 1

Building a Sustainable Future

Proceedings of the 2009 Construction Research Congress



Edited by
Samuel T. Ariaratnam, Ph.D., P.E.
Eddy M. Rojas, Ph.D.

ASCE

CI
Construction Institute

BUILDING A SUSTAINABLE FUTURE

VOLUME ONE

PROCEEDINGS OF THE 2009 CONSTRUCTION RESEARCH CONGRESS

April 5–7, 2009
Seattle, Washington

SPONSORED BY
Construction Institute (CI)
of the American Society of Civil Engineers

University of Washington

EDITED BY
Samuel T. Ariaratnam, Ph.D., P.E.
Eddy M. Rojas, Ph.D.

Published by the American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data

Construction Research Congress (2009 : Seattle, Wash.)
Building a sustainable future : proceedings of the 2009 Construction Research Congress, April 5-7, 2009, Seattle, Washington / sponsored by Construction Institute of the American Society of Civil Engineers [and] University of Washington ; edited by Samuel T. Ariaratnam, Eddy M. Rojas.
v. cm.
Includes bibliographical references and index.
ISBN 978-0-7844-1020-2
1. Building--Technological innovations--Congresses. 2. Construction industry--Congresses. 3. Sustainable architecture--Congresses. I. Ariaratnam, S. T. II. Rojas, Eddy M. III. Construction Institute. IV. University of Washington. V. Title.

TH5.C67 2009
624--dc22 2009005848

American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4400

www.pubs.asce.org

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefore. This information should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing this information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

ASCE and American Society of Civil Engineers—Registered in U.S. Patent and Trademark Office.

Photocopies and reprints.
You can obtain instant permission to photocopy ASCE publications by using ASCE's online permission service (http://pubs.asce.org/permissions/requests/). Requests for 100 copies or more should be submitted to the Reprints Department, Publications Division, ASCE, (address above); email: permissions@asce.org. A reprint order form can be found at http://pubs.asce.org/support/reprints/.

Copyright © 2009 by the American Society of Civil Engineers. All Rights Reserved.
ISBN 978-0-7844-1020-2
Manufactured in the United States of America.

Preface

We would like to welcome you to the 2009 Construction Research Congress (CRC) sponsored by the Construction Institute (CI) of the American Society of Civil Engineers (ASCE) and hosted by the University of Washington. The theme of "Building a Sustainable Future" is one that reflects a priority for construction professionals. It is only fitting that the Congress is held in picturesque Seattle, a city known worldwide for environmental preservation and sustainable development.

The two-volume Proceedings contain 152 peer reviewed papers covering 16 general state-of-knowledge research topic areas in construction engineering and management. There were 285 abstracts initially submitted that were reduced to 167 accepted draft papers following a peer review. From this, a final 152 papers were accepted for publication and presentation based on the same double peer review process used in abstract selection.

We are delighted to see that this event is truly global with representation from 16 foreign countries including Canada, Colombia, Thailand, Israel, United Kingdom, Saudi Arabia, India, Singapore, Hong Kong, China, Korea, Japan, Brazil, Australia, Turkey, and South Africa.

Our sponsors merit special mention. We would like to recognize our Platinum Sponsors – Mortensen Construction, Kiewit Corporation, and Turner Construction and our Gold Sponsor – GLY Construction. Their participation is greatly appreciated and enabled us to enhance many of the Congress activities.

In closing, we both hope that you enjoy these Proceedings and have a memorable experience of both the Congress and Seattle. It will be an excellent opportunity to catch up with old friends and colleagues and make new ones!



Samuel T. Ariaratnam, Ph.D., P.E.
Arizona State University
2009 CRC Technical Program Chair



Eddy M. Rojas, Ph.D.
University of Washington
2009 CRC Conference Chair

Acknowledgments

The 2009 Construction Research Congress Technical Program Committee should be acknowledged for their dedication and contributions to the conference program.

Conference Program Committee members are listed below:

Eddy Rojas, University of Washington (Conference Chair)

Samuel Ariaratnam, Arizona State University (Technical Program Chair)

Ahmel-Abdel Aziz, University of Washington

Yong Bai, University of Kansas

Carrie Dossick, University of Washington

Christine Fiori, Virginia Tech University

Jimmie Hinze, University of Florida

Vineet Kamat, University of Michigan

YongWoo Kim, University of Washington

Gunnar Lucko, Catholic University

John Messner, Penn State University

Giovanni Migliaccio, University of New Mexico

Panagiotis Mitropoulos, Arizona State University

Keith Molenaar, University of Colorado

Amlan Mukherjee, Michigan Tech University

William O'Brien, University of Texas

Aminah Robinson, University of Alberta

Janaka Ruwanpura, University of Calgary

John Schaufelberger, University of Washington

Lucio Soibelman, Carnegie Mellon University

Kenneth Sullivan, Arizona State University

Xiangyu Wang, University of Sydney

Contents

Volume One

Automated/Real-Time Systems for Project Control

An Automated Tool for Identifying the Implications of Changes in Construction Projects 1
Ronie Navon and Shabtai Isaac

Development of Human Pose Analyzing Algorithms for the Determination of Construction Productivity in Real-Time 11
Abhinav Peddi, Luke Huan, Yong Bai, and Seonghoon Kim

Benefits and Barriers of Monitoring Construction Activities Using Hi-Resolution Automated Cameras 21
Jeffrey S. Bohn and Jochen Teizer

Pro-Active-Real-Time Personnel Warning System 31
Clare E. Fullerton, Ben S. Allread, and Jochen Teizer

Interactive Visual Construction Progress Monitoring with D^4 AR—4D Augmented Reality—Models 41
Mani Golparvar-Fard, Silvio Savarese, and Feniosky Peña-Mora

Visualization Application for Interior Progress Monitoring in 3D Environment 51
Seungjun Roh, Feniosky Peña-Mora, Mani Golparvar Fard, and SangUk Han

Automated Data Acquisition System to Assess Construction Worker Performance 61
I.P. Tharindu Weerasinghe and Janaka Y. Ruwanpura

Project Information Management in Mega Oil Sands Projects 71
Zonghai Han and Thomas Froese

Validation of Vision Tracking at Egnatia Odos Motorway 81
Francisco Cordova, Dimitris Sideris, Ioannis Brilakis, and Demos C. Angelides

Operations, Productivity, and Workforce Issues

Towards Establishing an Innovativeness Index for Construction Sites 91
Andrew P. McCoy

Evaluation of Work Zone Capacity Models 101
Carolyn Hicks, Brenda McCabe, and Susan Tighe

The Relationship between Information Technology and Construction Productivity: A View from Country-Level Data 111
Dong Zhai and Paul M. Goodrum

Construction Industry Productivity: Omitted Quality Characteristics in Construction Price Indices 121
Bryan D. Dyer and Paul M. Goodrum

Measuring Construction Productivity Using the Write System.....131
Seonghoon Kim, Yong Bai, Luke Huan, and Abhinav Peddi

Construction Student Technology Skill Assessment: A Survey Instrument.....141
Thuy Nguyen, William O'Brien, and Kathy Schmidt

3D-GIS Based Earthwork Planning System for Productivity Improvement.....151
Sang Hyeok Kang, Jong Won Seo, and Kyeong Geun Baik

Surveying Methods for Bilingual Construction Workers.....161
Jenna Brummett and MaryEllen C. Nobe

Overtime and Productivity in Electrical Construction.....171
Awad S. Hanna and Gilbert Haddad

Procurement and Contracting

Unabsorbed Overhead: Eichleay and Other Methods.....181
Amarjit Singh and Thomas Taam

Approaches for Structuring Concession Lengths and Toll Rates for Transportation Infrastructure PPPs.....191
Martha E. Gross and Michael J. Garvin

Analyzing the Institutional Framework for Urban Public Private Partnerships in Indian States.....201
Ganesh A. Devkar, Ashwin Mahalingam, and Satyanarayana N. Kalidindi

Effects of the Regulatory Environment on Construction Project Delivery Method Selection.....211
Valerie R. Riecke Smith, Daniel Castro-Lacouture, and Rita Oberle

Development of a Fuzzy Expert System for Surety Underwriting.....219
Krista Marsh and Aminah Robinson Fayek

Analysis of Design-Build Procurement Activities Durations for Highway Projects.....229
Giovanni C. Migliaccio and Pramen P. Shrestha

Factors Affecting Litigation Outcomes of Differing Site Conditions (DSC) Disputes: A Logistic Regression Model (LRM).....239
Tarek Mahfouz and Amr Kandil

Study of Less Than Average Bid Method.....249
Rita E. Awwad and Photios G. Ioannou

Investigation of Supply Chain Management Practices in Industrial Projects: State of Practice vs. State of Knowledge.....259
Marcelo M. Azambuja and William J. O'Brien

A New Approach to Contracting Design Professionals.....269
John K. Michael, Brad D. Carey, and Kenneth T. Sullivan

Mapping the Value Thread in Local Government Service Delivery in South Africa.....279
C. I. Jay, P. A. Bowen, and K. S. Cattell

How Far a Contract Can Be Stretched? The First Building Block for Procurement Engineering.....288
Chen-Yu Chang

Organizational Leadership and Management

Exploring the Learning Styles of the Construction Practitioners in Hong Kong.....298
Peter S. P. Wong, Sai On Cheung, and Wally S. W. Lai

Integrating Uncertainty Management in Strategic Planning Practice.....309
Robby Soetanto and Andrew R. J. Dainty

The Last Decade Analysis and the Near Future Trends in International Construction 320
Suat Gunhan

Beyond Sustainability: The Contractor's Role in Regenerative System Design.....330
Rebecca Mirsky and Anthony D. Songer

Acquiring Local Knowledge for International Projects 338
Amy Javernick-Will and Raymond Levitt

Investigation and Modeling of Critical Success Factors in Construction Organizations.....350
Emad Elwakil, Mohammad Ammar, Tarek Zayed, Muhammad Mahmoud, Ahmed Eweda, and Ibarhim Mashhour

Use of A3 Reports to Focus Design and Construction Conversations 360
Kristen Parrish, Iris D. Tommelein, and Glenn Ballard

Creating Organizational Change: Minimizing Client Generated Construction Inefficiencies at the US Army Medical Command 370
Jacob S. Kashiwagi, Neha Malhotra, Eduardo Luna, Dean T. Kashiwagi, and Kenneth T. Sullivan

Technologies to Improve Project Planning, Design, and Construction

How to Determine Construction Project Rain Delay Times Using Local Rainfall Databases in Asheville, NC 380
George Ford, John Patterson, and Bradford Sims

Integrated Module for Mobile Crane Dynamic Instability Analysis and Supporting System Design 386
Shafiul Hasan, Mohamed Al-Hussein, U. H. Hermann, and Hassan Safouhi

The Realities of Building Information Modeling for Collaboration in the AEC Industry.....396
Carrie S. Dossick, Gina Neff, and Hoda Homayouni

Virtual Construction Automation for Modular Assembly Operations.....406
Jacek Olearczyk, Mohamed Al-Hussein, Ahmed Bouferguene, and Avi Telyas

Identification of Data Items Needed for Automatic Clash Detection in MEP Design Coordination 416
Fernanda Leite, Burcu Akinci, and James Garrett, Jr.

Early Design Energy Analysis Using BIMs (Building Information Models) 426
Annette Stumpf, Hyunjoo Kim, and Elisabeth Jenicek

Improving Site Utilization Planning through the Use of Interactive Workspaces 437
Robert M. Leicht and John I. Messner

Nanotechnology: Benefits, Barriers, and Impact on Construction.....447
Manu Venugopal, Jochen Teizer, and Winfried Teizer

Ontology-Based, Semi-Automatic Framework for Storing and Retrieving On-Site Construction Problem Information—An RFID-Based Case Study 457
Tarek Elghamrawy, Frank Boukamp, and Ho-Sung Kim

Building Information Model: The Role and Need of the Constructors.....467
Pooyan Aslani, F. H. (Bud) Griffis, and Lawrence Chiarelli

Developing Construction Network-Based Interface Management System 477
Yu-Cheng Lin

Virtual Supervision in Construction Projects.....487
Lahiru P. Silva, Janaka Y. Ruwanpura, and Kasun N. Hewage

3D Work Environment Modeling for the Intelligent Excavation System (IES).....497
M. Chae, G. Lee, J. Park, J. Kim, and M. Cho

Querying IFC-Based Building Information Models to Support Construction Management Functions 506
M. P. Nepal, J. Zhang, A. Webster, S. Staub-French, R. Pottinger, and M. Lawrence

Advanced Quality Control Methods for Road Paving Construction by Utilizing Sensory Devices 516
Yong K. Cho, Thaddaeus Bode, and Yong-Rak Kim

Sustainable Construction and Facilities

Embodied Energy of CDW Recycling and Technical Metabolism Due to Regional Differences and Building Designs.....526
Christopher Hermreck and Wai K. (Oswald) Chong

A Proposed Eco-Labeling Method for Building Design.....537
Joseph Rendall and Wai K. (Oswald) Chong

A Decision-Making Framework to Assess Stakeholder Value in Adoption of Sustainable Practices in Construction 548
Amlan Mukherjee and Helen Muga

Key Attributes of a Longitudinal Study of Green Project Delivery.....558
Sinem Korkmaz, Michael Horman, and David Riley

Performance Testing of an Integrated Solar Collector System 568
Marwa Hassan and Yvan Beliveau

Incentives for Green Residential Construction 578
Michael Sauer and Khalid Siddiqi

Adaptable and Visitable Housing: Affordable and Sustainable Changes 588
Lisa M. Johnson and Qian Chen

LEED Certification: A Constructor's Perspective 598
John Schaufelberger and Joshua Cloud

Optimization Model for the Selection of Materials Using the LEED Green Building Rating System 608
Daniel Castro-Lacouture, Jorge A. Sefair, Laura Flórez, and Andrés L. Medaglia

Quantification of Carbon Footprint on Underground Utility Projects 618
Shaik Sihabuddin and Samuel T. Ariaratnam

Improving Energy Efficiency in Building through Automated Computer Design Process 628
Jason Charalambides

Key Processes in the Building Delivery of Green Hospitals 636
Elena Enache-Pommer and Michael Horman

An Investigation of Real Option Theory to Evaluate Design, Procurement, and Construction of Renewable Energy Facilities 646
Carol Menassa and Feniosky Peña Mora

Economic and Environmental Analysis of Residential Greywater Systems for Toilet Use 655
Scott Glick, Angela Acree Guggemos, and Santosh Prakash

Sustainability for Advanced Technology Facilities 665
Allan D. Chasey and Atul Kumar Jain

Project Risks and Safety

Financial Model for Insuring against Catastrophic Storm Risks 675
Islam H. El-adaway

Development of the STAR Tool for the Management of Shutdown/Turnaround/Outage Projects 685
Donald A. Whittington and G. Edward Gibson, Jr.

Integrating Productivity and Safety Analysis with the Task Demand Methodology: A Case of Concrete Paving 695
Panagiotis "Takis" Mitropoulos and Manoj Namboodiri

The Validity of Data Dependent System Modelling to Predict Relative Physiological Workload during Construction Work 705
Tariq Abdelhamid, Lili Xi, and John G. Everett

Catastrophe Risk Management for Private-Public Partnership (PPP) Infrastructure Projects 716
Qiyu Qian and Robert Tiong Lee Kong

Applying Insurance Pricing Theory for Pricing ADR as an Insurance Product 726
Xinyi Song, Carol Menassa, Feniosky Peña Mora, and Robert F. Conger

A Prediction Model for Construction Project Time Contingency 736
Dalia Mohamed, Florida Srour, Wael Tabra, and Tarek Zayed

Project Risk Identification Methods for Construction Planning and Execution 746
Robert G. Batson

Supporting Market Entry Decisions for Global Expansion Using Real Option + Scenario Planning Analysis 756
Du Yon Kim, Byungil Kim, and Seung Heon Han

Resilience Engineering: A New Approach for Safety Management 766
D. Schafer, T. S. Abdelhamid, P. Mitropoulos, and T. Mrozowski

Identifying and Communicating Project Stakeholder Risks 776
Peter J. Edwards, Paul A. Bowen, Cliff Hardcastle, and Peter J. Stewart

A Risk-Based Approach to Contingency Estimation in Highway Project Development 786
Keith R. Molenaar and Craig R. Wilson

Volume Two

Project Planning and Control

Aligning Pre-Construction Planning and Project Management in the Electrical Construction Industry 796
Ziad Bou Nasr and Cindy L. Menches

Multi-Objective Optimization of Resource Scheduling in Construction Projects 806
Dho Heon Jun and Khaled El-Rayes

Automated CPM Schedule Generation for Early Project Planning: Methodology and Case Study 816
Youngsoo Jung, Young Hwan Lee, Sungkwon Woo, Jin-Soo Yang, Sang-Mok An, Young-Seok Oh, and Bok Nam Lee

Developing Effective Visual Representations to Monitor Project Performance 826
Namhun Lee and Eddy M. Rojas

Life-Cycle Assessment of Titanium Dioxide Coatings 836
Marwa Hassan

Global Optimization of Dynamic Site Layout Planning in Construction Projects 846
Khaled El-Rayes and Hisham Said

Understanding Collaborative Working Processes of Temporary Project Teams in Large-Scale Construction Projects 856
JeongWook Son and Eddy M. Rojas

Modeling the Effect of an Alternative Review Process: Case Study of a State Permitting Agency 866
Peter P. Feng, Iris D. Tommelein, and Glenn Ballard

An Approach to Classifying Uncertainties in Construction Schedules 876
H. Clay Phillips, Susan M. Bogus, and Timothy J. Ross

Assessment of Methods for Adjusting Construction Cost Estimates by Geographical Location 886
Giovanni C. Migliaccio, Paul Zandbergen, and Adam A. Martinez

Time Prediction for Highway Pavement Projects Using Regression Analysis 896
Ahmed M. Abdel Aziz

Development of People-Based Maps Experience Management System for Construction Projects 906
Yu-Cheng Lin

Application of the Resource-Constrained Critical Path Method to Multiple Calendars and Progressed Schedules 916
Jesús M. de la Garza and Kyunghwan Kim

Validating Renovation Phasing Schedules Using 4D Model Based Methods 926
Peggy Ho and Martin Fischer

Mapping Actors and Roles in Construction Knowledge 936
J. Zhang and T. E. El-Diraby

Project/Process Integration and Improvement

The Current Use of Offsite Construction Techniques in the United States Construction Industry 946
Na Lu

Forecasting Construction Manpower Demand: An Econometric Model 956
James M. W. Wong, S. Thomas Ng, Albert P. C. Chan, and Y. H. Chiang

The Core of Eden: A Case Study on Model-Based Collaboration for Integrated Project Delivery 969
Kihong Ku

Visualization Configuration Model for Integrating Presentation of Construction Project Management Data 979
Jianguo David Ye and Thomas Froese

Stakeholder Views on IT in Construction: A North American Perspective 989
Kasun N. Hewage, Janaka Y. Ruwanpura, and George F. Jergeas

Rules and Guidelines for Improving the Mechanical, Electrical, and Plumbing Coordination Process for Buildings 999
Thomas M. Korman

Lean Construction

Assessing the Environmental Impacts of Lean Supply System: A Case Study of Rebar Supply in High-Rise Condominium Construction Projects 1009
Jin-Woo Bae and Yong-Woo Kim

Production Flow in the Construction of Tall Buildings 1019
Rafael Sacks and Rebecca Partouche

How to Lower the River to Reveal the Rocks without Putting a Hole in Your Boat 1029
Glenn Ballard

Overcoming the Hurdle of First Cost: Action Research in Target Costing 1038
Glenn Ballard and Zofia K. Rybkowski

Structural Design Iteration: The Application of DSM to Seismic Retrofit 1048
Stan J. Tuholski and Iris D. Tommelein

From Lean to Green Construction: A Natural Extension 1058
Isabelina Nahmens

Quantitative Methods and Models

Progress Monitoring of Construction Projects Using Neural Networks Pattern Recognition 1068
Ashraf Elazouni and Osama Abdel-Wahhab

Material Selection in Building Construction Using Optimal Scoring Method (OSM) 1079
Jorge A. Sefair, Daniel Castro-Lacouture, and Andres L. Medaglia

Development of Project Level Engineering Productivity Benchmarking Index 1087
Pin-Chao Liao, Stephen R. Thomas, William J. O'Brien, Stephen P. Mulva, and Jiukun Dai

A Framework for Integrating Elitist GA and Project Management Tool 1096
Jin-Lee Kim and Ralph D. Ellis, Jr.

Creating Value in Housing Projects: The Use of Post-Occupancy Analysis to Develop New Projects 1105
Thaís da C. L. Alves, George S. Costa, and José de P. Barros Neto

Preparation of Incongruous Economic Datasets for Regression Analysis 1115
Gunnar Lucko and Zane W. Mitchell, Jr.

Infrastructure Management and Disaster Mitigation

Risk Assessment for Water Mains Using Fuzzy Approach 1125
H. Fares and T. Zayed

An Automated System for Optimizing Temporary Housing Arrangements after Natural Disasters 1135
Omar El-Anwar, Khaled El-Rayes, and Amr Elnashai

Planning Post-Disaster Reconstruction Efforts of Damaged Transportation Networks 1145
Wallied Orabi, Khaled El-Rayes, Ahmed Senouci, and Hassan Al-Derham

Assessment of Impacts of High-Rise Buildings on the Electric and Transportation Infrastructures in Developing Countries 1154
María L. Peralta, Dulcy M. Abraham, and Fred L. Mannering

Extracting Surveying Goals from Point Clouds to Support Construction and Infrastructure Inspection 1164
Pingbo Tang and Burcu Akinci

Infrastructure Risk Management in Renewable Energy Projects Using Risk Flexibility Theory 1174
Nicola Chiara

The Impacts of Infrastructure PPPs on Public Sector Capacity 1184
Stephan F. Jooste and Raymond E. Levitt

Automated Defect Detection in Urban Wastewater Pipes Using Invariant Features Found in Video Images 1194
W. Guo, L. Soibelman, and J. H. Garrett, Jr.

Real-Time Concrete Damage Visual Assessment for First Responders 1204
Zhenhua Zhu, Ioannis Brilakis, and Gustavo Parra-Montesinos

Underground Construction

Interactive Augmented Reality Visualization for Improved Damage Prevention and Maintenance of Underground Infrastructure 1214
Amir H. Behzadan and Vineet R. Kamat

Collaborative Tunneling Simulation Using Synthetic Environments 1223
S. M. AbouRizk, S. Hague, M. Al-Bataineh, and S. Fernando

Development of a Numerical Model for Predicting Pulling Loads on Fusible PVC Pipe 1233
Samuel T. Ariaratnam, Arnab Ghosh, Richard (Bo) Botteicher, and Siggi Finnsson

Horizontal Directional Drilling on the Snoqualmie River: A Case Study.....1243
Kimberlie Staheli and Michelle Ramos

Risk Allocation in Standard Forms of General Conditions for Tunneling Contracts.....1250
Veerasak Likhitruangsilp and Photios G. Ioannou

Trenchless in Anchorage—Case Studies 1260
Michelle Ramos and Brian Gastrock

Construction Simulation

Integrated Simulation-Based Scheduling for Module Assembly Yard 1270
H. Taghaddos, S. AbouRizk, Y. Mohamed, and R. Hermann

Integrating Agent-Based Simulation with Game Theory to Investigate the Hold-Up Problem in Project Networks.....1280
H. I. Unsal and J. E. Taylor

Modeling Architecture for Hybrid System Dynamics and Discrete Event Simulation 1290
A. Alvanchi, S. Lee, and S. M. AbouRizk

Planning Temporary Hoists for Building Construction.....1300
Seokyon Hwang

Alliance Team Selection for Infrastructure Projects Using Monte Carlo Simulations.....1308
Mounir El Asmar, Awad S. Hanna, Chul-Ki Chang, and Jeffrey S. Russell

Real-Time Simulation for Look-Ahead Scheduling of Heavy Construction Projects 1318
Lingguang Song, Casey Cooper, and Sang-Hoon Lee

Education

Development of a Construction Engineering Laboratory Course and Facility.....1328
David W. Johnston

A Balanced View of Sustainability in Civil Engineering and Construction.....1338
Leidy Klotz and Denise Grant

Engagement of Industry in Best Practices Research 1348
G. Edward Gibson, Jr. and Donald A. Whittington

Assessing Traits for Success in Individual and Team Performance in an Engineering Course 1358
Robert M. Leicht, Angela Lewis, David R. Riley, John I. Messner, and Brent Darnell

One Approach to Incorporating Sustainable Design into Undergraduate Engineering Programs.....1368
J. B. Pocock, Z. Mitchell, and A. J. Bates

Construction Education in Second Life 1378
Kihong Ku and Yogesh Gaikwat

Enhancing Construction Education with Contextual Service Learning.....1388
Christine M. Fiori and Anthony D. Songer

Improving the Internship Experience: Creating a Win-Win for Students, Industry and Faculty **1398**
Christine M. Fiori and Annie R. Pearce

Improving Course Comprehension through Experiential Learning **1409**
Kirsten A. Davis and R. Casey Cline

Visualization and Multimedia Applications in Cost Estimating Education **1419**
Saeed Karshenas

Work Experience Impacts on Construction Management Students' Cognitions Related to Construction Waste Recycling **1429**
MaryEllen C. Nobe

Key Skills for Graduating Construction Management Students—A Comparative Study of Industry and Academic Perspectives **1439**
Rizwan U. Farooqui and Syed M. Ahmed

Research Methods

Research Validation in the Construction Domain **1449**
Gunnar Lucko and Eddy M. Rojas

Research Methods Associated with Situational Simulations in Construction **1459**
Amlan Mukherjee, Nilufer Onder, and Eddy M. Rojas

Constructing Research with Case Studies **1469**
J. E. Taylor, C. S. Dossick, and M. J. Garvin

Techniques for Evaluating Automated Knowledge Acquisition from Contract Documents **1479**
Mohammed Al Qady and Amr Kandil

Techniques to Minimize Bias When Using the Delphi Method to Quantify Construction Safety and Health Risks **1489**
Matthew R. Hallowell

Opinion-Based Research: Lessons Learned from Four Approaches **1499**
David N. Sillars and Matthew R. Hallowell

Indexes

Author Index **I-1**

Subject Index **I-5**

VOLUME ONE

This page intentionally left blank

AN AUTOMATED TOOL FOR IDENTIFYING THE IMPLICATIONS OF CHANGES IN CONSTRUCTION PROJECTS

Ronie Navon, M. ASCE[1,2] and Shabtai Isaac[3]

Abstract

The impact of changes in construction projects often becomes clear only after their implementation, when it is difficult to make adjustments or consider alternatives. A model which identifies the impact of proposed changes on the primary client objectives of cost, schedule and performance is currently under development. The model utilizes available sources of project information in order to identify the impact of changes prior to their implementation in the project.

The model should be integrative, adaptive and stochastic. The basic aspects of the model are, accordingly, that it links the primary client objectives; that it is defined using a graph-based approach; and, that it represents project information as a stochastic network. Different change scenarios can be investigated using the model, and their consequences are quickly identified by tracing the relationships between the elements of the project.

1. Introduction

Deviations from client objectives in construction projects are often caused, amongst other reasons, by changes in project design and planning (Love and Li 2000; Manavazhi and Xunzhi 2001). The direct cost of post contract design changes in construction projects amounts to 5.1-7.6% of the total project cost (Cox et al. 1999).

Project teams often implement changes without fully understanding their eventual impact on the cost and duration of the project, or on performance requirements specified by the client. This is because the tools currently used for project planning and design do not facilitate the evaluation of the consequences of a specific change, before the plan and design are fully updated (Hegazy et al. 2001; Motawa et al. 2007). As a result, deviations from the client objectives, caused by changes in the project, are often revealed late in the project, or even after its completion. At that stage, it is obviously

[1] Associate Professor, Head, Construction Management & Economics – National Building Research Institute (NBRI); Faculty of Civil & Environmental Engineering, Technion City, 32000 Haifa, Israel. E-mail: ronie@technion.ac.il.
[2] Corresponding author
[3] Ph.D. candidate – Faculty of Civil & Environmental Engineering, Technion City, 32000 Haifa, Israel. E-mail: shabtai@technion.ac.il

much more difficult to make adjustments. It is often too late to consider alternatives to the implemented changes without causing significant delays and cost increases.

Managing changes in construction projects is difficult, because the changes often generate unanticipated side effects. These indirect consequences may require additional iterations of actions to resolve them, a circumstance which in its turn causes delays and incurs additional costs (Lee and Pena-Mora 2007). Such iterations and their consequences must, therefore, be taken into account when the impact of a change on the project is being assessed. However, management does not sit back idly during a project, but rather takes actions to try to bring late-running or over-spending actions under control. For example, resources such as manpower can be reallocated to shorten timelines for some tasks if the project begins to fall behind in time. A network simulation that simply carries through each iteration unintelligently, assuming no management action, often produces unrealistically wide distributions (Williams 2003). On the other hand, management reactions themselves often have unanticipated consequences which increase deviations from the client objectives. For example, changing the project activities network so that more activities are carried out in parallel may eventually cause longer coordination activities downstream and increased costs.

Existing methods of project control, such as cost control, focus on identifying and controlling deviations, such as cost escalation. What is required, however, is a method that, in addition to recognizing the symptoms, identifies and focuses attention on the elements that are a potential cause for deviations before they influence the project (Hastak et al. 1996). The timely identification of change impacts on construction projects could greatly contribute to effective project management (Lee and Pena-Mora 2007).

The present paper presents a model of construction projects that facilitates the analysis of the impact of proposed changes prior to their implementation, as a basis for change control.

2. Model requirements

Two approaches can be considered for obtaining information on the potential consequences of proposed changes: (1) subjective expert opinion and (2) analysis of project data using computer models such as Building Information Models (BIM). As for expert opinion, one practical problem is that in projects involving large teams it is difficult, if not impossible, for every team member to participate in every project review in order to answer questions concerning every proposed change. Another, more basic, aspect is that even assuming one had continuous contact with all the team members, they would have great difficulty inferring accurately the behavior of a complex dynamic system such as a construction project (Simon 1957). Interdependencies complicate analysis beyond the capabilities of human judgment, because a change in one part of the system may have implications on other, remote, parts (Sterman 1992).

As for computer models of construction projects, such as BIM, these may help overcome many of the limitations of human judgment. However, existing models still do not make it possible to fully analyze the impact of changes prior to their implementation in the design and construction of the project. There are three main

reasons for this, and, accordingly, three requirements have been identified for the model: (1) the model has to support the integration of various existing sources of information in the project in order to allow the analysis of the impact of proposed changes on different aspects of the project. This should be done in a single framework. (2) The model has to be adaptive in order to allow continuous modification of data, and the automatic propagation of change events. And (3) the model has to be stochastic in order to allow the analysis of the impact of changes before they are implemented in the project.

2.1. The need for an integrative model

Project data is currently stored in different sub-models which are not fully integrated (e.g. requirements, design, planning, risks, etc.). Efforts are being made to integrate different sub-models of construction projects. However even the different sub-models currently used for project planning, such as cost and risk estimation, are still not fully integrated. Other sub-models, such as design and requirements, are not integrated at all. Requirements are usually considered frozen after their definition in the building program at the inception of the project. In reality, requirements may change during the project (Kiviniemi 2005). It is, therefore, essential that client requirements are included in the evaluation of the impact of changes in the design. However, these changes are usually not recorded in the building program, and their impact on the client's requirements is often not identified prior to their full implementation. Consequently, the model should be integrative in order to allow a simultaneous analysis of the impact of changes on different aspects of a project.

2.2. The need for an adaptive model

There should be a continuous feedback between the model of the project as planned and the actual state of the project. Hence the model should be adaptive to support the continuous modification of data, and the automatic propagation of change events. One of the consequences of the fact that construction project models are currently non-integrative is that it is very difficult to update the model following changes in the project. For example, requirements are not adjusted to changes in the design because there exists no automatic support for this task (Kiviniemi 2005). Once the model is fully integrative, it could guarantee that the data throughout the model remains consistent after a certain element is modified. This requires that all types of structural dependencies between elements are taken into consideration when a modification is made.

2.3. The need for a stochastic model

A stochastic model incorporates uncertainty by allowing a certain range of possibilities for inputs, and the estimation of probability distributions of potential outcomes. Thus, a stochastic model may enable an estimate of the outcome of proposed changes before the functional relationships between project components are redefined in the design and planning of the project, and prior to the construction of these components. Furthermore, it informs project management of the extent of the risk, posed by proposed changes, to the fulfillment of the client's objectives.

Currently, uncertainty in construction projects is often treated through risk analysis and management tools. These tools, however, are not integrated, and generally fall into two distinct methods, with different data sets: (1) risk registers and (2) stochastic cost and duration estimates.

A risk register is a list of risks, identified by the project team, along with an assessment of their likelihood and consequences (Hall et al. 2001). This list is usually compiled at the beginning of the project, and ought to be maintained and managed throughout the project. However, the term "risk" is associated with adverse events, rather than more general sources of significant uncertainty. The risks that are identified in the register tend to address only a small proportion of the many sources of uncertainty in a project (Ward and Chapman 2003). Moreover, the register is compiled at the beginning of the project, when uncertainty is presumed to be high. Therefore, the risks, and their assessed consequences, are not explicitly linked to specific project components and activities, as these have often not been specified yet at such an early stage. Dependencies between risks, which may occur when they have an impact on the same components or activities, are often ignored, in spite of the fact that the risks might indirectly have an impact on one another (Ackermann et al. 2007). The fact that the risk register is not integrated with the project design and planning also makes it difficult to update the register according to changes in the project, and to a reassess the likelihood and consequences of the risks previously identified.

The second approach to the treatment of uncertainty in construction projects is the assessment of probability distributions for the cost and duration of each activity in the project, instead of the specification of deterministic values. These assessments are based on a *detailed* project design and schedule, and are therefore usually made in a more advanced phase of the project. Monte Carlo simulations are usually run with the specified probability distributions in order to assess the project cost and schedule (Williams 2003). An advantage of this approach is that the project components can be explicitly linked to the project cost and schedule assessments, via the planned activities. However, the assumptions and conditions concerning the events upon which the estimated probability distributions depend are usually not explicitly addressed (Ward and Chapman 2003). It is often not clear, for example, whether these events include the specific risks already identified and quantified in the risk register. Moreover, dependencies between the estimated probability distributions, caused by common risks, are ignored (Yang 2006).

A model for the analysis of change impacts should, therefore, link the project components explicitly both to the identified sources of uncertainty, *and* to the assessed probability distributions of the cost and duration of the planned activities. Thus, it could take into account correlations and dependencies between different events, and facilitate the tracing of links between proposed changes, components and assessed probability distributions for the attributes of planned activities. Such a model would integrate existing methods of risk assessment and change management in construction projects.

3. Model

The model utilizes available sources of project information in order to identify the impact of changes on the primary client objectives of cost, schedule and performance.

The analysis of change impacts is carried out prior to the implementation of the changes in the project, and without necessitating a full update of its design and plan.

3.1. Research assumptions

The present research assumes that: (1) The model relies primarily on available sources of information, such as the building program, design, budget and schedule. It requires minimal analysis and documentation of additional information, as the model would be less attractive if it required too much effort to maintain. (2) The model does not rely on information obtained from historic data, in light of the current lack, for most construction project teams, of a complete set of historical data which can be readily analyzed (Yang 2006).

3.2. Basic aspects of the model

Three requirements have been identified for the model: it should be integrative, adaptive and stochastic. Three basic aspects of the model are, accordingly: (1) The model links the primary client objectives of cost, schedule and performance; (2) It is defined using a graph-based approach; and (3) It represents project information as a stochastic network.

The primary client's objectives in construction projects are usually a combination of the objectives for performance of the completed scheme, for achieving this performance within a given cost, and for getting the project into use by a target date (Williams 2003). According to Williams (2003), this threefold criterion of success – meeting cost, schedule and performance targets – has become widely used as the standard success criterion. It also catches the essential trade-offs that are made in projects, and that the model must reflect. However, while cost and schedule have been linked in various other models, they have not been linked to the performance targets.

Performance is defined here as the extent to which the completed facility provides the resources demanded by the activities that take place in the facility. The demand for these resources is translated into project requirements, defined in the building program (Pennanen et al. 2005).

In order to allow the simultaneous analysis of the impact of changes on the three primary client objectives of cost, schedule and performance, the model should support the integration of these objectives into a single framework. To this end, the model supports the definition of the different types of elements in the project (e.g. requirements, building components, construction activities, etc.), their attributes, as well as the different types of relationships linking these elements (Figure1):

I. Client requirements, which specify user activities, can be linked to the project requirements, as documented in the building program, by identifying the space to which they are both related. For example, a teaching activity and its attributes, such as the expected number of students, can be linked to a classroom and its requirements, such as the required area for the classroom.
II. User activities are represented in the form of graphs, which can link activities to sub-activities in the client requirements model. For example, different types of

teaching sub-activities, such as laboratory and lecturing activities, can be linked to a general teaching activity.

III. The project requirements can be linked to building components in the project design through *design subjects*. Each design subject contains the components which satisfy a specific project requirement. For example, *lighting* design subjects contain windows and electrical fixtures, which satisfy the requirement for minimum illumination levels in a certain space.

IV. The project design is represented in the form of graphs, which can link building components to their systems in the project design model. Building components of one system may also be linked to components of another system through physical relationships defined in the design model (such as *supported by* or *enclosed by*). For example, a pipe can be linked to the sprinkler system to which it belongs, as well as to the concrete slab which supports it.

V. Building components can be linked, via planned construction activities, to sub-models of construction methods (such as pre-cast or cast-in-place) and of resource allocation (such as crew and material resources).

VI. Construction activities can be linked to the budget and schedule via sub-models of unit costs and sequencing constraints.

With the model, a graph is created where the nodes represent the project elements, linked directly and indirectly through different types of relationships. A graph-based model possesses various attributes, which facilitate the analysis of the impact of proposed changes. Graph-based approaches to modeling problems have been used in operations research in general (Geoffrion 1987), and specifically in decision analysis (Morgan and Henrion 1990) and workflow management (Reichert and Dadam 1998). Apart from the use of PERT or Gantt chart for scheduling, the tools commonly used in construction project management are mainly based on either 2D/3D visual representations of the design, or on spreadsheets. Drawings, or CAD models, are obviously restricted in their ability to represent performance, time and cost related attributes of the project. Meanwhile, spreadsheets offer no way to visualize the overall structure of a project, and obscure dependencies that exist between the elements in the project (Iyer et al. 2005).

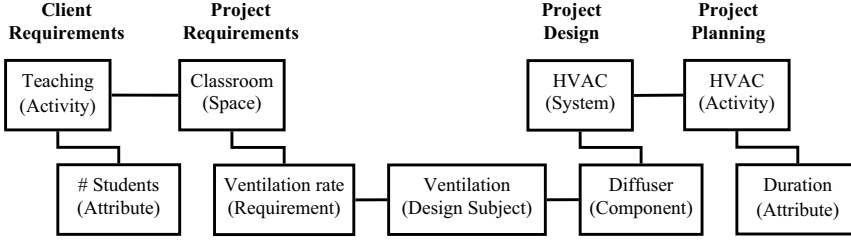


Figure 1: Representation of relationships in the project through a graph-based model

A graph-based approach, on the other hand, facilitates the tracing of relationships between project elements in the integrated model, in order to identify the elements that

are expected to be influenced by a proposed change. *Requirements traceability* is widely practiced in software development projects, and refers to the ability to trace relationships between requirements and their deployment and use in the design (Gotel and Finkelstein 1996). In the present research, the concept of traceability is expanded to include tracing different types of relationships among various project elements. The impact of changes on all three primary client objectives can thus be identified. The elements of the graph-based model are grouped into modules according to their generic type, and the modules are grouped into higher order modules according to a predefined hierarchy. When an attribute of a certain element is changed, the child and parent nodes, which are influenced by the change, can be traced in the graph. When the impact is indirect, it can be identified by tracing a chain of relationships from the proposed change to the client objective.

A graph-based approach can also facilitate the adaptivity of the integrated model. Graph-based models are flexible enough so that it is easy to adapt and extend them to include changes. Flexibility is achieved with the graph-based approach by supporting the definition of rules for implementing and propagating changes, also called *Graph Transformations* (Heckel 2006). Changes may involve adding a new element to the model, deleting an existing element, and merging or dividing existing elements. In order to relieve users from having to perform the necessary adjustments of the model manually, rules can be specified for the automatic implementation and propagation of changes (Figure 2):

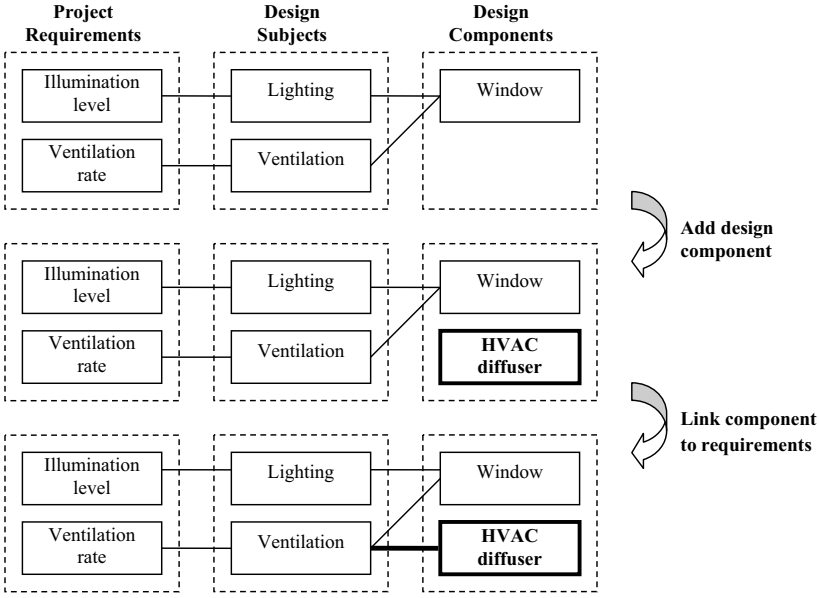


Figure 2: Implementing changes in the model through pre-specified rules

(a) When an element is added to the model, new relationships with other existing elements in the model must be defined, while maintaining the correctness and consistency of the model. Different types of relationships, defined in the model, specify which elements can be linked automatically.
(b) When an existing element is deleted, sub-elements (or child nodes in the graph) are automatically deleted, as are relationships between the deleted element and other elements in the model.
(c) When existing elements are merged, the merged element inherits all the relationships of the original elements.
(d) When an existing element is divided into two or more elements - as often occurs when a design is elaborated - the new elements inherit the relationships of the original element. Only relationships that conform to the rules, specifying which elements may be linked, are inherited. For example, when a building component (such as a wall) is divided into distinct components (such as columns and partitions), the new components can be linked to the project requirements of the divided component through the appropriate design subjects (thus, partitions will be linked to a requirement for sound insulation, but not to a requirement for structural support).

An additional feature of the model is that it incorporates uncertainty, in order to facilitate an assessment of the magnitude of the impact of a proposed change. The proposed graph can be transformed into a stochastic network by defining marginal distributions for the project elements – the nodes in the graph are allowed to have values that are specified probabilistically. By allowing the edges in the graph to have values, the degree of dependence between the specified marginal distributions is defined. These values can be obtained by statistical analysis on historical data (Ranasinghe 2000), or by subjective expert opinions. The former is a reliable approach, yet the latter is more often applicable in construction projects due to the current lack of available historical data for most project teams. With the resultant stochastic network the risk of a deviation from the client objectives, due to the impact of a proposed change, can be assessed through network simulation. This feature of the model is currently being developed, as further research is undertaken to extend the model's ability to quantify change impacts through simulation.

Historically, for reasons of computational tractability, dependencies between random variables have often been ignored in network simulations (Bier et al. 2006). This has led, however, to an underestimation of total uncertainty in projects (van Dorp and Duffy 1999). It is possible to take dependency into account by specifying the joint distributions of random variables as a product of marginal and conditional distributions (i.e. Bayesian networks). A disadvantage of this approach is that the required number of probability assessments can grow exponentially to the number of variables (Clemen and Reilly 1999).

In recent years another approach – the use of copulas – has become more common, and it is regarded as an efficient method for constructing joint distributions of random variables (Bier et al. 2006). Copulas are functions that require marginal distributions and measures of dependence among the random variables (correlation coefficients). A Diagonal Band Copula can be used to determine the joint distribution of dependent

elements. It requires a dependence parameter that can be elicited using a quantity that is more easily interpreted by the project team (van Dorp and Duffy 1999). The impact on the client objectives can then be generated via Monte Carlo analysis.

4. Conclusions

This paper presents a model that identifies and assesses the possible impact of proposed changes in construction projects. The model can enable the definition of management decisions concerning proposed changes, and can indicate what would be likely to happen in particular change scenarios, step by step. Using the model, different change scenarios can be investigated by the project management when evaluating proposed changes. The consequences of change scenarios are identified by the tracing of relationships between elements in the project. Quantifying these consequences enables the modification of a simulation in order to take them into account.

Further research is currently being undertaken to develop the model's ability to quantify the extent of the change impact through simulation, using probability distributions and correlation coefficients elicited from the project team. Research is also being undertaken to link the model to existing models of project control. Such a linkage could facilitate an ongoing feedback process which would inform project management of the actual impact of a change that is being implemented in the project.

References

Ackermann, F., Eden, C., Williams, T., and Howick, S. (2007). "Systemic risk assessment: a case study." *Journal of the Operational Research Society*, 58(1), 39-51.

Bier, V. M., Cox, L. A., Edward, W., Miles, R., and von Winterfeldt, D. (2006). "Probabilistic risk analysis for engineered systems." Advances in Decision Analysis, Cambridge University Press, New York.

Clemen, R. T., and Reilly, T. (1999). "Correlations and Copulas for Decision and Risk Analysis." *Management Science*, 45(2), 208-224.

Cox, I. D ,.Morris, J. P., Rogerson, J. H., and Jared, G. E. (1999). "A quantitative study of post contract award design changes in construction." *Construction Management and Economics*, 17(4), 427-439.

Geoffrion, A. M. (1987). "An Introduction to Structured Modeling ".*Management Science*, 33(5), 547-588.

Gotel, O., and Finkelstein, A. (1996). "An Analysis of the Requirements Traceability Problem." Software Change Impact Analysis, R. Arnold and S. Bohner, eds., IEEE Computer Society Press.

Hall, J. W., Cruickshank, I .C., and Godfrey, P. S. (2001). "Software-supported risk management for the construction industry." *Civil Engineering*, 144(1), 42-48.

Hastak, M., Halpin, D. W., and Vanegas, J. (1996). "COMPASS - New Paradigm for Project Cost Control Strategy and Planning ".*Journal of Construction Engineering and Management*, 122(3), 254-264.

Heckel, R. (2006). "Graph Transformation in a Nutshell." *Electronic Notes in Theoretical Computer Science*, 148, 187-198.

Hegazy, T., Zaneldin, E., and Grierson, D. (2001). "Improving Design Coordination for Building Projects. I: Information Model." *Journal of Construction Engineering and Management*, 127(4), 322-329.

Iyer, B., Shankaranarayanana, G., and Lenard, M. L. (2005). "Model management decision environment: A Web service prototype for spreadsheet models." *Decision Support Systems*, 40(2), 283-304.

Kiviniemi, A. (2005). "Requirements Management Interface to Building Product Models," Ph.D. Dissertation, Stanford University.

Lee, S., and Pena-Mora, F. (2007). "Understanding and managing iterative error and change cycles in construction." *System Dynamics Review*, 23(1), 35-60.

Love, P. E. D., and Li, H. (2000). "Quantifying the causes and costs of rework in construction." *Construction Management and Economics*, 18(4), 479-490.

Manavazhi ,M. R., and Xunzhi, Z. (2001). "Productivity oriented analysis of design revisions." *Construction Management and Economics*, 19(4), 379-391.

Morgan, M. G., and Henrion, M. (1990). *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge University Press, New York.

Motawa, I. A., Anumba, C. J., Lee, A., and Pena-Mora, F. (2007). "An integrated system for change management in construction." *Automation in Construction*, 16, 368-377.

Pennanen, A., Whelton, M., and Ballard, G. (2005). "Managing stakeholder expectations in facility management using workplace planning and commitment making techniques." *Facilities*, 23(13/14), 542-557.

Ranasinghe, M. (2000). "Impact of correlation and induced correlation on the estimation of project cost of buildings." *Construction Management and Economics*, 18(4), 395-406.

Reichert, M., and Dadam, P. (1998). "ADEPTflex - supporting dynamic changes of workflows without losing control." *Journal of Intelligent Information Systems*, 10(2), 93-129.

Simon, H. A. (1957). *Models of Man*, Wiley, New York.

Sterman, J. D. (1992). "System dynamics modeling for project management".

van Dorp, J. R., and Duffy, M. R. (1999). "Statistical Dependence in Risk Analysis for Project Networks Using Monte Carlo Methods." *International Journal Of Production Economics*, 58, 17-29.

Ward, S., and Chapman, C. (2003). "Transforming project risk management into uncertainty management." *International Journal of Project Management*, 21(2), 97-105.

Williams, T. (2003). "The contribution of mathematical modeling to the practice of project management." *IMA Journal of Management Mathematics*, 14(1), 3-30.

Yang, I. T. (2006). "Using Gaussian copula to simulate repetitive projects." *Construction Management and Economics*, 24(9), 901-909.

DEVELOPMENT OF HUMAN POSE ANALYZING ALGORITHMS FOR THE DETERMINATION OF CONSTRUCTION PRODUCTIVITY IN REAL-TIME

Abhinav Peddi[1]; Luke Huan[2]; Yong Bai[3]; and Seonghoon Kim[4]

Abstract
To enhance the capability of rapid construction, an automated on-site productivity measurement system is developed. Employing the concepts of Computer Vision and Artificial Intelligence, the developed system wirelessly acquires a sequence of images of construction activities. The system first processes these images in real-time to generate human poses associated with the construction workers at a project site. The poses are first manually classified into three categories as effective work, ineffective work, and contributory work. Then, a built-in neural network trained on these classifications, determines the worker's status by comparing the in-coming images to the developed human poses. The labor productivity is determined from these comparison statistics. This system has been tested for accuracy on a bridge construction project. The analysis results were accurate as compared to the results of the manual method. This research project made several major contributions to the advancement in construction industry. First, it applied advanced image processing techniques for analyzing construction operations. Second, the results of this research project made possible the automatic determination of construction productivity in real-time. Thus, an instant feedback to the construction crew was possible. As a result, the capability of rapid construction was improved using the developed technology.

Keywords: Construction, Computer Vision, Neural Network, Productivity, Real time

[1] Research Assistant, Department of Electrical Engineering and Computer Science, University of Kansas, 2001 Eaton Hall, Lawrence, KS 66045; PH (785) 864-4620; FAX (785) 864-3226; E-mail: abhinav@ku.edu
[2] Assistant Professor, Department of Electrical Engineering and Computer Science, University of Kansas, 2034 Eaton Hall, Lawrence, KS 66045; PH (785) 864-5072; FAX (785) 864-3226; E-mail: jhuan@ittc.ku.edu
[3] Associate Professor, Department of Civil, Environmental, and Architectural Engineering, University of Kansas, 2135-B Learned Hall, Lawrence, KS 66045; PH (785) 864-2991; FAX (785) 864-5631; E-mail: ybai@ku.edu
[4] Ph.D. Candidate, Department of Civil, Environmental, and Architectural Engineering, University of Kansas, 2160 Learned Hall, Lawrence, KS 66045; PH (785) 864-2598; FAX (785) 864-5631; E-mail: steve072@ku.edu

1. Introduction

Productivity plays a key role in influencing the schedule of a construction project and so measuring it has been a wide practice in evaluating the performance of construction activities. A project schedule needs to be effectively developed to be economic and efficient, as it is governed by several constraints such as labor, finance and environment. After the September 11, 2001 terrorist attacks and the hurricane Katrina, rapid re-construction of damaged infrastructure has been paid close attention by government agencies, engineering and construction communities. There is an urgent need for the development of innovative technologies to enhance the capability of rapid construction. To achieve this, it is necessary to develop advanced technology that is capable of measuring on-site construction productivity in real–time. With the real-time productivity data, project managers can take actions immediately in case construction operations run behind the original schedule. Existing productivity measurement methods are however not real-time and require the involvement of a human in the productivity determination, which causes the estimation prone to human errors. This paper presents human pose analyzing algorithms for automated and real-time construction productivity estimation. The authors begin with capturing a video of the construction site and detecting workers in every image using motion segmentation. Then, tracks of these workers over successive images are generated. Finally, the poses from these workers are extracted and analyzed using a neural network for determining the productivity.

2. Related Work

Besides the traditional stopwatch method for measuring construction productivity, several other empirical and analytical approaches have been presented in the literature. Some of these approaches are based on analysis by simulation and are application specific such as a situation based modeling for construction productivity measurement by Eldon and Janaka (2005). Other models employing neural networks were developed by Manjula, Aminah Robinson et al. (2005), Ming, AbouRizk et al. (2000), and Li-Chung and Miroslaw (1994). Additional approach based on neural networks was presented which analyses the attitude patterns of the workers to determine the productivity (George, Irina et al. 2000). However, these approaches are not automated and there is a need for human involvement. Labor inputs can be measured automatically as shown by Navon, R., and Goldschmidt, E. (2003). Models employing the global positioning system (GPS) were proposed by Navon, R., and Shpatnitsky, Y. (2005) and also by Heng, Li., Zhen, C., Liang, Y. and S.C.W. Kong (2005)". In this paper, the authors present an innovative method based on worker pose classification to automatically and continuously determine the construction productivity in real-time.

3. Methodology

The human poses based productivity determination method has two phases: (1) pose extraction and (2) productivity determination. In the pose extraction phase, image-processing algorithms are employed to identify the workers, to assign each of them a unique ID and to extract their corresponding poses. Since workers form the moving objects in the video, common methods for detecting them include average

background modeling (Hong-Wen, Shao-Qing et al. 2006) and optical flow methods (Baron, Fleet et al. 1994). In this research project, average background modeling is utilized. Neural network based algorithms developed by the authors are used to analyze these poses and hence determine the efficiency of the workers. A work flow diagram of this model is shown in Figure 1.

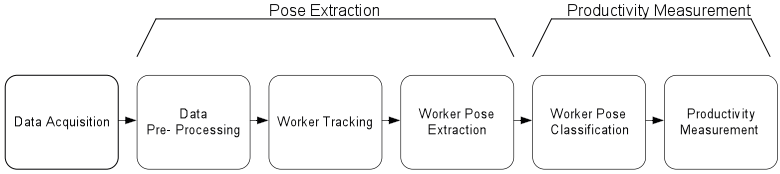


Figure 1. Work flow diagram of the human pose based system.

3.1 Data Acquisition

The authors acquired data as a series of images of the construction activities using the **w**ireless **r**eal-t**i**me produc**t**ivity m**e**asurement (WRITE) system (Bai et al. 2007). It captures the images of the activities using a video camera and transmits them via the Internet. This system allows remotely controlling the camera's focus by adjusting its pan, tilt and zoom settings.

3.2 Data Pre-Processing

In this block, the incoming images are processed to identify and extract the workers in them. The assumption in worker identification is that the workers are in motion when performing an activity and the background is static. Hence, a motion segmentation algorithm similar to Lim et al. (2006) is developed to identify all the moving objects in these images. If moving objects are of interest in an image, then all the other regions which are static are collectively termed as "background". A moving average model is used to compute such background. Once the background is computed, it is subtracted from the current frame (*N)* to extract the workers using a mask level background subtraction.

Definition 1: *If* $I^N(x,y)$ *be the intensity of the pixel at location (x,y) on* N^{th} *frame, then the intensity of the pixel on its background image,* $BG^{N^{th}}$ *at the same location (x,y), computed over K frames is defined as*

$$I^{BG}(x,y) = \frac{1}{K}\left(\sum_{i=N-K/2}^{i=N+K/2} I^i(x,y)\right)$$

Definition 2: *If* I^N_{avg} *and* I^{BG}_{avg} *denote the average of pixel intensities of the mask M (typically 5) in the* N^{th} *frame and its background respectively, then the intensity of a pixel* I^{SG} *of the segmented image SG, over the same mask is defined as*

$I^{SG}(x- i, y- i) = 1;$ *if* $\frac{1}{M}\left|I^{N}_{avg} - I^{BG}_{avg}\right| > T,$ a predetermined threshold, typically 25.

$= 0;$ *otherwise*

where $I^{N}_{avg} = \sum_{j=-M/2}^{j=M/2} I^{N}(x-j, y-j)$, $I^{BG}_{avg} = \sum_{j=-M/2}^{j=M/2} I^{BG}(x-j, y-j)$ *and* $i = \left[\frac{-M}{2}, \frac{M}{2}\right]$

3.3 Worker Tracking

In the tracking terminology, the silhouettes are often referred to as blobs or objects and images are often referred to as frames. The blob of each worker is identified and similar pixels are clustered and colored to form regions. It is to be considered that the workers far away from the camera have smaller blobs and it is difficult to extract and process their characteristics. To eliminate these workers from analysis, only the blobs with size greater than a pre-determined value are considered and the rest are discarded.

Tracking Approach

Worker tracking is performed by finding correspondences between blobs in the previous frame and the blobs in the current frame. In the first frame, a new track is generated for each blob and is declared as *new*. In the subsequent frames, the matching blobs for each track in the previous frame are searched and if found, the tracks are updated. If a track in the previous frame could not be updated, then it is declared as *lost*. The tracker does not delete the track but waits for some frames in hopes to finding a matching blob and *regain* the track. If a track cannot be *regain*ed for LL (lost limit, typically 5) consecutive frames, it is then deleted. If a blob in the new frame cannot be matched to a track in the previous frame, then a new track is generated for it and is declared as *new*. So, if a track is lost due to blob occlusion, there is a scope to regain it in the subsequent frames.

Matching Criteria

An effortless criterion for matching a blob in the current frame to the tracks in the previous frames is by using the distance-based match matrix. The track with the minimum distance is updated with this blob if its distance $d \le D$, where D is the global distance threshold. This criterion uses a global value for the distance threshold and can be applied if all workers (blobs) move at the same speed. However, in reality, workers move at different speeds and along different directions and so this global threshold cannot be applied. To handle this uncertainty, a modified tracking method is designed based on the same distance-based match matrix, which predicts the next position of a track based on its current speed and direction. The matrix is populated with the distances of the blobs to the new predicted positions of the tracks in the previous frame. A track with the minimum distance to a blob $d \le D$ is updated with that blob. An example of input image (construction workers tying rebar) and the corresponding silhouettes image are shown in Figures 2 and 3. It can be seen that the blobs of workers pointed with arrows were considered and blobs of all the other workers were discarded due to the size restriction.



Figure 2. Input image

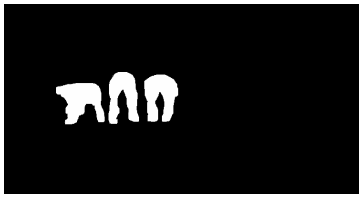


Figure 3. Silhouette

3.4 Worker Pose Extraction

The worker poses in every image are extracted by skeletonizing their corresponding blobs using a fast parallel algorithm for image blob thinning developed by Zhang and Suen (1984). Each blob is thinned to form a *skeleton* of one pixel thick. The end points and pixel connectivity are preserved so that a continuous skeleton is obtained and also the distortion is minimal. Figure 4 represents the skeletons obtained by this algorithm for the three workers/blobs in Figure 2. These obtained poses are analyzed as whole individual entities and so identification of different body parts of a worker is not necessary in our method.

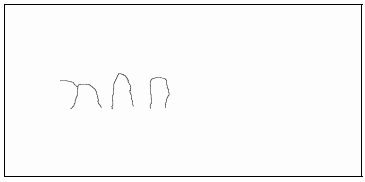


Figure 4. Skeleton image

3.5 Worker Pose Classification

The worker poses are classified by performance into three classes: effective work, ineffective work and contributory work. Two algorithms using neural networks are developed to classify poses into these categories. They are *Instance Algorithm* and *Activity Algorithm*. For analysis by these algorithms, the extracted poses are clipped from their original images and are scaled to a fixed size of WxH irrespective of their original sizes (W= 140, H= 280).

Instance Algorithm

In this algorithm, the classification is performed at a pose level meaning that only the information available from the current pose is used for analysis. As a pose does not contain information about its contributiveness, this class is not considered. This algorithm undergoes two work phases: learning phase and execution phase. In the learning phase, training data sets are manually annotated such that each pose is assigned to one of the two classes: effective and ineffective. This annotated training data is used to train the neural network using the back propagation learning algorithm. In the execution phase, this algorithm communicates with the tracker and requests the I.D of the worker associated with each incoming pose. Using this ID, it searches for the worker's record and creates a new one if it could not find any. It

then updates this record with the results of the pose classifications and hence determines the worker's real-time productivity $P_I(W)$.

$$P_I(W) = \frac{I_{effective}(W)}{\left(I_{effective}(W) + I_{ineffective}(W)\right)}$$

Where, $I_{effective}(W)$ = total effective instances of the worker W

$I_{ineffective}(W)$ = total ineffective instances of the worker W

Activity Algorithm

The instance algorithm does not cover the gray area of contributory work and thus does not precisely detect the ineffective work instances. In order to detect the inefficiency more precisely, the activity algorithm was developed. This algorithm was developed as an extension of the instance algorithm by adding another block called *activity analyzer* and the classification is performed at an activity level. All the additional functionality above the instance algorithm is incorporated into this block. This exposes two challenges: Firstly, different activities interpret contributory work in different ways, and prior knowledge of the activities being progressed is required. Secondly, poses that represent contributory work in one instance may represent ineffective work in another. Thus, a clear distinguishing of these situations is needed. The phase of tying a rebar in a bridge construction is analyzed in this paper. It involves an activity of tying the rebars at different locations in the work scene. The worker needs to bend for tying the rebar and then walk to move to the next location. By the instance algorithm, the phase of bending is considered effective and the phase of walking is considered contributive. If a worker walks for more than the allowed duration, then the extra time is considered ineffective.

As with the instance algorithm, the activity algorithm also undergoes two work phases: learning phase and execution phase. In the learning phase, training data sets are manually annotated such that each pose is assigned to one of the three classes: effective, ineffective and contributory. This annotated training data is used to train the neural network using the back propagation learning algorithm. In the execution phase, this algorithm communicates with the tracker and requests the I.D of the worker associated with each incoming pose. Using this ID, it searches for the worker's record and creates a new one if it could not find any. It then updates this record with the results of the pose classifications and hence determines the worker's real-time productivity.

$$P_A(W) = \left(\frac{1}{2}\right)\left(P_{A1}(W) + P_{A2}(W)\right)$$

where $P_{A1}(W) = \frac{\left(I_{effective}(W) + I_{contributory}(W)\right)}{\left(I_{effective}(W) + I_{contributory}(W) + I_{ineffective}(W)\right)}$

$$P_{A2}(W) = \frac{(I_{effective}(W))}{(I_{effective}(W) + I_{contributory}(W) + I_{ineffective}(W))}$$

$I_{effective}(W)$ = total effective instances of the worker W
$I_{ineffective}(W)$ = total ineffective instances of the worker W
$I_{contributory}(W)$ = total contributory instances of the worker W

4. Experimental Study

An experimental study of the performance characteristics of the human pose analyzing algorithms was conducted. A steel girder bridge reconstruction project was utilized for the study. Construction activities were collected using the WRITE System as a series of color images at a rate of 120 frames per second. To account for the delays involved with wireless streaming, the rate was down sampled to 1 frame per second similar to the time-lapse filming (Howard B. Sprinkle, 1972). These images were of size 720x480 pixels with a resolution of 96 dots per inch. A set of 1,000 such images was selected for analysis. A worker performed tie rebar was chosen and his poses on these images were manually classified to generate the ground truth data. The ground truth data for both algorithms are shown in Table1.

Table 1. Characteristics of the Data Sets

Algorithm	Total Samples	Total Effective	Total Ineffective	Total Contributive*
Instance	1000	637	363	--
Activity	1000	637	180	183

* The contributory class does not apply to the Instance Algorithm

4.1 Experimental Protocol

Every incoming image from the video was passed through the video processing block to extract the constituent workers. For the motion segmentation, the background model was computed over a window of K=10 and was eliminated using a mask of size M=3 with threshold T=25. The objects are then filtered for pattern-match using a mask size of M_v = 7 and threshold T_v = 40. The extracted workers are each assigned

a unique ID (i = 1,2,3,…) and tracked for their new positions in the subsequent images with a search limit N = 30. All the images related to a single worker were isolated from the image and scaled to a size of 140x280, irrespective of their original sizes. Their corresponding poses were extracted by using the pixel-based image thinning software by Zhang and Suen (1984). To analyze these poses, artificial neural networks were used as a part of JOONE (Java Object Oriented Neural Engine). Feed forward neural networks with a back propagation-learning algorithm were used in this project.

To derive the training sets for the neural network, a simple random sampling (SRS) was implemented. The poses were divided into two groups (effective and ineffective) for the instance algorithm and three groups for the activity algorithm (effective,

contributory and ineffective), and samples were then chosen from each group to form the training sets of even sizes, with the minimum size of 2 and a maximum size of 30. The neural networks were trained over these training sets and were then tested on the set of 1,000 samples. This procedure was repeated for 200 times.

4.2 Experimental Results

The performance of the algorithms is gauged by its precision, recall and accuracy values. Precision can be defined as the ratio of true positives to the sum of true positives and false positives. Recall can be defined as the ratio of true positives to the sum of true positives and false negatives. Accuracy can be defined as the ratio of sum of true positives and true negatives to the total predictions. A true positive occurs when the algorithms classify a pose as representing effective work, and the pose is indeed representing effective work. A false positive occurs when the algorithms classify the pose as representing effective work, but the pose is actually in the ineffective work status. For the instance algorithm, effective work poses are considered as positives and ineffective work poses are considered as negatives. For an activity algorithm, contributory work poses are also considered as positives. The precision, recall and accuracy curves for the instance algorithm and the activity algorithm are shown in Figures 5(a), 5(b) and 5(c) and Figures 6(a), 6(b) and 6(c), respectively. Each of them shows the average, 95 percent and 5 percent curves obtained over 200 experiments.

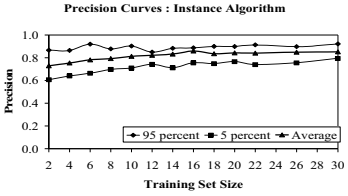


Figure 5(a). Precision: instance algotirhm

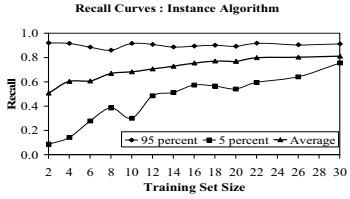


Figure 5(b). Recall: instance algorithm

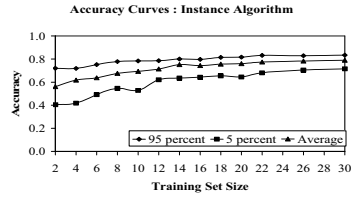


Figure 5(c). Accuracy: instance algorithm

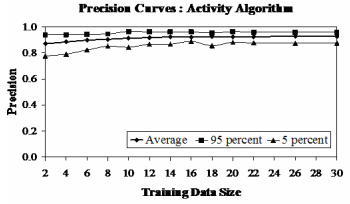


Figure 6(a). Precision: activity algorithm

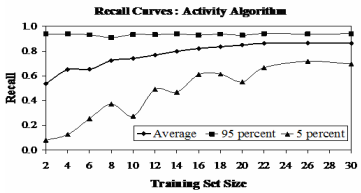


Figure 6(b). Recall: activity algorithm

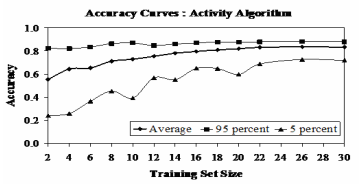


Figure 6(c). Accuracy: activity algorithm

4.3 Productivity Measurements

The construction productivities were computed with the classification results from the algorithms. From the experiments conducted, it is observed that the system employing these two classification algorithms exhibits a stable performance when the constituent neural networks were trained with training sets of sizes of ≥ 22 samples. At any point in this range, the system exhibits a reliable, stable and maximum performance. Hence a training set size of 26 samples was chosen within this range and the productivities were computed as the average over the 200 experiments. The productivity results are presented in Table 2.

Table 2. Productivity Measurements for Training Size of 26

Algorithm	Manual (%)	By Algorithm (%)
Instance	63.7	58.3
Activity	82.0	76.5

5. Conclusions and Contributions

Existing construction productivity measurement methods require an active and continuous human involvement to analyze and determine the productivity. Thus, the analysis results are prone to errors due to human biases and limitations. To overcome these shortcomings, two intelligent algorithms were developed for the automation of such analysis, completely eliminating the need for human involvement. An experimental study was conducted to determine the accuracy of the developed algorithms. Results of analyses indicated that the developed algorithms produced productivity measurements with accuracy close to 85 percent compared to the manual method. This research project made several major contributions to the advancement of construction industry. First, it applied advanced image processing techniques for analyzing construction operations. Second, the results of this research project made it possible to automatically determine construction productivity in real-time. Thus, an instant feedback to the construction crew was possible. As a result, the capability of rapid construction was improved using the developed technology.

6. Acknowledgements

This research project was funded by the Kansas University Transportation Research Institute, Kansas Department of Transportation, Federal Highway Administration, and National Science Foundation. The financial support from these agencies is greatly appreciated.

7. References

Bai, Y., Kim, S. H. and Burkett, W. R. (2007). "Enhancing the Capability of Rapid Bridge Replacement after Extreme Events," Engineering, Construction and Architectural Management, Vol. 14, No. 4, pp 375-386.

Sprinkle, H. B. (1972) "Analysis of Time-Lapse Construction Films," Journal of the Construction Engineering Division, Vol. 98, No. 2, pp 183-199.

Baron, J. L., Fleet D. J. and Beauchemin, S.S (1994). "Performance of Optical Flow Techniques," International Journal of Computer Vision, 12 (1), pp 43-77.

Eldon, C., and Janaka Y. R., (2005). "Situation Based Modeling for Construction Productivity," 2005 CRC Proceedings, San Diego, California, Vol. 183, No. 40754.

Lin, Hong-Wen, Yang, Shao-Qing, Xia, Zhi-Jun, and Kang, Chun-Yu (2006). "A Moving Objects Detection Approach for Smart Sensor". International Conference on Machine Learning and Cybernetics, Dalian, China, pp 3751-3754.

Li-Chung, C., and Miroslaw, J. S. (1994). "Estimating Construction Productivity: Neural-Network-Based Approach." J. of Computing in CE, 8 (2): pp 234-251.

Dissanayake, M., Aminah R. F., Russell, A.D., and Pedrycz, W., et al. (2005). "A Hybrid Neural Network for Predicting Construction Labour Productivity," ASCE International Conference on Computing in CE, Vol. 179, No. 40794.

Ming, L., S. M. Abou Rizk, et al. (2000). "Estimating Labor Productivity Using Probability Inference Neural Network," J. of Computing in CE, 14 (4), 241-248.

Zhang, T. Y. and C. Y. Suen (1984). "A Fast Parallel Algorithm for Thinning Digital Patterns," New York, ACM**,** 27(3), pp 236-239.

Navon, R., and Goldschmidt, E. (2003). "Can Labor Inputs be Measured and Controlled Automatically?" J. of Constr. Eng. Manage., 129(4), 437-445.

Navon, R., and Shpatnitsky, Y. (2005). "Field Experiments in Automated Monitoring of Road Construction." J. of Constr. Eng. Manage., 131(4), pp 487-493.

Heng, Li., Zhen, C., Liang, Y. and S.C.W. Kong (2005)"Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency" International Conference for Construction Information Technology, 14 (3), pp 323-331.

BENEFITS AND BARRIERS OF MONITORING CONSTRUCTION ACTIVITIES USING HI-RESOLUTION AUTOMATED CAMERAS

Jeffrey S. Bohn[1] and Jochen Teizer[2]

[1]Graduate Student, RAPIDS Laboratory, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA, 30332-0355, PH (404) 894-8269, FAX (404) 894-2278, e-mail: j.bohn@gatech.edu
[2]Assistant Professor, RAPIDS Laboratory School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA, 30332-0355, PH (404) 894-8269, FAX (404) 894-2278, e-mail: teizer@gatech.edu

Abstract
Monitoring construction projects is a constant task for project managers and executives. The shear size of many projects makes complete coverage difficult and time consuming. Emerging technologies are entering the industry to aid workers in maintaining project controls, but additional research is needed to clearly identify benefits and barriers associated with their use, as historically, data has not been collected in this area. Hi-Resolution construction cameras can allow project managers to see a broader perspective of construction activities and operations and allow these people to do so anywhere internet connectivity is available. This paper focuses on creating a standard approach to quantify cost-benefits of new technologies, specifically construction cameras. Results of a multi-phased survey to industry professionals were collected in order to identify benefits and barriers and develop a cost-benefit model for implementation of new technology in construction.

1. Introduction

The often complex nature of processes related to construction project delivery creates a significant potential for ever more streamlined processes to reliably deliver high quality and more economical projects. Monitoring and tracking the performance of construction projects plays a major role in achieving this goal, but is often a difficult and complicated task due to the consistently changing job site environment. Although construction site control in the majority of the construction industry is still mostly a manual task using visual inspection and paper based checklists, project participants such as owners, architects, contractors, and subcontractors increasingly rely on using technologies to update data when collecting site performance information.

Examples of field technologies that do not require placing physical devices on the object, but otherwise depend on optical measurements that require line-of-sight,

are: Lasers rangefinders for machine guidance and position, laser scanners for three-dimensional point cloud measurement (Akinci and Ergin 2008, Bosche and Haas 2007, Lytle and Saidi 2006), and 3D range imaging cameras (Teizer et al. 2005).

The reader will become familiar with the features and capabilities of used camera types and their application areas in construction. To determine the benefits and barriers of camera technology in each of the identified application areas, a survey instrument will be introduced, followed by a discussion of the survey results. This paper then identifies construction tasks where automated camera technology is likely to have a high impact.

2. Background on Camera Technology in Construction Management

The following paragraphs review how camera technology in the construction industry is used to measure, evaluate, document, and correct projects or work tasks. The reader will learn about hardware and software that ranges from still image to video cameras, from small handheld cameras to commercially used remotely operating cameras for construction purposes only. An introduction to the application areas of automated high-resolution cameras and their cost is given in more detail since they are relevant for the remainder of this paper. The flow diagram in Figure 1 illustrates the phases where monitoring and controlling technology in construction can assist project participants in making better decisions faster.

2.1. High Resolution Digital Cameras in Construction

The growths of information technologies and data storage opportunities in recent years have made image and video data collection and processing available and affordable for many construction companies. This has been manifested in the form of high-resolution automated cameras provided by third party suppliers. These types of cameras are used to take static images at set intervals and record moving video of a site and its operations (Hannon 2007). High-resolution cameras were chosen for the scope of this research due to the increasing adoption of the technology and large amount of benefits they produce. Additionally, static cameras rather than video cameras were analyzed due to the low use of video cameras across the construction industry and the significant drawbacks they create, for example, setting high data storage requirements. The components of a camera in a typical construction camera are shown in Figure 2 in cross sectional view. A summary of the features and capabilities of both the hardware and software of construction cameras is provided in Table 1. A standard screenshot of a typical user interfaces, including archived calendar, weather, and recorded images is shown in Figure 2.

2.2. Application Areas of Automated High-Resolution Cameras

The following paragraphs detail the application areas that were the focus of this survey. Included are project controls, communication/documentation, resource management, and safety and travel.

Project Controls: Having well maintained project controls and management is vital to minimize unnecessary cost on construction projects. Data collected at random time periods and in a non-standardized fashion is not as helpful for project management as data collected regularly. Standardization will make identifying

problems and deviations more obvious. Cameras are useful in monitoring the progress of construction activities, especially from a distance and at a standardized viewpoint. Camera users can log into a web user interface and see if building sections or components have been completed or if re-work is needed, allowing for early detection of issues or problems while still performing the same construction tasks. The ability to follow the progress of activities allows users to predict upcoming roadblocks and better plan for the immediate next or following work task(s). Digital images may also reduce time needed for inspection by allowing this task to be done remotely (Brilakis 2007). Seeing real-time weather can help project managers to plan and schedule.

Communication and Documentation: One of the most significant problems in managing construction projects arises in delays resulting from poor communication or documentation. When meetings are held, meeting participants can instantly learn about the project status, thus eliminating waiting periods to retrieve information. Site visits can thus be optimized and condensed. Another important documentation advantage stems from the standardization of site pictures. Since a camera is mounted in a single spot, all pictures are taken from the same vantage point, thus reducing confusion that may arise from multiple perspectives. A standard time between each photograph taken allows users to know what time scale they are looking at and can accurately gage progress (Fard and Pena-Mora 2007). This reduces time needed for field employees to venture into the site to take pictures. The standardization of pictures allows for time-lapse photography, which can be used for post-project analysis and training or marketing purposes. Pictures can be used for legal purposes such as dispute avoidance and litigation, possibly saving millions of dollars in expenses, time, and relationships.

Resource Management: Cameras are considered "semi-automated" in the sense that the physical task of tracking resources in a sequence of images is performed by the user or image processing algorithms. Using cameras for tracking workforce, materials and inventory, and equipment across a site can reveal a number of important imbalances for a project. Time wasting, task completion time, and inefficiencies can be recognized and adjusted for better optimization of project resources (Senior and Swanber-Mee 1997). Inventory and control of large equipment and bulk materials can be quickly located if they are in view of the camera. Presence and location of project workforce personnel can effortlessly be identified as well.

Safety and Travel: Travel can become a large cost for project managers, executives, and owners if they work directly on project sites which can be located hundreds of miles away from their main office. Instant access to a website that hosts an image library of the project can reduce the frequency of trips, saves gas expenses, and wear-and-tear on company vehicles. Cameras can become a useful tool in scheduling site visits, since managers can judge when certain stages may be completed or need input, and plan their trips accordingly. Safety issues, like jobsite hazards can be recognized remotely and the staff on duty can be informed to remove the hazard. Improper methods being used onsite can be identified and stopped if captured by the cameras. Theft and vandalism to site equipment and materials may also be reduced by the presence of protective camera housing alone.

2.3. Costs of Automated High-Resolution Cameras

Costs for cameras include initial purchase, service fees, installation, maintenance, training for employees, and any expenses for troubleshooting during the operational time. A baseline cost in 2008 for purchasing construction cameras is around $2,000-12,000 annually depending on the model and capabilities needed. There is typically a one time hardware cost and then either recurring service fee or running cost. Due to the harsh environment construction cameras operate in, warranties are given for a specified amount of time in case of damage. Monthly service fees for access, operation, and technical support, usually are between $200 and $600.

3. Research Objective and Methodology

A study conducted by the National Highway Cooperative Research Program (NCHRP) states that the largest barrier for successful implementation of camera technology is "lack of understanding/knowledge of the potential applications of jobsite images and video" (Hannon 2007). This research tries to better understand the benefits and limitations of the use of cameras in more detail for that reason, a survey was conducted to determine and quantify the benefits and limitations.

Based on the performed literature review, preliminary discussions with several camera providers, and phone interviews with a handful of experienced camera users, a survey instrument was developed and distributed to a large number of existing camera users of construction camera suppliers. 142 individuals from 114 different organizations answered. Although the exact number of contacted survey participant is kept confidential (to researchers and camera suppliers), the performed data analysis is not significant. The data analysis performed in this study, however, includes a total number of responses that is up to eight times larger than any of the previously conducted research studies, for example, Hannon (2007), and involves a variety of construction project types that go beyond infrastructure construction only. This survey was based on many different project types, sizes, budgets, and lengths and thus was not skewed in any one direction.

4. Survey and Results

The following sections present results obtained from questions the survey. The results will be presented in the order that they were asked. Information was obtained for personal and company background of the survey respondent.

4.1. Project Type Breakdowns

An important research task was to identify which work tasks cameras impact the most and least when considering project specific types, such as duration, budget, stories/floors, and acreage. This analysis may help camera users identify in which areas they can expect considerable benefits and in which they might not yield sufficient return on investment when using cameras.

Duration: Cameras become beneficial to some users when used as safety enforcement tool for longer termed projects. Survey respondents might see little impact of using cameras in manually tracking resources in longer termed projects. A potential solution could be automating the tracking of resources using camera images.

Budget: Cameras were most beneficial in use in projects ranging from $26-50 million when supporting internal communication and knowing the project status

before visiting the site. Projects with higher budgets (>$26 million) found higher value for using cameras in lawsuit and dispute avoidance.

Stories/Floors: Based on the height of the project, cameras show a high return when being used in smaller sized projects (1-10 floors) and see large impact for scheduling site trips. It is likely that project managers are in charge of few to many smaller projects at the same time, thus benefiting the most of using cameras to oversee several constructions sites at the same time with less effort.

Acreage: Cameras have the biggest impact on smaller projects (1-5 acres) and mostly used for internal communication and scheduling purposes, while cameras on larger projects (>5 acres) have impact on external communication. Larger projects are often more complex and thus have more people outside of an organization involved who need to share information.

4.2. Observed Benefits

An important objective of this survey was to measure if the envisioned benefits before applying camera technology in construction later meet the observed benefits once camera technology has been applied. If a difference between expectations and reality exists, corrective actions may be taken. The first step is to determine the *envisioned benefits*. The ordinal values of survey questions for questions (A), (B), and (C) are multiplied, weighted, and then ranked. Each weighted rating takes into account task impact, potential for improvement, and potential improvement from camera use. The formula is:

Envisioned Benefits = [(A) x *(B)* x *(C)] / [Total Sum of values]*
A = General Task Impact on Project
B = General Potential for Improvement
C = Envisioned Potential on Improvement on Task using Cameras
D = Impact of Cameras on Task Observed

The second step includes the calculation of the *observed benefits* by multiplying the envisioned benefits with the score of survey question (D). Similar to the envisioned benefits, the *observed benefits* are weighted and ranked.

Observed Benefits = [(A) x *(B)* x *(C)* x *(D)] / [Total sum of values]*

A chart displaying the weighted ratings of each task for both envisioned and observed benefits is illustrated in Figure 3. These weights can further be used to develop a toolkit for further cost-benefit analysis for construction cameras as explained later in this section.

4.3. Benefits and Barriers in Current and Future Uses

Respondents were then asked to pick the top barriers for further implementation of construction cameras. Presented with a list of 11 choices and asked to pick three choices, 46% of all survey respondents identified price as major barrier for more widespread use of camera technology in construction. Either camera technology has not been considered “in the budget” or the “owner won’t pay for it”. A rigorous cost-

benefit analysis that quantifies cost and benefits can help solve this problem.

4.4. Return for Projects

Although many survey respondents were able to qualitatively describe the benefits of using camera technology, they were unable to quantify an absolute return-on-investment. Several reasons can cause this lack of sufficient data. First, data is not collected or available in the detail needed to accurately describe monetary or schedule benefits. Decision makers have not recorded detailed data since their job priorities lay in different areas (managing day to day operations, etc.). Secondly, the data that needs to be collected is unknown or difficult to obtain or quantify. Additionally, the relatively low cost of camera technology (a few thousand dollars) may prohibit a serious research effort. Tracking this information would be a useful but significant and time consuming undertaking.

Camera savings over a longer time frame can be analyzed for several projects using the weighted values found in this research (see Figure 3). Comparisons need to be made for each task in year X and subsequent years X+1. Year X would be the control project (not using automated cameras), while year X+1 would be the same or a similar project that uses cameras. Data would need to be record both on a cost basis (dollars) and a schedule basis (time) involved in each task. Project managers, for example, would need to document their schedule throughout the observation period and eventually record detailed schedule data on deviations. Values could then be compared, showing possible savings in time and money. This method can then be applied for all tasks and multiplied by their given weight factors in order to normalize the task appropriately. The formula is as follows for a typical project:

$$\textit{Savings due to cameras} = (\$\Delta \textit{ in Task 1 from X to X+1}) \times \textit{(Task 1 Weight factor)} + (\$\,\Delta \textit{ in Task 2 from X to X+1}) \times \textit{(Task 2 Weight factor} + \ldots + (\$\,\Delta \textit{ in Task N)} \times \textit{(Task N Weight factor)}$$

If this analysis was implemented across a number of projects, one could begin to see value savings, for example, documenting savings on external communication due to cameras. Using the weighted values of the observed benefits, the difference in dollar savings from year 1 and year 2 would be multiplied by this factor. If the savings were found to be $5,000 between the two years for these tasks, this value would need to be properly weighted in order to quantify the savings achieved from camera use. For external communication, the weight factor found in the survey was 8.11%. Multiplying ($5,000)x(0.0811) yields $405.5 yearly savings for external communication due to construction cameras.

Looking at an individual project as an example can help illustrate quantitative savings, created by cameras. For this research, a construction camera was placed overlooking the demolition and construction of the 14th Street Bridge in Atlanta, GA. It is not uncommon for project managers to be based out of locations far from a project site. The distance requires frequent site visits by a manager in order to asses conditions of the site and make decisions to move the project along. For the 14th Street Bridge project, the headquarters of the general contractor was in a suburb of Atlanta. Assuming a manager is billed at $80 per hour and completes a weekly site visit in three hours, traveling 30 miles for a round trip, the cost for this task can be

calculated using the IRS standard of 50.5 cents per vehicle mile travelled. The 12 hours per month equal to $960. Travel alone would cost $75.75. In summary a cost of $1,035.75 per month occurs. This cost or part of it may be avoided if the project manager is able to view the bridge using the cameras instead of a site visit that was planned. If three trips are avoided by a project manager, that is equal to roughly the cost of a camera unit (approximately $3,000). In these cases, the initial invested cost of the camera is paid back to the purchasing company.

With more detailed studies, savings due to material tracking can be quantified also. Figure 4 shows the placement and compaction of an asphalt layer for Interstate 75/85 over a two day period. This task lasted 15 hours. Project managers can use cameras to quantify costs for this timeframe by visualizing productivity of the operation throughout the days. Wasted or unnecessary downtime can be identified and the processes adjusted to be scheduled properly, reducing the number of hours worked and saving money. From the images, six workers can be seen completing the paving task. Using the ENR labor cost of $32.74 per hour (The McGraw-Hill Companies 2008), the total labor cost is estimated at $2,946.60. Any reduction of time or process (i.e. unnecessary worker identified, obstructions) would create savings for the project. Identifying one unnecessary worker would save $491 in labor cost for this task alone. This labor cost could then be applied to another aspect of the project for tasks that are behind schedule or require more manpower.

Qualitative impact of the cameras was generated through increased public awareness of the project. Contractor and Georgia Department of Transportation (GDOT) received positive publicity in an article published in the Atlanta-Journal Constitution that informed readers about the camera accessibility and linked them to the website interface. Because of this, the public could be just as up to date as project staff. Prior to this article, the average users per day were approximately 20 people. The following week had an average of 1,337 users per day, far greater than the initial average. For the remaining weeks of the project, the number of users averaged out to approximately 225 users per day and remained in this range for many weeks.

Demolition of the bridge was one of the most involved and most dangerous tasks for this project. Figure 4a and 4b show the sequences in the progress of the bridge demolition and paving recorded by the camera.. Officials at GDOT stated they would use these images in the future as a training device for new engineers, demonstrating the proper procedure for bridge construction. By creating a log of the events in the camera, offsite user from can compare the planned schedule to as-builts. For many large tasks such as bridge demolition, detailed schedules are not created, rather a generalized process is listed and many of the more detailed tasks are left to the discretion of superintendents and managers. The original demolition schedule showed five unique tasks, whereas 15 tasks were identified and recorded in the daily camera logs. This allows for better planning on future projects by having a much more detailed idea of what equipment is involved, how many hours workers are present, and the tasks that need to be completed.

5. Conclusions

This paper presented the benefits and barriers associated with the use of hi-resolution construction cameras for construction management. It recognized tasks where

cameras have a large impact and areas for improvement for construction project monitoring. The benefits of construction cameras have been consistently found to exceed their expected impacts and a large potential exists for improving their use, for example in resource management. Determining quantitative savings was a difficult task, as companies currently do not record supporting data. A more in-depth analysis of individual projects is required. While the participating companies were unable to determine quantitative savings, qualitative results show that cameras are having a significant impact on projects. From interviews with users and data collected from surveys, the majority of respondents supported the use of cameras and expressed the desire to continue their use on future projects. The rapid adoption of this technology by construction companies tends to support this claim. Long-term research will need to address quantitative savings.

TABLE 1 Hardware and Software Features and Capabilities

Hard/Software Features	Capabilities
Mounting hardware	Fixed wall or pole mount
High-definition cameras	3-10megapixels (between 2048x1536 and 3600x2700 pixels)
Wide angel lens	6.3-63 mm (38-380mm equivalent in 35mm photography)
Optical zoom	Up to 50 times
Electric protection	Integrated surge protection, 120 Volts, 83 watts (solar option)
Data storage	Central server, transmitting automatically 30 min after install
Weather proofing case	Operate in most weather types
Frame rate	25/30 frames/second (video); 1 image/10-15 min (still)
Heat/cold resistance	Operate from -40°C to 56°F
External recording	DVR, DVD, or film
Image transmission	Dial-up (56kbs), LAN, WAN, cellular
Hosted project website	Interactive interface: Retrieve/categorize project photos
Time-lapse photography	Automatic Production, Image comparison to detect changes
Weather data and features	Real-time, historically recorded, auto-response lens wipers
Camera movement	Digital pan, tilt, zoom (78 degrees of view when static)
User Interface	Internet browser (restricted password protected)

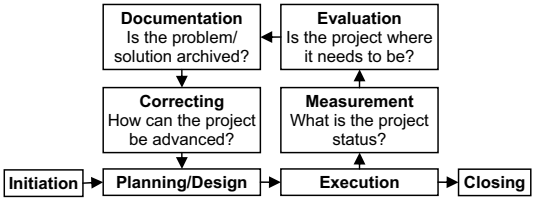


FIGURE 1 Typical Development Phases to Control a Project or Work Task

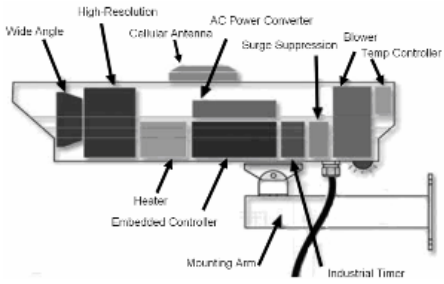




FIGURE 2 Components and User Interface of Construction Cameras (OxBlue, Inc.)

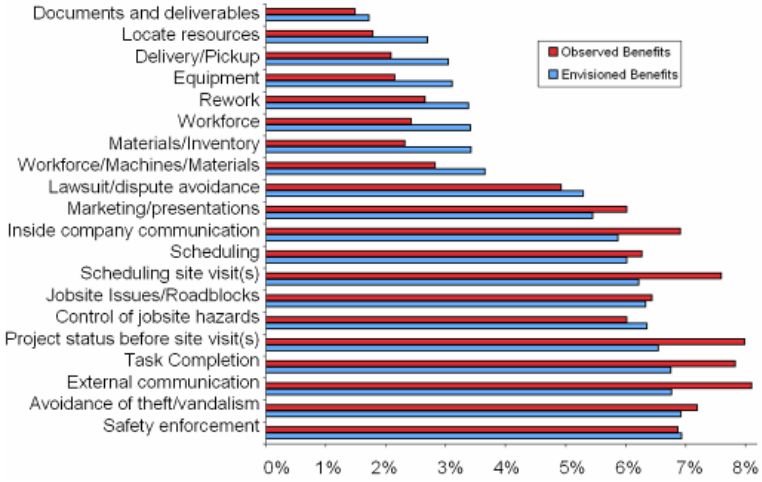


FIGURE 3 Observed vs. Envisioned Benefits

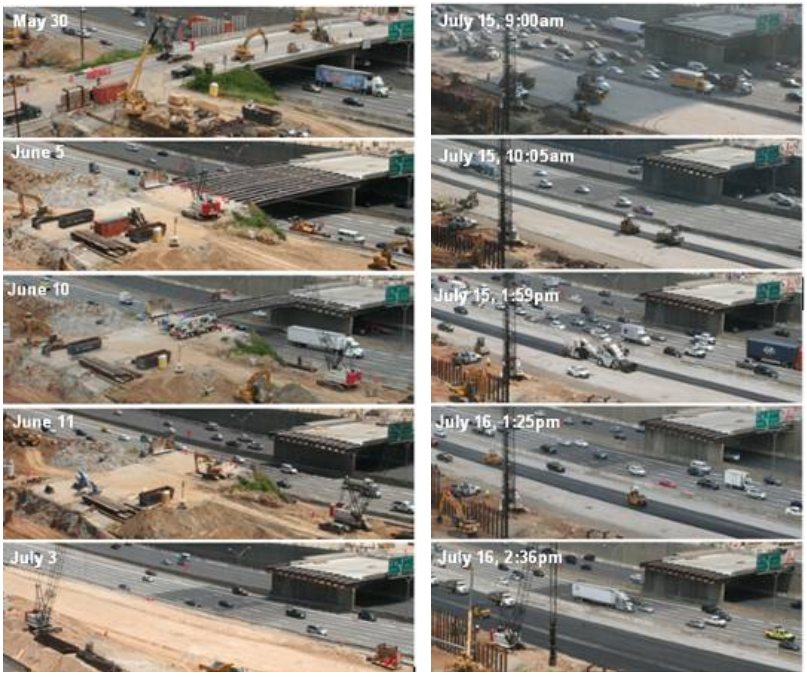


FIGURE 4 Progress Monitoring of Two Construction Tasks by Day and Minute

References

Akinci, B. and Ergin, E. (2008). Simulation-based Identification of Possible Locations for Mobile Cranes on Construction Sites. *Journal of Computing in Civil Engineering*, 22(21), 21-31.

Bosche, F. and Haas, C. (2007). Towards Automated Retrieval and 3D Design Data in Sensed Data. *Proceeding of the 2007 ASCE International Workshop on Computing in Civil Engineering,* Pittsburgh, PA.

Brilakis, I. (2007). Long Distance Wireless Networking for Site - Office Data Communications. *Journal of Information Technology in Construction,* 12, 154-164.

Brilakis, I., Cordova, F., and Clark, P. (2008). Automated 3D Vision Tracking for Project Control Support, *Joint US-European Workshop on Intelligent Computing in Engineering*, Plymouth, UK.

Caldas, C.H. and Soibelman, L. (2003). Automating Hierarchical Document Classification for Construction Management Information Systems. *Automation in Construction,* 12(4), 395-406.

Engineering News-Record (2008). "Construction Economics." The McGraw-Hill Companies, Inc. <http://enr.construction.com>. (Jul. 1, 2008).

Fard, M.G. and Peña-Mora, F. (2007). Application of Visualization Techniques for Construction Progress Monitoring, *Proceedings of the ASCE International Workshop on Computing in Civil Engineering*, Pittsburg, PA, 261(27), 216-223.

Hannon, J. (2007). The National Highway Cooperative Research Program (NHCRP) Synthesis 372: Emerging Technologies for Construction Delivery, A Synthesis of Highway Practice. In *Transportation Research Record,*, Washington, D.C., 50-57.

Lytle, A. and Saidi, K. (2006). Status of the NIST 3D Imaging System Performance Evaluation Facility. *Autonomous Robots*, 22(3), 211-221.

Oxblue, Inc. (2008). <www.oxblue.com> (Jul 1, 2008)

Senior, B.A. and Swanberg-Mee, A. (1997). Activity Analysis Using Computer-Processed Time Lapse Video. *Proceedings of the ASCE Construction Congress V*, Minneapolis, MN. 462-469.

Teizer, J., Kim, C., Haas, C., Liapi, K. and Caldas, C. (2005). Framework for Real-Time Three-Dimensional Modeling on Infrastructure. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1913, Transportation Research Board of the National Academies, Washington, D.C., 177-186.

PRO-ACTIVE-REAL-TIME PERSONNEL WARNING SYSTEM

Clare E. Fullerton,[1] Ben S. Allread,[2] and Jochen Teizer[3]

[1]B.S. Student, RAPIDS Laboratory, Department of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA 30320-0355. e-mail: clarefullerton@gatech.edu
[2]M.S. Student, RAPIDS Laboratory, Department of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA 30320-0355. e-mail: ben.allread@gatech.edu
[3]Assistant Professor, RAPIDS Laboratory, Department of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA 30320-0355. PH (404) 894-8269, FAX (404) 894-2278, e-mail: teizer@gatech.edu

Abstract
Collisions between personnel on foot and heavy equipment or materials on a construction site can be characterized as a contact collision. These types of incidents are a common occurrence on a work site. Pro-active-real-time safety technology is needed to improve the safety of a work zone by alerting workers that they are in danger of collisions. Furthermore technology may assist to collect (previously unrecorded) data on "near-misses". This new approach can then lead to improve the overall safety performance in construction and elsewhere through improved learning and education by providing relevant information to decision makers at all levels. The technology that was developed and is presented in this paper uses the radio frequency wave spectrum to alert workers in real-time when they are in danger. Various experiments are described that have been conducted in order to gain better understanding of the technology's potential, including machine blind spots. Preliminary results are demonstrated and will conclude that this technology also has the capability of collecting important safety data while pro-actively detecting hazardous situations and warning workers and equipment operators of an imminent predicament.

1. Introduction

A construction work zone is mostly a dynamic place consisting of heavy equipment, materials, and personnel that are in motion to each another. The sometimes unstructured or almost random movement can lead to incidents between two objects. These incidents are then characterized as contact collisions and are often a threat to the safety of personnel that is in too close proximity to equipment. These collisions

can be attributed to various problems that begin with the closeness in which vehicles and workers operate. Pratt, et al., explains how workers are often unloading materials from a vehicle for an extended period of time, and operators become unaware that workers remain in proximity. Workers become unaware of their surroundings due to fatigue and task repetition, which causes lower awareness and loss of focus on surroundings. These situations are dangerous for all workers, and machine operators must deal with machine blind spots, too. Therefore, there needs to be an alert that will alarm workers from their specific tasks and alert them to their surroundings.

Current safety statistics have been published by the Census of Fatal Occupational Injuries (CFOI) for 2007, while the report will not be completed until the spring of 2009, initial investigation shows that there is significant fatality rates for personnel being struck by vehicles. 21% of all occupational fatalities occur in the construction industry which accounts for 1,178 people. Within the construction industry, most fatalities of workers being struck by objects occurred in heavy construction and to specialty contractors (10% and 13% of all fatalities respectively). Statistics showed that 6% of all occupational injuries were from workers being struck by vehicles. (CFOI 2007) This information shows that there is a need for a "second chance" warning device that alerts workers that they are in danger.

Fosbroke (2004) published on the Construction Research Program created by NOISH which identifies the following contributing factors to the issue of contact collisions. There is lack of knowledge of specific risk factors; all data collected on incidents is collected after-the-fact and no real-time information is gathered during the incident such that the specific safety needs on a site have yet to be sufficiently identified. There is insufficient adaptation of intervention technologies used in other industries; the train industry and mining industry have both been implementing various safety technologies that if adapted could be used in the construction industry. (Fosbroke 2004) There is a lack of scientific evaluation for newly and existing intervention technology; emerging safety technology needs to be evaluated through research of current methods along with case studies and data analysis. These issues will be addressed in this research through the evaluation of current safety practices, uses of technology in safety, creation of proactive safety technology using active Radio Frequency Identification (RFID), and subsequent evaluation of the technology.

2. Background

Technology can be seen as the first and last barrier of safety. The Causation Model for Accidents (Figure 1) has been adapted from the Swiss Cheese Model (after Reason 1990). The model shows how in each level of construction there are "holes" in the initial safety plan; as the plan advances to the construction phase the lack of safety planning results in more "holes," and thus higher probability of incidents. The Construction Industry Institute (CII) published "Safety Plus: Making Zero Accidents A Reality" (RS 160-1) in February 2003, reported that "the findings show that the better safety records occurred when site-specific safety programs were prepared for the projects". Therefore, better front end planning will result in safer worksites.

There are many different technologies emerging in the construction industry; each technology has the potential to help improve site safety conditions. Technology can be used as a final barrier by giving workers a "second chance" of escape using a

warning device. Information from the "near-misses" that occur through the alert can be collected and used to change future safety plans at the beginning of a project. Effective implementation will strive to close up the "holes" and decrease the number of accidents on worksites; the technology(s) will become a first barrier tool of safety.

OSHA regulations are not enough to prevent these kinds of collisions from occurring. The Center for Disease Control (CDC), Pratt, et al. (2001), conducted a study in 2001 that categorized the various kinds of fatalities that occur on a construction site, both along a highway and off a highway. All gathered information is after-the-fact data. (Pratt 2001)

The statistics presented earlier from CFOI coincide with the statistics from previous years; it is evident that not much has improved in preventing workers from being killed by vehicles. The following information was also gathered from the CFOI but was compiled by Pratt et al. for NIOSH and displays statistics between 1992 and 1998. The study found that out of the 465 vehicle related fatalities, 318 of the fatalities were workers on foot. The type of vehicle they were struck by was most commonly a type of truck (60%) followed by a construction machine (30%). 110 fatalities were machine operators, most of those accidents occurred to a worker operating a construction vehicle (53%), and followed by a truck. The remainder of the fatalities occurred to supervisors and other personnel. The majority of the fatalities (51%) occurred when the vehicle was in reverse mode; this can be attributed to the large amount of blind spots that are prevalent in the backside of a vehicle. (Pratt 2001)

During 2006, the CFOI reported 369 workers were killed by a motor vehicle during highway construction that accounted for 7% of all occupational deaths. 560 workers were reported killed by being struck by an object that accounted for 10% of all occupational deaths. There is limited data on the specific happenings of an occupational fatality. Of those incidents that did not result in fatalities, most workers were severely injured which resulted in missed days of work. (CFOI 2007) Figure 2 is an image of an unsafe situation; a worker on foot is working in between two pieces of heavy equipment and is unseen by the machine operator. This situation could lead to an accident as described earlier.

2.1. Current Safety Practices

There are different methods of maintaining safety on work zones including the modification of behavior methods employed on the work zone, passive safety technology, and active safety technology. Passive technology does not use any sensing technology once installed, for example, helmets, goggles, or safety vests. Active technology uses sensing technology and works in two different ways; the first is with two or more sensors that transmit information to each other and the second is the use of cameras that identify objects through image processing. Within active safety technology there is a distinct difference between reactive and proactive safety technology; reactive technology collects data in real time that can then be analyzed to determine the best way to change future situations to make improvements and proactive technology works in real-time to alert personnel of the dangers occurring at that moment.

Pratt et al. (2001) discovered that the first method to improve safety on a work zone is by altering the behavior of the individuals on the safety zone. All ground workers and operators should be trained on how to use their tools and equipment, and machine operators should be trained not only how to use their machine but also how to work around the construction site since they too move on foot throughout the site. Supervisors should monitor workers performing their tasks and operators checking their machines to ensure they are in optimum working condition. By mandating refresher courses or by giving incentives for taking refresher courses the contractors and owners can ensure that each worker is up to date on their training (Ultimate Goal 2008). Furthermore, pre-work fitness, driving performance, and physiological factors should be monitored on all machine operators to ensure there is no driver impairment.

2.2. Safety technologies

The aforementioned safety techniques have been unable to eliminate contact collisions on the work site, because accidents occur daily. Active safety technology comes in two forms: reactive and proactive. Reactive safety technology may include the use of video cameras, where the cameras would allow supervisors and owners to assess project on a daily basis. Assessments may include features like the impact of the weather, accurate accident investigations, and asset tracking. This information can then be used as a way to improve the productivity of the work site, monitor the safety by noting any potential hazards, and note any breach of regulation by workers and sub-contractors (Abeid 2002). Cameras can also be used in a proactive method; by transmitting the feed-back to a hub and incorporating the data with a 2D algorithm, the tracker can choose a worker, material, or piece of equipment to track in 3D real-time. This method gives a clear picture of the object selected and allows the tracker to monitor any potential threatening situations that could endanger the work zone.

Laser scanning is also a reactive method to improving the safety of the worksite. A laser scanner collects a three-dimensional point cloud of objects in its field-of-view. An accurate 3D model of the entire worksite can be assessed in the same ways video cameras work. By taking digital images of project sites in real-time, all project coordinators are able to monitor the progress through a virtual environment. Owners can then locate tasks or areas that are unsafe and inform workers of the issue without entering the site. Laser scanning will be used in this research as a way of discovering the blind spots on different pieces of equipment (Jaselskis 2005); see section 4.1.

Radio Frequency Identification (RFID) can be coordinated to be used as a proactive safety measure. Traditionally RFID has been used as a method of coordinating a site by “tagging” various materials, equipment, and personnel as a way of tracking all the moving parts of a construction zone. This method has allowed supervisors and owners to monitor the movement and analyze ways to improve the site by increasing efficiency, but is a reactive use of RFID. RFID transfers data in real time, and is capable to observe real-time movements. However, this technology is moving forward and is being implemented as a method of proactively preventing collisions. An antenna, which reads the RFID from various distances depending on the tag being used, can be mounted within a truck along with a small alarm. When

the antenna reads the tag the alarm will be triggered, which will alert the machine operator that a worker on foot is nearby. This research focuses on the use of RFID technology in proactively alarming workers when equipment, ground personnel, and materials are in close proximity of each other.

The system employed in this research uses active RFID technology and is comprised of an in-cab device and a hand-held device. The in-cab device contains a single antenna, reader, and alarm; this part is called the Equipment Protection Unit (EPU). The hand-held device contains a chip, battery, and alarm; this part is called the Personal Protection Unit (PPU). The battery on the hand-held device potentially allows for the tag to intercept the frequency at approximately 30 meters. Once the tag intercepts the frequency the alarm in the hand-held device is triggered and the information on the chip is sent back to the reader. When the reader intercepts the information the alarm within the in-cab device is triggered and both worker and operator are sufficiently warned that they are in close proximity. This sending and receiving of information is instantaneous; the whole process occurs in real-time.

2.3. Previous Studies and current applications

Similar studies have been done with RFID in both work site productivity and safety. The North-South Bypass Tunnel Project in Brisbane, Australia that is currently in progress and plans to be completed by 2010, implemented passive and active RFID tags for different purposes. The passive tags were used as entry key cards to access the facilities of the construction site. The active tags are being used to track employees throughout the 4.8 km tunneling project. RFID technology improved safety by monitoring the location of all workers and was able to locate and identify anyone who was injured or missing within the tunnel. Furthermore, the tags contain important technical information involving the specific skills of each laborer such that specific workers can be located quickly, if needed. The active tags were found to be very useful in the tracking of employees to improve safety and efficiency simultaneously, so much so they were soon implemented as asset tracking by tagging all equipment. (RFID 2008)

NIOSH created a prototype called HASARD that uses a magnetic sensing system. Magnetic waves are emitted from a transmitter and whenever the magnetic wave is interfered with an alarm is triggered. The system is oriented in such a way that the transmitter is a magnetic loop that is coiled to condense the system and decrease the amount of power emitted yet still making it effective (Schiffbauer). The prototype was tested for six months in a mine; a mine was chosen for the test because of the extremely harsh conditions (Schiffbauer and Mowrey). The sensors were placed on people and walls to prevent collisions from a Continuous Miner (CM), a machine used to mine underground. The signal was found to penetrate through all coverings and could be calibrated to be used above ground as well.

Aker Yards, a shipping yard in Turku, Finland, has implemented RFID tags to monitor workers as they embark and disembark along the entry bridges to the various ships. This allows for fire and rescue to monitor in real-time the head count of all personnel on the boats in case of an emergency. Also, it allows for fire and rescue to quickly realize if someone has been on the boat for an exorbitant amount of time, in which they could be injured or trapped in some area of the ship. The tags were

placed inside the helmets to prevent any contact of the tag with anything else; the tags also held important information about the worker including a picture to verify the person found was the right person in the helmet (RFID 2008).

Radio Frequency Identification Technology has been implemented into the health industry to track patients throughout the hospital and holds pertinent information about each patient to prevent misdiagnosis and improper care. Furthermore, it has been combined with asset management in tagging materials and equipment. RFID technology was chosen because it does not interfere with hospital equipment and machinery (RFID 2008).

RFID has also been seen in warehouses, mines, and train depots being used as a safety mechanism. In warehouses, forklifts pose a large threat to the safety of all workers due to blind spots and the small spaces in which they work; additional blind spots are created in such tight areas of operation. To warn workers on foot, warehouses have put RFID technology at corners that trigger alarms when a forklift is in proximity of the sensors. Furthermore, the forklifts can be tracked throughout the warehouse and monitored for any potential dangerous situations. The mining industry places readers on walls and tags the equipment within the mines to prevent operators from colliding into the wall.

3. Methodology

The purpose of this research is to increase work zone safety in heavy equipment operations by utilizing embedded radio frequency technology for real-time pro-active warning devices. Sensing technology will be developed that may assist ground personnel and equipment operators in detecting and recognizing hazardous environments, e.g., from being too close to heavy equipment. In such an event of being too close, visual, acoustic, and vibration technology will activate alarms to the personnel through so called Equipment and Personal Protection Units (EPU and PPU). This technology will also address the lack of information on “near-misses”; it will collect data on the cause of potential collisions as a means to discovering new ways of improving the safety of a construction site.

This technology will be scientifically evaluated through the following experimental plan. First, blind spot measurements will be taken for heavy equipment found commonly in construction sites including trucks, excavators, graders and surfacing machines, semi-trucks, and standard trucks using a laser scanner as mentioned previously. Next, testing will be performed where the system is in optimum conditions; the points at which the alarm is triggered will yield the largest theoretical safety zone the system can create. Then, the system will be tested on each machine by mounting the reader inside each machine and walking the tag around the perimeter of the equipment and marking the points where the alarm is triggered. These measurements will be taken using a total robotic station to ensure accuracy. The safety zone may vary for each machine due to unique mounting solutions, which alter in-cabin EPU obstructions.

4. Experiments/Results

The following paragraphs detail the experimental procedure in two stages and present the results.

4.1. Blind Spots

The blind spots of common construction equipment including, but not limited to, excavators, rollers, dozers, dump-trucks, and cranes, may be determined through the use of 3-D laser scanning. A complete 360-degree laser scan of each machine will be collected, and each completed scan will yield a virtual model, in which anyone can navigate around on a computer. These 3-D models will aid in determining all blind spots (direct and indirect) of the machinery in different types of scenarios and poses, including operator height differences. Direct line-of-site is what the operator can see in front of him/her without the use of cameras or mirrors. When direct line-of-site is blocked it is termed a direct blind spot. An indirect blind spot is an area of visibility that is obstructed even with the use of cameras or mirrors. Once these blind spots have been determined, the necessary safety zone can be established for each machine. The safety zone is the area in which an alarm sounds, alerting both the operator(s) and worker(s) that the safety zone is breached, and a collision is probable.

4.2. Development of Proximity and Warning Device

Through the examination of safety needs on a construction site, which was determined from background information and blind spot measurements, a prototype for a safety device was devised. The following describes the technology that was manifested.

Preliminary Testing – Stage 1: Laboratory like conditions were created to initially test the prototype. The tests were done outside on clear days in open areas free of obstructions and without any outside interference. A one second Robotic Total Station (RTS) was used to take distance measurements. The RTS records the distance at which the wireless antenna reads the tag, and the reference frame established by the User allows for approximate angles/azimuths for each point recorded, with respect to the antennae "field of view." The RTS was placed in the center of the field along with the EPU, and a tester walked around with the Data Collector and PPU. The following steps were taken to test the technology:

1. Reference frame (zero degree azimuth) established on the RTS
2. Tester starts on zero azimuth about 35-40 ft away from the reader
3. Tester walks toward the apparatus, holding the tag in front of him/her, while also holding the prism rod for the RTS
4. Tester stops walking when RFID Reader "reads" the tag
5. Tester records the distance from the apparatus to the tag
6. Tester moves to the next "degrees" checkpoint (every 20 degrees around the apparatus to form a "complete circle")

This process was followed to establish a base perimeter around the EPU, before any obstacles were put into place. The manner in which the EPU would be placed on the equipment and the PPU would be placed on the worker was also determined for use in stage 2.

Preliminary Testing – Stage 2: The system was then tested in field like conditions; harsh construction settings with equipment and obstacles were used to mimic the day-to-day setting in which the device was intended to be used.

Machinery was kept stationary but was set in close proximity of materials, other equipment, and lab personnel acting as workers. The EPU was set inside the cab of the equipment and the PPU was placed on a person. The technique used to take measurements of the alarm sounding was the same technique used in Stage 1, except the checkpoints were at about every 30 degrees instead of 20 degrees.

The proximity warning device was tested on a forklift, excavator and dozer. The reader was placed inside the cab of the machine. Figure 5 displays the results obtained by an active RFID experiment. The grey area is the unsafe zone, the general blind spots area – the area in which the alarm must sound. Outside that area the worker is in the safe zone. The orange lines represent the points where the proximity alarm sounded. The worker never entered into the unsafe zone. The dozer and excavator were in close proximity of each other and a worker was standing between them as seen in Figure 2.

Field Trials – Stage 3: The next step is to implement the system into a long-term field trial. The prototype will be integrated into the safety measures on a construction site of a project. A long-term case study will demonstrate the defaults of the prototype in dealing with the rigors of a construction site, the ability for it to stand up to various weather conditions, different tasks such as excavations and multiple story projects, and different obstacles that have the ability to obstruct or diminish the signal will be shown. Then the impact of safety will be measured by calculating the number of "near-misses" that occur through the use of the proximity detection system.

4.3. Evaluation

Once testing is completed a total evaluation of the technology will be performed. Interviews will be conducted with the workforce to establish what kind of safety the workers feel is needed on the construction site. The interviews will hopefully discover what kind of intervention the workers are willing to have, how much monitoring and watching they do not mind having, and what they think of the proposed technology. The interviews will determine if workers think pro-active-real-time-warning-system will make a difference, and if they think the PPU is a comfortable, good style of protection device. Also, the impact of the device on safety will be evaluated along with a cost-benefit analysis.

5. Conclusion

From the preliminary results and background review the proposed technology has proven to have the possibility of being effective in aiding the safety needs in the construction environment. The developed devices can detect the presence of heavy equipment, including a forklift, excavator, and dozer. Based on signal strength the device can simultaneously activate and warn workers and equipment operators from being too close to each other. In various environments, auditory, visual, and vibration alarms have been tested loud and strong enough. The technology has the capability to record previously unrecorded data of close calls and near misses. This data is being analyzed and used to improve positioning of workers and equipment and assist in the development of new safety concepts and training.

6. Acknowledgement
The project is funded by a grant from the National Science Foundation under Award Number CMMI #0800858. NSF's support is gratefully acknowledged.

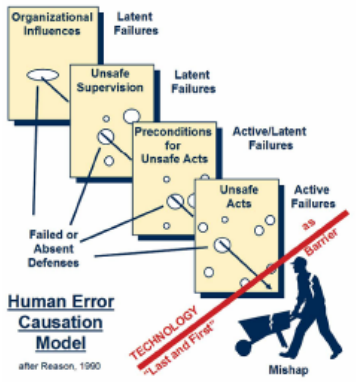


Figure 1 Swiss Cheese Model

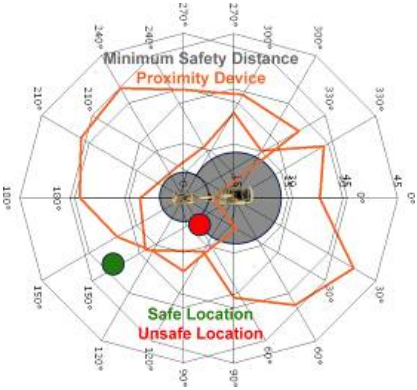


Figure 5 Active proximity warning zone



Figure 2 Hazardous situation on work sites measured using 3D laser scan image



Figure 3 3D geometry of different poses of roller



Figure 4 Schematic blind spots

References

Abeid, J., and Aditi, D. (2002). Time-Lapse Digital Photography Applied to Project Management. Journal of Construction Engineering and Management, 128(6), 530-535.

CFOI (2007). Fatal Occupational Injuries By Event Or Exposure, 2001-2006. (2007). Census of Fatal Occupational Injuries. U.S. Bureau of Labor Statistics <http://www.bls.gov/news.release/cfoi.toc.htm> (Accessed July 12)

Cordova, F. and Brilakis, I. (2008). On Site 3D Vision Tracking of Construction Personnel. *16th Annual Conference of the International Group for Lean Construction*, Manchester, UK.

Fosbroke, D. E. (2004). NIOSH Reports! Studies on Heavy Equipment Blind Spots and Internal Traffic Control. 2004 Roadway Work Zone Safety & Health Conference, Baltimore, MD.

Jaselskis, E. J., Gao, Z., and Walters, R. C. (2005). Improving Transportation Projects Using Laser Scanning. Journal of Construction Engineering and Management, 131(3), 377-384.

Pratt, S. G., Fosbroke, D. E., and Marsh, S. M. (2001). Building Safer Highway Work Zones: Measures to Prevent Worker Injuries From Vehicles and Equipment. Department of Health and Human Services: CDC, NIOSH, 5 - 6.

Reason, James. Human Error. New York: Cambridge UP, 1990.

RFID (2008) Articles by Topic. RFID Journal. Retrieved July, 2008, from <http://www.rfidjournal.com/article/topics/ >(Accessed July 15)

Schiffbauer, W. H. (2001). An Active Proximity Warning System for Surface and Underground Mining Applications. Pittsburg, PA: National Institute for Occupational Safety and Health, NIOSHTIC-2 No. 20021434.

Schiffbauer, W. H., & Mowrey, G. L., Ph.D. (2001). An Environmentally Robust Proximity Warning System for Surface and Underground Mining Applications. Pittsburg, PA: National Institute of Safety and Health, NIOSHTIC-2 No. 20021435.

"The Ultimate Goal: Zero Incidence." (2007). Construction Zone Safety Mar. 2007: 4-12. Rental Product News, Equipment Today, Concrete Contractor and Construction Distribution <http://constructionzonesafety.epubxpress.com/wps/portal/czss/c1//> (Accessed January 15)

Univeristy of Texas at Austin (2003). CII: Safety Plus: Making Zero Accidents A Reality. Research Summary 160-1.

INTERACTIVE VISUAL CONSTRUCTION PROGRESS MONITORING WITH D^{4}AR - 4D AUGMENTED REALITY- MODELS

Mani Golparvar-Fard[1], Silvio Savarese[2] and Feniosky Peña-Mora[3]

[1] William E. O'Neil Pre-Doctoral Student in Construction Management and Master of Computer Science Student, University of Illinois, Urbana-Champaign, 205 N. Mathews Ave., Urbana, IL 61801; PH (217) 333-2071; FAX (217) 265-8039; email: mgolpar2@illinois.edu
[2] Assistant Professor, Electrical and Computer Engineering, University of Michigan, Ann Arbor, MI 48109-2122; PH (734) 647-8136; FAX (217) 265-8039; e-mail: silvio@eecs.umich.edu
[3] E.W. and J.M. Gutgsell Endowed Professor in Construction Management and Information Technology, Civil and Env. Eng., University of Illinois, Urbana-Champaign, 205 N. Mathews Ave., Urbana, IL 61801; PH (217) 244-0187; FAX (217) 265-8039; email: feniosky@illinois.edu

Abstract

Visualization of construction progress helps construction project managers to study spatial aspects of as-built and as-planned performances, identify progress discrepancies, better utilize resources and equipments in different locations and make timely corrective decisions. This needs as-built performance model to be generated and superimposed over as-planned allowing progress discrepancies to be visualized. In this paper we discuss methodology of generating, analyzing and visualizing progress with D^{4}AR (4 Dimensional Augmented Reality) models using daily construction photographs and 4D as-planned model. We use three construction cases to illustrate how the as-built progress models could be sparsely reconstructed using daily site photographs and how the reconstructed model is superimposed over the as-planned model. We also demonstrate how the D^{4}AR model is applied in these ongoing construction projects. As a result of this research, automatic and more frequent visual progress data collection, analysis and reporting will become possible.

1. Introduction

A systematic progress monitoring through a rigorous identification, processing and visualization of progress discrepancies between as-built and as-planned performances is a necessity for successful project management. It provides an early warning to project managers and allows them to diagnose progress discrepancies and performance problems, and in turn take timely corrective actions. However systematic implementation of progress monitoring has significant challenges because: (1) Current practice is *time-consuming* as it needs extensive as-planned and as-built progress data extraction (Navon and Sacks 2007); (2) Quality of the manually collected data maybe low and *subjective*; (3) Existing methods are also *non-systematic,* so there is always a tendency to let project inputs serve as surrogate measures for performance outputs which affects the quality of the results (Meredith and Mantel 2003); (4) Reports are *visually complex* and they do not effectively represent multivariable progress information (i.e., schedule, cost, and performance) in a holistic manner nor do they intuitively reflect information pertaining to spatial aspects of as-built and

as-planned performances and their associated complexities (Poku and Arditi 2006; Wang and Dunston 2005); (5) Furthermore, current reporting methods *increase the time required to describe and explain progress situation* in progress coordination meetings and in turn could delay decision making. Thus, with current mechanism, it may not be easy to understand the progress situation clearly and quickly (Golparvar-Fard et al. 2006).

Current techniques for automating progress data collection have limited applicability as either they are still labor-intensive or expensive with limited applicability. Techniques such as laser scanners allow quantities of work performed to be estimated but they require scanning of construction site from different sides, which is proven to be time-consuming and in some cases as shown in (El-Omari and Moselhi 2008) not possible. Barcodes or RFID (Radio Frequency Identification) sensors are also excessively time consuming to set up and costly for many projects. Additionally they cannot be attached to many types of components and they do not capture progress of partially installed components. Also none of these techniques provide any visual reliable information about work sequence logistics, site layout or configuration of construction crew.

To address these issues, a new image-based modeling method for automating and visualizing progress monitoring is introduced wherein progress discrepancies between as-planned and as-built construction performances are visualized through superimposition of 4D (3D+time) as-planned models over site photographs using different visualization techniques such as traffic light metaphor. Our approach is based on computing, from the images themselves, the photographer's locations and orientations, along with a sparse 3D geometric representation of the as-built scene using progress daily photographs and superimposition of the reconstructed scene over as-planned 4D model. Within such an environment, progress photographs are registered in the virtual as-planned environment and this allows a large unstructured collection of daily construction images to be interactively browsed and explored. In addition, the results of progress comparison study between as-planned and as-built performances is visualized in D^4AR (4D Augmented Reality) environment. In such an environment, construction project manager would be able to: 1) use the 4D as-planned model as a baseline for progress monitoring, compare it to daily construction photographs and study workspace logistics; 2) interactively and remotely browse and explore registered construction photographs in a 3D environment; 3) automatically analyze registered images and quantify as-built progress; 4) automatically measure discrepancies between as-planned and as-built performances; and 5) visually represent progress discrepancies through superimposition of 4D as-planned models over progress photographs, make control decisions and effectively communicate those with project participants. Figure 1 shows a comparison between traditional representations of construction as-planned and as-built data and how D^4AR associates these two sets of information to visualize progress discrepancies and workspace logistics in single imageries. In this paper, the reconstruction of the as-built scene, superimposition over as-planned model and visualization of the discrepancies are discussed. We have included results of generation of these models for three ongoing construction projects, ranging from $14M to $62M over a span of two to three years.

The remainder of this paper is structured as follows. First we give an overview of the approach. Then we survey related works in construction domain as well as computer vision and graphics domain. Subsequent to that we present our approach to obtain an as-built spare reconstruction of the scene, geo-registration of cameras within the reconstructed scene, as well as superimposing that model over as-planned 3D model. Finally we present our case studies and system results, and conclude with a discussion of limitations and future works.

2. Overview on D^4AR Model- 4 Dimensional Augmented Reality Model

In this section, we discuss different features of our system. In our work, visualization of construction progress refers to merging spatial as-built and as-planned construction progress

information within a single virtual environment. In other words, visualization problem is that of generating a model that visualizes both as-built and as-planned progress performances allowing progress monitoring to be automatically measured. Our goal is to work with a set of daily construction photographs as well as construction plan and view drawings, but still generate an environment where in both as-planned and as-built scenes could be studied and progress discrepancies could be automatically visualized. There are three main components to this system. First part relates to generating an as-built scene. This component is based on using camera pose (location, orientation, and field of view) and sparse 3D reconstruction using large collection of daily site photographs to create a new scene that could be browsed. While the camera pose is known, images are placed into a common 3D coordinate system and the user can virtually explore the scene by moving in 3D space from one image to another. The backbone of this component is a robust *Structure from Motion* (*SfM*). First, we compute features in each image and subsequently find correspondences between images, using feature descriptors that are robust to variations in pose, scale, and lighting, the common issues in construction daily photographs. Then we run an optimization algorithm to recover camera parameters and 3D position of those features. The result is a sparse reconstructed scene and registered progress images within a single virtual environment.

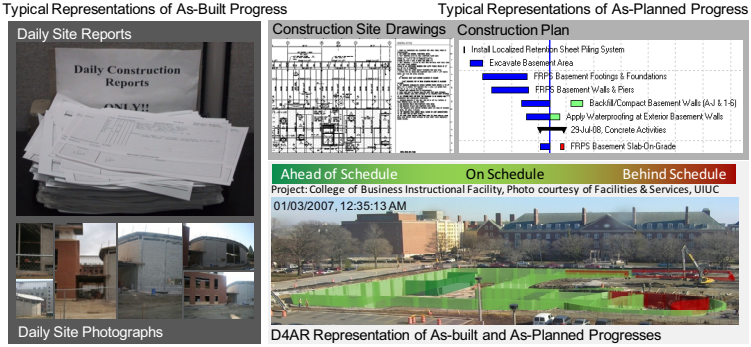


Figure 1. Comparison of traditional representations of progress and D^{4}AR Model

The second component of our system is a 4D as-planned model. Monitoring and correspondence of site activities defined by a schedule require component detection, a thorough record of construction site occurrences and a robust comparison with progress baseline. To achieve this goal 4D as-planned model acts as an underlying component to our D^{4}AR system where it functions as a pre-construction tool as well as a powerful baseline for progress monitoring. During construction phase, component identification and comparison with scheduled activities are essential functions of site monitoring. However site monitoring is an analogous process, i.e., is a manual process and therefore functions that could enable digital identification of construction components and provide ability to check if they are on schedule would be very useful. In order to extract information from the as-planned model, we use a visualization technique where different construction components could be interactively chosen and geometrical information as well as timely occurrences for those being extracted. This visualization is simple and allows easy access to progress baseline data.

The final component of our system is visualization of progress discrepancies. Simply at this stage, as-built sparse reconstruction model is superimposed over the as-planned model. This *superimposition* procedure creates a direct connection between as-planned and actual construction models. Then following Golparvar-Fard et al. (2007), we use a set of metaphors

(e.g., colors, color gradients, and color quadrants) to visualize progress and communicate progress to a wide range of construction audience.

3. Related works

The D^{4}AR model is composed of two main components. Each of these components could be used as a stand-alone system, but the combination allows discrepancies to be visualized and progress monitoring to be automatically measured. In this paper, visualization aspects of D^{4}AR system and registration of both scenes are discussed. Development of the automatic progress measurement by extracting information from images themselves is not in the scope of this paper. Each component of the system is described in the following sections:

3.1. As-Built Sparse Reconstruction and Registration of Construction Photographs

Site Photographs are becoming valuable sources of accurate project information (Soibelman et al. 2008). Nowadays, it is a common practice among all parties involved in projects from construction managers to subcontractors and from clients to architects to take digital photographs from construction sites to create a complete progress photo-log and utilize the log for coordination, communication as well as supplementary documents to potential claims. The availability of such rich imagery of large parts under different viewing conditions presents enormous opportunities, in progress monitoring, studying workspace logistics, quality assurance/ control, safety, as well as construction productivity. From the stand point of progress monitoring, these site photographs present the ultimate data set, which should enable modeling a significant portion of as-built geometry at high resolution. Therefore it will enable 3D visualization of as-built scene, localization, communication and recognition that can impact a construction project at large.

To date, this imagery is almost unexploited even by computer vision researchers (Snavely et al. 2007). The construction images are usually not organized, uncalibrated and widely variable and are taken under various illumination, resolution, and image qualities. Developing computer vision and image processing techniques that can operate effectively with such imagery has been a major challenge. Within such scope, one key challenge is image registration, i.e., figuring out correspondences between images, and how they relate to one another in common 3D coordinate system. This procedure is called *Structure from Motion* (*SfM*). While substantial progress has been done in these areas over the last two decades (recent examples: Snavely et al. 2008, Brown and Low 2005, Hartley and Zisserman 2004), the challenging aspects are still unresolved. For instance, there is a necessity to work with images that are capturing sites whose appearance is constantly changing due to progress or excessive movement of objects (e.g., site crew and machinery). Furthermore, site photographs taken are either from specific activities under progress or are taken in a panoramic manner and they do not carry enough information for a more global reconstruction of the as-built scene. Here we present some of the state-of-the-art steps towards solving this problem:

Feature Detection and Correspondence

Despite three decades of research on feature detection and matching, only recently researchers have proposed techniques that prove to be successful in extracting and detecting salient regions (in image/scale space) that are invariant with respect to scale, orientation and affine transformations. Mikolajczyk et al. (2005) reviews some recently developed view-invariant local image descriptors and experimentally compares their performances.

Structure from Motion

Structure from Motion (*SfM),* aims to reconstruct the unknown 3D scene structure and estimate camera positions and orientations from a set of image feature correspondences. Photogrammetric techniques such as bundle adjustment (Triggs et al. 1999) have made their way into computer vision and are now considered as gold standard for optimization of 3D

reconstruction and *SfM* technique. There are different approaches for *SfM*, such as self-calibration. We use the simple and effective method introduced by (Snavely et al. 2007, and, Brown and Lowe 2005). While this techniques have been applied for image navigations and touring, our paper marks the first successful demonstration of *SfM* technique being applied to geospatially photographs that are capturing a dynamic construction scene.

Image based Rendering

Following Snavely et al. (2006), Image based Rendering techniques can be used to synthesize new views of a scene from a set of photographs. In that paper, these techniques are reviewed. Our work is close to *Phototour* of Snavely et al. (2006) and *Sea of Images* (Aliaga et al. 2003) where a large collection of images are taken throughout architectural spaces. In our work, image are casually acquired on the site (as in Snavely et al. 2006), rather than being taken from fixed locations or on a guided robot (as in Aliaga et al. 2003).

3.2. As-Planned Progress Model

The application of 4D technology in construction site simulation, for the purposes of process evaluation and communication, has been under development for some time. Forerunners to this field are the groundbreaking works of (Williams 1996 and Collier and Fishcer, 1995). The mutual description of schedules and geometries of a scheduled event in a chronological manner helps to visualize the construction process.

Techniques such as (Kamat and Martinez 2008, and Behzadan and Kamat 2008) also exist where construction simulation has been visualized within operational details either in a 4D or an Augmented Reality (AR) environment. These techniques visualize construction operation, while the second application requires location tracking which is obtained by GPS. Because our approach does not require GPS or any other instrumentation, it has the advantage of being applicable to the existing image databases that are being collected on a daily basis on almost every construction site. Furthermore, our proposed feature correspondence estimation and sparse reconstruction of the as-built scene goes beyond what is possible in mentioned location-based systems, since it opens up the possibility to do various image processing techniques to extract information about progress, productivity, safety, and even have textual information associated with the sparse representation.

3.3. Visualization of Progress Discrepancies

In this context, Song et al. (2005) introduced project dashboard as a 3D-model visual representation to show a holistic picture of a project by applying multiple project data sets to geometric attributes (e.g., shape, faces and edges) of the building product model through color- tone variations and motion. It was shown that consistent application of colors would allow project performance metrics to be represented easily. This would also purge visual complexities which could be caused by complexities associated with large and sophisticated building product models. Nonetheless in their system, as-built progress was not visualized using photographs or any other means different from that of as-planned model. Rather, geometric attributes of the building product model were used to communicate progress. Based on the same concept, Lee and Peña-Mora (2006) conceptually superimposed planned product models over photographs and initiated a new paradigm on visualization of construction progress. Our work (Golparvar-Fard et al. 2008) is a continuation of these techniques where progress discrepancies as well as construction sequences have been visualized using traffic light color, its gradients as well as color quadrangles. Figure 2 shows how these concepts have been used for time-lapsed photographs to visualize progress discrepancies.

In the following section, concept of reconstructing the as-built scene is discussed. Following to that, the results of the reconstruction is visualized on three ongoing construction projects.

4. 3D Sparse Reconstruction of the As-built Construction Scene

Our system like any other Augmented Reality applications requires accurate information about relative location, orientation, and intrinsic parameters (e.g., focal length, distortion) of each construction site photograph. In addition superimposition of the reconstructed scene over as-planned model requires absolute locations of the cameras. However in our system, we do not rely on camera or any other equipment such as GPS or wireless location trackers for detecting location, orientation, or geometry. Rather, we compute such information from site images themselves using computer vision techniques. We first detect features in each image, then match features across images, and finally run *SfM* procedure to recover camera parameters. We use EXIF tag of image files to initialize our estimate on focal length. This component of the system allows photographs being taken from any type of camera to be applicable for sparse reconstruction. In this system, *SfM* only provides the *relative* position of each camera, while we are interested in *absolute* coordinates. Therefore we use an interactive semi-automated technique similar to that of (Golparvar-Fard et al. 2008) to register the as-built scene over the as-planned model. Each of these steps is described in the following subsections.

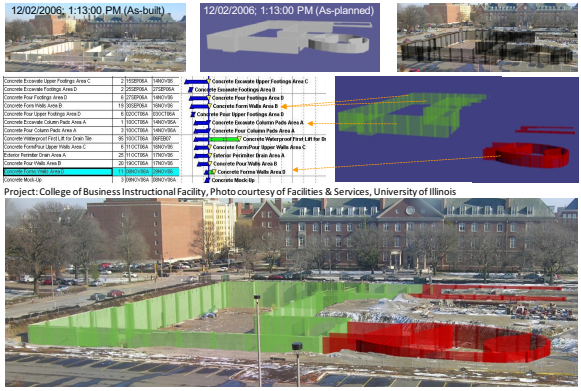


Figure 2. Visualization of progress discrepancies using traffic light metaphor: As-planned model is superimposed over site image. Project: College of Business Instr. Facility, Univ. of Illinois.

Feature Detection and Matching

The first step in reconstruction of the as-built scene is to find feature points in each image that are robust to changes in illumination, scale and viewpoint. We use the commonly used SIFT –Scale-Invariant Feature Transform- keypoint detector (Lowe 2004) to find such features. The details on detection of these features can be found in (Brown and Lowe 2005, Lowe 2004) and similar techniques are reviewed in Mikolajczyk (2005). Figure 3 shows the detector features along with their descriptor arrows.

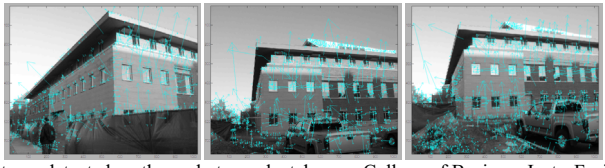


Figure 3. Features detected on three photographs taken on College of Business Instr. Facility, Univ. of Illinois. An average of 1,600 SIFT features was detected in sub-sampled 1024x800 photographs.

Once features are detected, keypoint descriptors need to be matched. We use the approximate nearest neighbor *kd*-tree package of Arya et al. (1998). The details of such approach could be

found in Lowe (2004) and Arya et al. (1998). Once these features are matched in different images, we estimate a Fundamental matrix between each pair of images using RANSAC. During each RANSAC iteration we compute a solution matrix for Fundamental matrix using 8-point algorithm of Hartley and Zisserman (2004). Finally outliers with respect to a threshold (e.g., less than 50 matches) are removed to allow a better Fundamental matrix to fit. Figure 4 shows how SIFT features between two images are matched.



Figure 4. Red lines show how SIFT features are matched in an image pair taken on college of business construction site; Photograph courtesy of University of Illinois.

Structure from Motion – Correspondence Estimation and Reconstruction

Once the matches are set, according to Snavely et al. (2007), we can recover a set of camera parameters (e.g., rotation, translation, and focal length) for each image and a 3D location for each feature. First an initial pair with a large number of matches with minimum homography is chosen to avoid degenerate cases of *SfM* minimization problem. Figure 5 shows the number of SIFT features, the number of matches after fitting Fundamental matrix within a RANSAC loop. Also the homography score - Mapping between a points on a ground plane seen from one camera, to the same points on the ground plane as seen from another camera - among each image pair is shown. The initial pair is chosen to have at least 200 matches with minimum homography score.

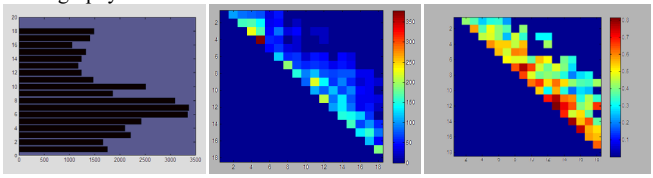


Figure 5. From left of right: number of SIFT features detected on an 18 photo subset, number of inliers for fitting a Fundamental matrix within a RANSAC loop and homography scores between image pairs.

Once the initial pair is chosen, camera parameters for this pair are estimated using Nistér's implementation of five-point algorithm (Nistér 2004) and then the tracks visible in the image pair are triangulated. Then another camera would be added to the optimization process and new camera's extrinsic parameters are detected using direct linear transform (DLT) technique (Hartley and Zisserman 2004). Finally, we add tracks observed by the new camera added into the optimization process. This procedure is repeated for one camera at a time, until no remaining camera observes any reconstructed 3D point. To minimize the objective function, at every iteration sparse bundle adjustment library of Lourakis and Argyros (2004) is used (Details can be found in Snavely et al. 2006). Figure 6 shows the reconstruction of the Student Dinning and Residence Hall projects in Champaign, IL.

Superimposition of Sparsely Reconstructed Scene over As-planned Model

The final step of the D^4AR generation process is to align the reconstructed as-built model with 3D as-planned to enable the determination of absolute geocentric coordinates of each camera and proper registration of augmented reality environment. The estimated camera locations are, in theory, related to the absolute locations by a similarity transform (global translation, rotation, and uniform scale) however The *SfM* procedure estimates relative camera locations. To determine the correct transformation, user manually specifies

correspondences between points or cameras and locations in an image or map, as in the work of Golparvar-Fard et al. (2008).

5. Case studies for D[4]AR model

As-built photos required for reconstruction of the as-built scene are collected on three different construction sites on a daily basis. One of the authors is working on two concurrent projects within a single construction site and has taken regular daily construction photos. On the third project, time-lapsed and walk-through progress photos have also been collected. These projects are as follow: (1) *Student Dining Hall Project*: A two-story masonry and curtain wall LEED Silver certified building with partial basement of about 139,327sf. This project is $36M steel frame with composite decking for about 25 month of scheduled work. (2) *Residence Hall Project*: A two-story masonry and curtain wall LEED Silver certified building with partial basement of about 58,000sf with structure base being reinforced concrete frame. This project is a 21 month and the construction cost is approximately $15M. (3) *College of Business Instructional Facility:* A four story Silver LEED certified building with almost 160,000sf of usable space. This project is $62M for 25 month scheduled work.

6. Results

We have evaluated and validated our system using the case studies. For the reconstruction of the as-built scene on Student Dining and Residence Hall project, we tested different datasets of daily photos for reconstructing the scene. The results of the reconstruction are shown in Figure 6. In addition, the results of D[4]AR images are very precise. Figure 7 shows the result of superimposition of as-planned model over site photographs for three different cases.

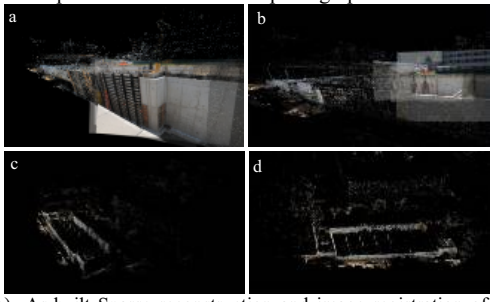


Figure 6. (a) and (b)- As-built Sparse reconstruction and image registration of Student Dining and Residence Hall with 288 photos; (c) and (d) Sparse reconstruction of Residence Hall with 141 photos.

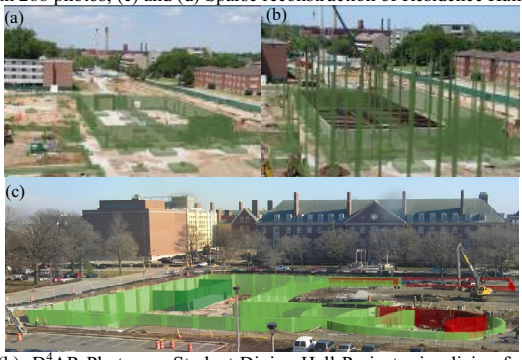


Figure 7. (a) and (b): D[4]AR Photos on Student Dining Hall Project, visualizing foundation work and steel erection; (c) D[4]AR photo on College of Business Instr. Facility visualizing progress using traffic light metaphor: behind-schedule in red and ahead-of-schedule and on-schedule in dark and light green.

7. Conclusions and Future work

We have presented a novel system for concurrent visualization of as-planned and as-built progress together. D^{4}AR allows daily construction site images to be registered within the as-planned environment and this opens up a new paradigm for an all-inclusive system wherein different use scenarios could be imagined:

Use Scenario 1: Progress Monitoring Coordination

Within such an environment, progress photographs are registered in the virtual as-planned environment and this allows a large unstructured collection of daily construction images to be interactively browsed and explored. In addition, the results of progress comparison study between as-planned and as-built performances visualized in D^{4}AR allows construction project manager to use the 4D as-planned model as a baseline for progress monitoring, compare it to daily construction photographs and study work logistics; interactively and remotely browse and explore registered construction photographs in a 3D environment and visually represent progress discrepancies through superimposition of 4D as-planned models over progress photographs, make control decisions and effectively communicate those with project participants specifically in project coordination meetings.

Use Scenario 2: Automating Progress Monitoring

Photographs registered within D^{4}AR environment are mapped with 3D elements and that opens up a new paradigm for automatic progress detection wherein progress of all visible components could be analyzed using image-processing techniques. This significance lays in having a large visual dataset to extract from and being able to visual the results in D^{4}AR from different viewpoints.

Use Scenario 3: Context Aware Information Storage and Retrieval

3D sparse reconstruction of the as-built scene is based on feature detection and matching and this can open up a new possibility for attaching textual information in form of annotation to these features. Putting this into the context of awareness systems, it allows safety information, specifications and other site related information be attached to a series of points and be visualized in all images that share those common features.

Use Scenario 4: Productivity and Safety Analysis, Site Layout Management and Work Logistics Configurations

D^{4}AR has a potential of being the basis of productivity and safety improvement. If there are too many worker are appearing in one group, a platform on a scaffold is located too high, a truck is located in an unsafe location, e.g., over a steam tunnel and etc., D^{4}AR can provide discussion and further thinking about those cases and could be used as a powerful tool for progress coordination meeting.

Our D^{4}AR algorithm currently has several limitations that we like to address in future. We would like to allow not only photos that are taken from exterior or façade of building, but also all the images that are taken indoors to be automatically registered in this environment. Also some scenes where construction components are repetitive are challenging to automatically reconstruct. We plan to work on these issues and extend our system's applicability. Also we will work on automatic progress detection component, as it has a great potential in this new environment wherein multiple images could be associated with each construction component.

8. Acknowledgements

We would like to thank Turner, Gilbane, Williams Brothers, Grunloh Construction companies as well as University of Illinois- Housing, Facilities and Services, and College of Business for their contributions to this research project. This work was financially supported by National Science Foundation Award No. CMMI-0800500.

9. References

Aliaga, D., Funkhouser, T., Yanovsky, D., and Carlbom, I. (2003). "Sea of images". IEEE Computer Graphics and Applications, 23 (6), 22-30.

Arya, S., Mount, D., Netanyahu, N., Silverman, R., and Wu, A. (1998). "An optimal algorithm for approximate nearest neighbor searching fixed dimensions" J. of the ACM 45 (6), 891-923.

Behzadan, A., Timm, B., and Kamat, V. (2008). "General purpose modular hardware and software framework for mobile outdoor augmented reality applications in engineering" Advanced Eng Informatics 22, 90-105.

Brown, M. and Lowe, D. (2005). "Unsupervised 3D object recognition and reconstruction in unordered datasets" Proc., Int. Conf. on 3D digital imaging and modeling, 56-63.

Collier, E. and Fischer, M. (1995). "Four-Dimensional modeling in design and construction", CIFE Technical Report No. 101. Stanford University, Stanford, CA, 411-423.

El-Omari, S. and Moselhi, O. (2008). "Integrating 3D laser scanning and photogrammetry for progress measurement of construction work" J. of Automation in Constr., 18 (1), 1-9.

Golparvar-Fard, M., Peña-Mora, F., Arboleda, C. and Lee, S. (2008). "Visualization of construction progress monitoring with 4D simulation model overlaid on time-lapsed photographs" ASCE J. of Computing in Civil Eng., Special Ed. on Graphical 3D Visualization in AEC, in press.

Golparvar Fard, M., Sridharan, A., Lee, S., and Peña-Mora, F. (2007). "Visual Representation of Construction Progress Monitoring Metrics on Time-Lapse Photographs" Const. Mgmt and Econ. 25th Anniv. Conf., Univ. of Reading, UK.

Golparvar Fard, M., Staub-French, S., Po, B. and Tory, M. (2006). "Requirements for a mobile interactive workspace to support design development and coordination", Proc., XI Joint Int. Conf. on Computing and Decision Making in Civil & Building Eng., ASCE, Montreal, QC, 3587-3596.

Hartley, R. and Zisserman, A. (2004). Multiple View Geometry. Cambridge University Press.

Kamat, V., and Martinez, J. (2008). "Software mechanisms for extensible and scalable 3d visualization of construction operations", Adv. in Eng. Software, 39 (8), 659-675.

Lee, S., and Peña-Mora, F. (2006). "Visualization of construction progress monitoring". Proc., Joint Int. Conf. on Computing and Decision Making in Civil & Building Eng., 2527-2533.

Lowe, D. (2004). "Distinctive image features from scale-invariant keypoints". Int. J. of Computer Vision 60(2), 91-110.

Meredith, J. and Mantel, S. (2003). Project management: a managerial approach. J. Wiley and Sons.

Mikolajczyk, K., et al. (2005). "A comparison of affine region detectors". Int. J. of Computer Vision 65 (1/2), 43-72.

Navon, R. and Sacks, R. (2007). "Assessing research in automated project performance control (APPC)", J. of Automation in Construction, 16(4), 474-484.

Nistér, D. (2004). "An efficient solution to the five-point relative pose problem", IEEE Transactions on Pattern Analysis and Machine Intelligence (PAMI), 26(6), 756-770.

Poku, S. and Arditi, D. (2006). "Construction scheduling and progress control using geographical information systems" J. of Computing in Civil Engrg, 20 (5), 351-360.

Pollefeys, M., van Gool, L., Vergaumen, M., Verbiest, F., Cornelis, K., Tops, J. and Koch, R. (2004) "Visual modeling with a hand-held camera", Int. J. of Computer Vision, 59(3), 207-232.

Robertson, D., and Cipolla, R. (2002). "Building architectural models from many views using map constraints". Proc., European Conf. on Computer Vision, 2, 155-169.

Snavely, N., Seitz, S. and Szeliski R. (2006). "Photo tourism: exploring photo collections in 3D." Proc., ACM Transactions on Graphics, 25 (3), 835-846.

Snavely, N., Seitz, S. and Szeliski, R. (2007). "Modeling the world from internet photo collections". Int. J. of Computer Vision.

Snavely, N., Seitz, S. and Szeliski, R. (2008). "Finding path through the world's photos", ACM Transactions on Graphics (Proc., SIGGRAPH 2008), 27 (3), 11-21.

Soibelman, L., Wu, J., Caldas, C., Brilakis, I. and Lin, K.Y. (2008). "Management and analysis of unstructured construction data types", J. of Adv. Eng. Informatics 22, 15–27.

Song, K., Pollalis, S. and Peña-Mora, F. (2005). "Project dashboard: concurrent visual representation method of project metrics on 3D building models." Proc., Int. Conf. on Computing in Civil Engrg..

Wang, X., and Dunston, P. (2005). "Heavy equipment operator training via virtual modeling technologies" Proc., Construction Research Congress 2005, San Diego, CA, 618-622.

Williams, M. (Bechtel Corp) (1996) "Graphical simulation for project planning: 4D-PlannerTM." Proc., the 3rd Congress on Computing in Civil Eng., 404-409.

VISUALIZATION APPLICATION FOR INTERIOR PROGRESS MONITORING IN 3D ENVIRONMENT

Seungjun Roh[1], Feniosky Peña-Mora[2], Mani Golparvar Fard[3], and SangUk Han[4]

[1]PhD Student, Construction Management and Information Technology, Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign, 205 N. Mathews Ave, Urbana, IL 61801; PH (217) 244-0691; FAX (217) 265-8039; e-mail: roh3@illinois.edu

[2]Edward W. and Jane M. Gutgsell Endowed Professor of Construction Management & Information Technology, Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign, 205 N. Mathews Ave, Urbana, IL 61801; PH (217) 244-0187; FAX (217) 265-8039; e-mail: feniosky@ illinois.edu

[3]PhD Student, Construction Management and Information Technology, Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign, 205 N. Mathews Ave, Urbana, IL 61801; PH (217) 333-2071; FAX (217) 265-8039; e-mail: mgolpar2@ illinois.edu

[4]Master Student, Construction Management and Information Technology, Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign, 205 N. Mathews Ave, Urbana, IL 61801; PH (217) 244-0691; FAX (217) 265-8039; e-mail: han12@ illinois.edu

ABSTRACT

In the interior construction of building projects, a significant amount of schedule delay is caused by an inability of realistic appreciation the complicated interior work. Using computer visualization techniques, such as 4D or Augmented Reality (AR) model and color and pattern coding, users may compare the as-planned with the as-built interior construction progress. These technologies therefore play an increasing role in automatically analyzing the progress of complicated interior construction works, visualizing its progress condition, and making appropriate and quick corrective decisions. This paper introduces a visualization application that enables the user to monitor interior construction progress efficiently using construction photographs superimposed over a 3D model. This prototype of application represents as-built interior construction photographs, user's viewing point information, and the status of construction progress. This application allows the user to walk-through the 3D environment so that the user has an intuitive understand of the interior construction progress represented with colors and patterns.

INTRODUCTION

Many schedule delays and cost overruns in interior construction are caused by unrealistic understanding of detailed and complicated interior works (Koo et al. 2000). To minimize these potential conflicts in interior construction, web-based real-time project monitoring systems (Abeid et al. 2003) are developed to detect discrepancies at early stages and take corrective action through use of visualized data. However, the main problem of construction progress monitoring is time-consuming due to the use of huge amounts of collected as-built data and its evaluation of progress to make control actions (Golparvar Fard and Peña-Mora 2007). Moreover, progress reports through current media and applications have limitations in providing spatial context and in representing the complexities of interior components (Koo et al. 2007). Especially in monitoring interior construction progress, there are many obstructions in the building. As compared with a building exterior, it is not easy to monitor the inside of a building with fixed cameras. Many numbers of cameras are required to view all of the interior areas with the user's various perspectives. These problems make interior progress monitoring more complicated and challenging.

For overcoming the limitations of interior progress monitoring, the demands of efficient visualization for interior construction have been increased. 3D model and visualization techniques have suggested to provide realistic appreciation of the project to clients, and to eventually minimize many cause of rework in interior design and construction (Li and Love 1998, Chan et al. 1998). Based on the 3D design and visualization system, computer visualization approaches, such as metaphors, color gradient, and Augmented Reality (AR) are introduced for systemic and comprehensive progress monitoring and control (Lee and Peña-Mora 2006). This research has been developed more with advanced computer vision and image processing techniques, such as camera registration, material-based progress recognition, and removal of occlusions to automate the visualization process (Golparvar Fard and Peña-Mora 2007). Such research especially allows users to visually understand and communicate construction progress. In 4D or AR model, the visualized supporting system could eventually help in reducing project schedule through improving the processes of construction progress monitoring and control. However, this progress monitoring is mainly focused on exterior related works. In order to monitor the whole of construction process and to improve the efficiency of interior construction, comprehensive and visualized techniques are required to develop an automated system for interior construction.

This paper discusses visualization technologies that can store and collect photographs of interior construction, and analyze the interior construction progress in 3D environment. A carry-on camera is used to capture as-built interior construction progress. It is assumed that the user's context data, such as time, location of view point, and perspective is manually inputted into the system. Stored photographs are superimposed over 3D model to analyze the interior construction progress for supporting intuitive progress communication. The visualization techniques developed by Lee and Peña-Mora (2006), and Golparvar Fard and Peña-Mora (2007) are applied to represent the progress of interior construction with color coding and extended with pattern coding to provide robust and intuitive understanding. The following section briefly explains concepts for developing interior progress monitoring that use

visualization technologies to represent construction progress conditions. A prototype of application is also proposed that allows the user to walk-through a 3D environment with indoor photographs that store the user's viewing point information and the status of construction progress.

RESEARCH APPROACH

There are mainly three issues for interior construction progress monitoring: time, as-planned model, and progress data collection. Construction progress can be monitored through comparison between as-planned and as-built schedules. Based on the evaluation of construction progress, each activity is linked with a 3D model to develop a 4D or AR (Augment Reality) model (Song et al. 2005). For better understanding and quick decision making, the status of construction progress is represented with visualization techniques, image match-up and color code index (Golparvar Fard and Peña-Mora 2007, Golparvar Fard et al. 2007, Lee and Peña-Mora 2006). The other issue is data collection. In the construction phase, construction engineering documents and photos are collected and stored in a project database to be used for multiple purposes (Liu et al. 2004). This data is used for changing design with 4D or AR model, providing updated construction progress, and operating and maintaining the building with visualized progress model. Using visualization techniques with 3D or AR model could provide significant benefits to monitor and control interior construction progress during the whole of construction phases. Therefore, three issues of interior progress monitoring could be developed for visualization of complicated interior construction progress with the digital as-built data.

In this research, as shown in Figure 1, three stages, *collection, analysis, and integration* are proposed to develop the system for construction interior progress monitoring.

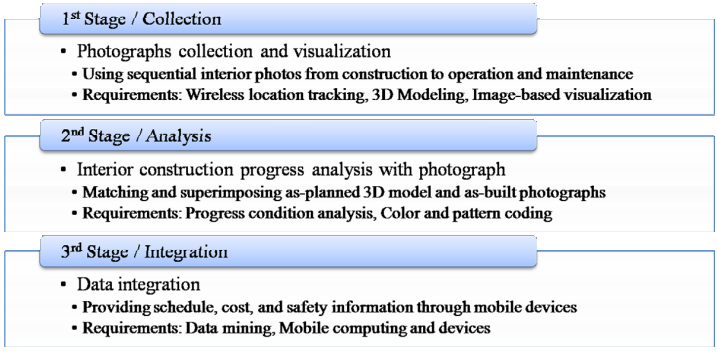


Figure 1. Framework of developing the system for interior progress monitoring

According to this framework, lots of data and photos would be used in the whole of the construction processes. At the first stage, interior photos and data are *collected*

in the system, and located into 3D model. Then, stored data and photos can be used for *analysis* of interior construction progress in the next stage. Finally, according to user's context information, such as location and time, *integrated* information is automatically transferred to user's device in real-time.

CONCEPTS FOR INTERIOR PROGRESS MONITORING

Indoor Location Tracking

Compared with exterior photos which are taken with fixed location, the user's viewing points and perspectives inside a building are not fixed, thus photographs taken in the building are also varied. These characteristics of interior photos make interior progress monitoring more complicated. Therefore, location tracking is required for getting the exact user's position data inside a building. Then, the photos which are stored in database are added user's context information, such as time and positioning data from indoor location tracking sensors.

The Global Positioning System (GPS) is perhaps the most widely publicized location-sensing system. In contrast to outdoor tracking technology using GPS, the tracking signal is not accurate when the user goes into a building (Behzadan et al. 2006). Thus, location sensing with wireless network has been recently emerging and used inside buildings, because it uses the same infrastructure that provides the building's general-purpose wireless networking (Cho and Youn 2006, Tseng et al. 2004, Hightower and Borriello 2001). As such, wireless networking standards, such as IEEE802.11b/g have been widely adopted in most building. During the construction and maintenance stage, this wireless infrastructure can be used for standard wireless connections for laptop or PDAs, and location tracking at the same time. However, the indoor channel environment is still challenging for a number of reasons: channel fading, path loss and shadow fading, and interference (Sayed et al. 2005). Furthermore, the accuracy is 0.3 to 1 m depending on signal and tags (Behzadan 2008, Aziz et al. 2005). For achieving good accuracy, use of WLAN technology should be optimized to track exact position inside a building.

Walk-Through in 3D Environment Model

Recent development in visualization and network technology offers resources for the 3D visualization of models with enough realism to be used for design review and change management systems. A walk-through model has been developed to accomplish these goals and efficiency related to immersion and interactivity capabilities (Funkhouser et al. 1992). The walk-through model is an important communication tool to demonstrate how the building will be seen by pedestrian users of a building. This model does not confine the viewer to a single view point but permits the possibility of seeing the building from all angles. Figure 2 presents a system for interactively browsing and organizing large unstructured collections of photographs of a scene which utilizes common 3D geometry (Snavely et al. 2006). This system is based on computer image-based 3D geometric representation from the photographers' locations and orientations. In a walk-through model which is built in 3D environment, a large collection of construction photos of an interior area or an

object, analyzes them for similarities, and displays them in a reconstructed 3D space. Thus, the walk-though model allows designers, construction managers and owners to quickly understand interior as-built construction progress using photographs in 3D environment.

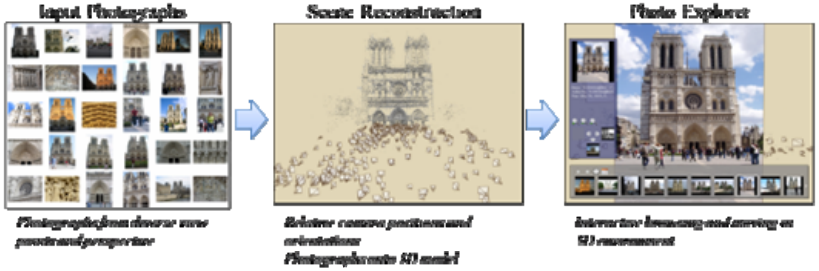


Figure 2. Exploring photographs in 3D model (Snavely et al. 2006)

Color and Pattern Coding to Visualize Interior Construction Progress

Through image-based 3D walk-through environment, 4D or AR model could be built to create the relationships between the activities of the planned schedule and the interior construction components from 3D model. For evaluating the project schedule, progress conditions of schedule have been represented with color coding in 4D or AR model (Lee and Peña-Mora 2006, Song et al. 2005). Colors can represent the progress condition of the construction schedule: behind, on time, and ahead of schedule. As shown in Figure 3, "green" components represents works ahead of schedule, and "red" are behind of schedule. These color representations provide intuitive understanding of current progress condition using integrated visualization in real-time.

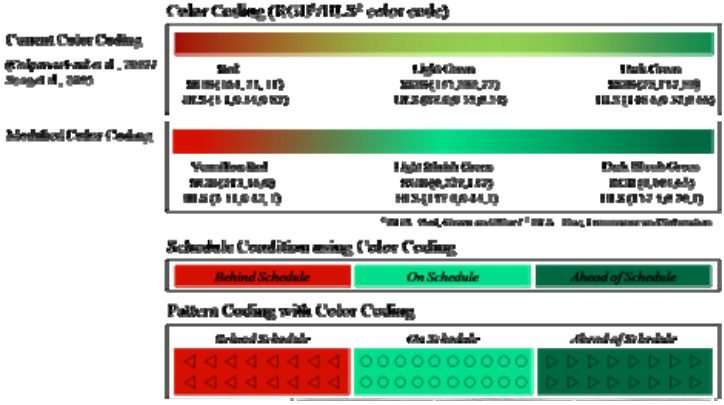


Figure 3. Visual representation of progress condition using Color and Pattern coding [Extended from Lee and Peña-Mora 2006, Song et al. 2005]

However, one difficulty that arises is the issue of color blindness. The most common form of color blindness, color vision deficiency, causes problems in distinguishing "red" and "green" colors, because they have similar levels of intensity (Ware 2004). Furthermore, color coding could be hard to recognize its deviation under black and white printing or faxing. This problem could be corrected by making the green color much less saturated or lighter than the red (Few 2006), or by using color and pattern coding together. In Figure 3, modified color and pattern coding are described with its example of visualizing schedule situation. A pattern is rendered on 3D model to provide more robust and intuitive understanding using texture mapping with gradient color coding. Moreover, pattern coding provides rich information which helps the viewer to quickly understand complicated interior construction progresses under the black and white prints.

DEVELOPING INTERIOR ROGRESS MONITORING SYSTEM

Interior construction progress monitoring system will be developed with the concepts: indoor location tracking, a walk-through model, and visualization with color and pattern coding. Figure 4 describes the whole process of this visualization system for interior progress monitoring.

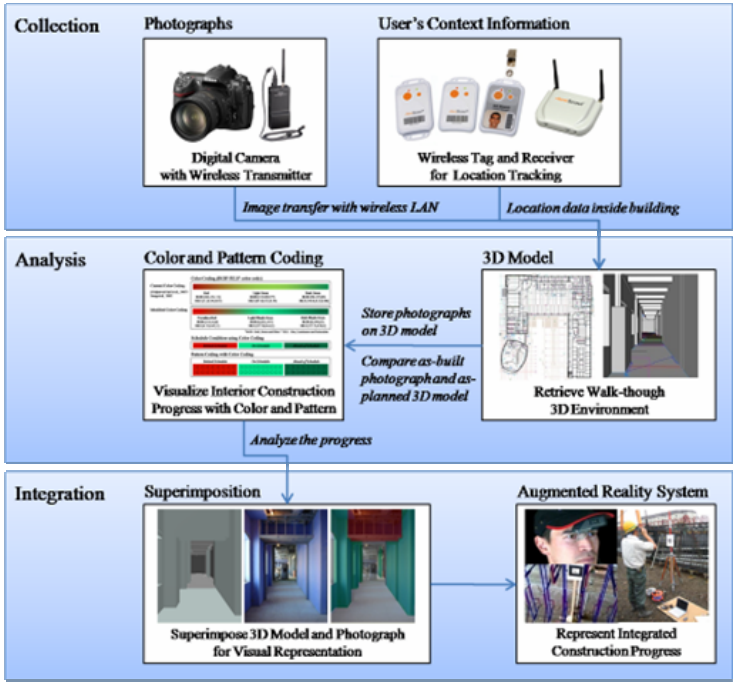


Figure 4. System Processes of Interior Progress Monitoring

In connection with a mobile device, network infrastructures, such as wireless tag, access points, and wireless receivers inside a building detect the user's location and receive contextual information. This indoor location tracking provides spatial information to allocate user's position in a walk-through model. When the user gathers as-built construction photographs in the building, a wireless transmitter attached with the digital camera would automatically send photographs to a database server for the construction project, and store it on 3D environment in real time. According to the user's context information, a walk-through model is retrieved from construction project 3D model. Color and pattern coding are used for visualization of interior construction progress to analyze the progress of the elements in 3D model as compared with as-built photographs. Thus, the 3D model and photographs are superimposed using computer visualization technologies, and the results of interior construction progress are represented with augmented reality systems. In the following section, this process is further discussed with the developing system.

Prototype of Interior Construction Progress Monitoring System

For developing interior progress monitoring system, according to the user's view point and perspective, the photos should be transferred and positioned on 3D model. It also requires that users can easily browse 3D walk-through environment to find photographs in 3D model. Thus, OpenGL (Open Graphics Library) is used for this visualization technique, which is a standard specification defining a cross-language cross-platform application programming interface (API) for writing applications that produce 3D computer graphics (Angel 2006). OpenGL allows users to build 3D environment and define locations of 3D objects and photographs related with the viewing system.

Figure 5 shows a prototype application for placing 3D model in walk-through 3D environment, transforming user's view point and perspective, and building 3D model using texture mapping with color and pattern coding. This application is tested with Java OpenGL (JOGL) which supports the Java platform and provides a minimal and easy API that handles many of issues associated with building multithreaded OpenGL applications. First, the coordinate system of 3D model is transformed to match with the coordinate system of 3D environment and to place the 3D model on the axis. Then, a walk-through model is designed to allow the user to browse inside the building and to change the perspective of the 3D environment. The user can go back and forth with freely rotating right and left directions. The user is also enabled to rotate the viewing perspective up and down. All of these movements and rotations are implemented with transformation and rotation matrices of OpenGL. After building the walk-through model in 3D environment, color and pattern coding is applied as a pattern texture to 3D object. The results of the progress condition are converted to specified color and pattern texture in texture memory. 3D object is represented with both texture and geometric coordinates.

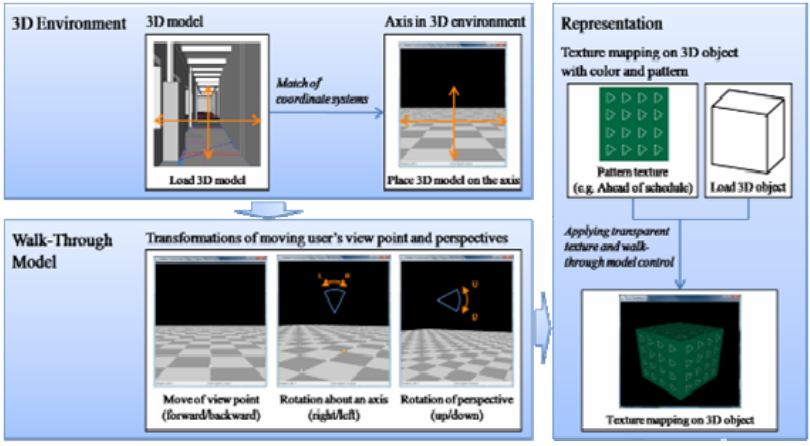


Figure 5. Prototype Application of Interior Progress Monitoring

Figure 6 illustrates the example of interior progress monitoring with semi-automated camera matching between 3D model and the camera moving inside the building. We assume that progress photographs are taken with the information of the user's view point and perspective, and the as-planned 3D model is retrieved from this information. The viewing scenes from the camera and 3D model are eventually aligned on the 3D environment with taken photographs. After visualization system manually matches construction progress photographs with 3D model, the progress condition is represented with color and pattern coding on 3D model. For example, superimposed photograph in Figure 6 is performed based on as-planned progress information in color and pattern coding representation. In black and white printing, color coding is not identified, however pattern is still working to present interior construction progress.

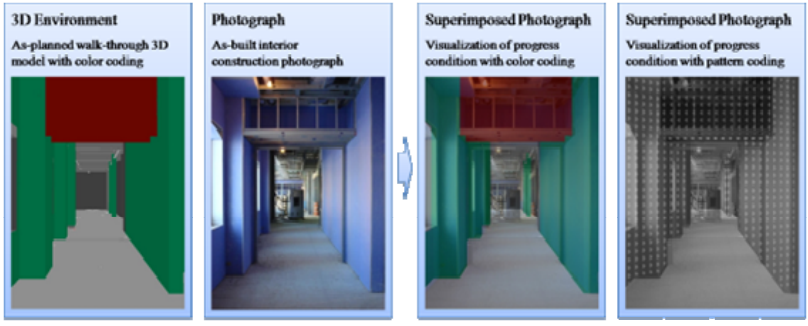


Figure 6. Examples of Interior Progress Monitoring in 3D Environment

CONCLUSIONS

In this paper, the visualization application has been proposed for representing interior construction progress monitoring. This application stores and positions as-built interior construction photographs on a walk-through model of 3D environment with manual matching of view point and perspective. After building 3D environment, interior construction progress is represented with color and pattern coding based on its status: ahead of schedule, on time, and behind schedule. Finally the visualization application provides the user to browse as-built interior construction photographs with moving view points and rotating perspectives in 3D environment so that the user can have an understanding of the interior construction progress. This realistic and quick appreciation of the interior construction in a walk-through model and visualized 4D model could eventually minimize many causes of rework and schedule delays and determine the immediate corrections of the original plan in interior design and construction.

In future work, current application needs to identify technologies that automatically retrieve exact information of user's view points and perspectives inside the building. Also there needs to be increased matching accuracy between 3D model and photographs. In order to automatically store photographs, retrieve user's context information, and transfer the construction progress, wireless infrastructure, such as wireless tags and mobile devices, wireless receivers, and access points should be installed inside building. However, the construction schedule for installing the wireless infrastructure could conflict with temporary electrical or finishing work that would need to be monitored and controlled. Thus, scheduling the installation of wireless infrastructure should be considered to use the same wireless network during and after construction. Moreover, it would be take a great effort to optimize wireless network in a dynamic construction environment because of accuracy problems which highly depend on the pre-installed wireless infrastructure. After fully developing this application, a process of validation tests will be carried out to define limitations of automated visualization techniques and to ensure the accuracy of the application.

REFERENCE

Abeid, J., Allouche, E., Arditi, D. and Hayman M. (2003). "PHOTO-NET II: a Computer-based Monitoring System Applied to Project Management." J. of Automation in Construction, 12 (5), 603-616.

Angel, E. (2006). "Interactive computer graphics : a top-down approach using OpenGL." 4th Edition, Addison-Wesley, Boston.

Aziz, Z., Anumba, C.J., Ruikar, D., Carrillo, P.M., and Bouchlaghem, D.N. (2005). "Contextaware information delivery for on-Site construction operations." 22nd CIBW78 Conference on Information Technology in Construction, Institute for Construction Informatics, CBI Publication (304), 321-332.

Behzadan, A.H., Khoury, H.M., and Kamat, V.R. (2006). "Structure of an Extensible Augmented Reality Framework for Visualization of Simulated Construction Processes." the 2006 Winter Simulation Conference, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, NJ.

Behzadan A.H., Aziz Z., Anumba C., and Kamat V.R. (2008). "Ubiquitous Location Tracking for Context Specific Information Delivery on Construction Sites." Automation in Construction, 17(6), Elsevier Science, New York, NY, 737-748.

Chan, B., Tse, H.M., and Wang, W. (1998). "Design of a walkthrough system for indoor environments from floor plans." Information Visualization, 1998 IEEE Conference, 50-57.

Cho, Y.K., and Youn, J.H. (2006). "Wireless Sensor-driven Intelligent Navigation Robots for Indoor Construction Site Security and Safety." the 23rd International Symposium on Automation and Robotics in Construction (ISARC), Tokyo, Japan, 493-498.

Few, S. (2006). "Information Dashboard Design: The Effective Visual Communication of Data." O'Reilly Media, Inc., Sebastopol, CA.

Funkhouser, T.A., Séquin, C.H., and Teller, S.J. (1992). "Management of large amounts of data in interactive building walkthroughs." Proc. of the 1992 symposium on Interactive 3D graphics table of contents, Cambridge, Massachusetts, United States, 11-20.

Golparvar Fard, M. and Pena-Mora, F. (2007). "Application of Visualization Techniques for Construction Progress Monitoring." Proc., ASCE Int. Workshop on Computing in Civil Engrg, Pittsburg, PA.

Golparvar Fard, M., Sridharan, A., Lee, S. and Pena-Mora, F. (2007) "Visual Representation of Construction Progress Monitoring Metrics on Time-Lapse Photographs." Proc., Construction Management and Economics Conference (CME25), Reading, UK.

Hightower, J., and Borriello, G. (2001). "Location systems for ubiquitous computing." Computer, 34(8), 57-66.

Koo, B., and Fischer, M. (2000). "Feasibility Study of 4D in Commercial Construction." J. of Construction Engrg. and Mgmt., 126(4), 251-260.

Lee, S. and Peña-Mora, F. (2006). "Visualization of Construction Progress Monitoring." *Proc. of Joint Int. Conf. on Computing and Decision Making in Civil Engrg.* 2527-2533.

Li, H., and Love, P.E.D. (1998). "Visualization of building interior design to reduce rework." Information Visualization, Proc. of 1998 IEEE Conference, 187-191.

Liu, L., Soibelman, L., and Trupp, T. (2004). "Novel Technologies for Construction Field Data Collection." International Conference on Computing in Civil and Building Engineering(ICCCBE), Weimar , Bauhaus-Universit, 42-50.

Sayed, A.H., Tarighat, A., and Khajehnouri, N. (2005). "Network-based wireless location: challenges faced in developing techniques for accurate wireless location information." Signal Processing Magazine, IEEE , 22(4), 24-40.

Snavely N., Seitz, S.M., and Szeliski, R. (2006). "Photo tourism: Exploring photo collections in 3D." ACM Transactions on Graphics (SIGGRAPH Proceedings), 25(3), 835-846.

Song, K., Pollalis, S. and Peña-Mora, F. (2005). "Project Dashboard: Concurrent Visual Representation Method of Project Metrics on 3D Building Models." Proc. of Int. Conf. on Computing in Civil Engrg., ASCE.

Tseng, Y.C., Kuo, S.P., Lee, H.W., and Huang, C.F. (2004). "Location tracking in a wireless sensor network by mobile agents and its data fusion strategies." Computer Journal, 47(4), 448-460.

Ware, C. (2004). "Information visualization: perception for design." 2nd ed., Morgan Kaufman, San Francisco, CA, 99-118.

AUTOMATED DATA ACQUISITION SYSTEM TO ASSESS CONSTRUCTION WORKER PERFORMANCE

I.P. Tharindu Weerasinghe[1] and Janaka Y. Ruwanpura[2]

[1]MSc. Student in Project Management Specialization, Department of Civil Engineering, Schulich School of Engineering, University of Calgary, ENF 232, University Dr. NW, Calgary AB Canada T2N 1N4, Tel: 403-667-8313, Fax: 403-282-7026, email: ipweeras@ucalgary.ca

[2] MASCE, Canada Research Chair in Project Management Systems, Director and Associate Professor of Project Management, Department of Civil Engineering, Schulich School of Engineering, University of Calgary, ENF 232, University Dr. NW, Calgary AB Canada T2N 1N4, Tel: 403-220-6892, Fax: 403-282-7026, email: janaka@ucalgary.ca

Abstract

This paper presents a real time and fully automated system using signal processing techniques for data extraction from digital video images, audio files and thermal images of construction work activities. This data extraction system is developed to detect the construction workers and their movements within a given work area to measure tool time and to assess worker productivity. The worker tracking system is based on the characteristics of the hardhat extracted from digital videos to differentiate worker from others such as supervisors and engineers. Furthermore, the work status of the worker is tracked using Infrared cameras and unidirectional microphones. Thermal images extracted from infrared cameras recognize whether the worker is working or idle. The audio files from the microphones identify the sound wave patterns of the worker tools. This real time and automated information is expected to measure the tool time and productivity of a given work within a specific time period. The information extracted and analysed from the system will certainly aid the project managers to better plan to optimize labor and crews to achieve the expected productivity.

Introduction

Construction industry is known for the lack of use of information technologies and data acquisition systems to improve performance and productivity of construction projects (Hewage and Ruwanpura 2008). Most of the project managers' decisions are affected by the appropriateness and accuracy of information available to assess onsite performance (Sacks et al. 2002). According to the reported data, 30-50% of the field

supervisory time is spent recording and analyzing field data, distracting them from the more important tasks of supervising and monitoring the project (McCullouch 1997; Navon and Shpatnitsky 2005, Gannoruwa and Ruwanpura 2008). The accuracy level of these field data significantly decreases because of the human errors and limitations in data (Kannan & Vorster 2000). To collect accurate and timely data on actual performance, the contractor needs to employ observers who measure the time to perform each construction activity, record the number of workers in each crew, and calculate the respective tool time and productivity (Navon and Goldschmidt 2002). Thus, a data acquisition system with high accuracy is a dire necessity. Accurate data is required not only to monitor and control current projects, but also to update the historic database. Such updates will enable better planning of future projects in terms of cost, schedule, labor allocation, etc. This paper explains an integrated system to automatically capture site data using a number of sources to assess worker performance and productivity.

Background and Related Work in Construction

Image processing has been used in many sub-areas of civil engineering. In mining, it has been used to measure aggregate size, shape, and void ratio in granular materials (Chandan et al. 2004; Kim et al. 2004). This technique has been used to detect speed of vehicles in transportation engineering (Oh and Leonard 2003).

A number of attempts have been made to develop systems for collecting data by researchers for construction management. For example, a site inspector used a pen-based computer to input image information for a Field Inspection Reporting System (Rojas & Songer, 1997). This particular system sends inspection data to the internet web server to store in a common database, which is accessible to all parties involved in the project. Using a similar concept, a video camera and a microphone connected to a pen-based notebook computer were mounted on a hard hat (Liu 1997), which could be worn by site personnel while walking on site. The data were transferred by means of a wireless network to a desktop server in the site office. This device had the advantage of transferring images to remote experts in real time. Several of these systems were developed for analyzing the data after they were collected and input by the user. Some of the automatic data acquisition systems developed in the past, has limitations and may be applied only in certain circumstances or for a specific construction process (Ghandour 2007). The system developed by Ghandour (2007) to detect construction vehicles is not fully automated and requires the user involvement. A dynamic scheduling system, PHOTO-NET, linked digital videos of construction activities to a Critical Path Method schedule for project progress control. However, the progress data required manual entry into the system by the user (Abeid & Arditi 2002a).

The web-based project performance monitoring system signalled the project manager in a timely manner when it detects project problems including those related to people, cost, and schedule (Cheung et al. 2004). In this system too, all related data had to be input by the user. Further, surveillance and web cameras have been used to monitor certain activities (for example, tracking of a hopper and a hook in concrete placement). The detection in this case was based on one characteristic of the activity, large motion of the hopper, and the properties of the hook (Almassi and McCabe

2008). That is a fully automated system focused only on a specific task and it did not demonstrate the capability to measure human activities. None of the above mentioned systems have the capability to automatically measure construction worker activities (such as nailing, fixing, etc.) and their productivity without significant intervention from site observers and manual entry.

Summary of objectives

The main objective of this study presented in the paper is to develop a fully automated system that extracts accurate data from the construction worker activities and operations in real time without any personnel involvement. Following are the sub-objectives of the research.

1. Track the number of human figures and their coordinates/location to assess the patterns of human movement.
2. Identify/differentiate the human figures (example: differentiate a worker, a supervisor and a site engineer)
3. Assess the worker status (example: working or idling)
4. Recognize the work activity of each tracked worker
5. Develop a system to measure tool time and the productivity.

This paper only outlines the objectives 1 to 4 and presents the concepts of extracting the necessary on-site construction related real-time information from video files, thermal images and audio files by using signal-processing techniques. The main sources of the tracking processes are video files from high end surveillance cameras, thermal images from infrared cameras and audio files from unidirectional microphones. This paper presents the conceptual details about how to track human figures from cameras and to use audio files to assess tool time. Figure 1 shows the data processing flow of the proposed methodology. Conceptual research strategies to achieve the first four sub-objectives are discussed in the paper.

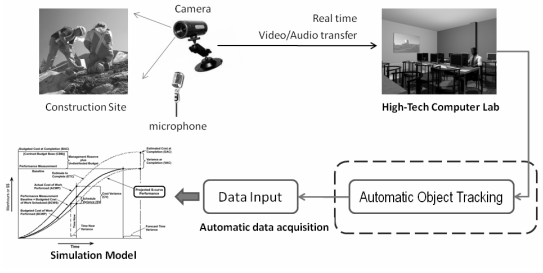


Figure 1: General Research Overview

Methodology

Following research strategies have been chosen to achieve the defined sub-objectives (see Figure 2).

1. Detect the number of hard hat shapes in video image frames extracted from surveillance cameras.
2. Check the color of the tracked hard hats.
3. Analyse the thermal image of the tracked workers (after step 2 above) using infrared cameras
4. Extract sound pattern information from audio files of the work activities of the tracked workers.

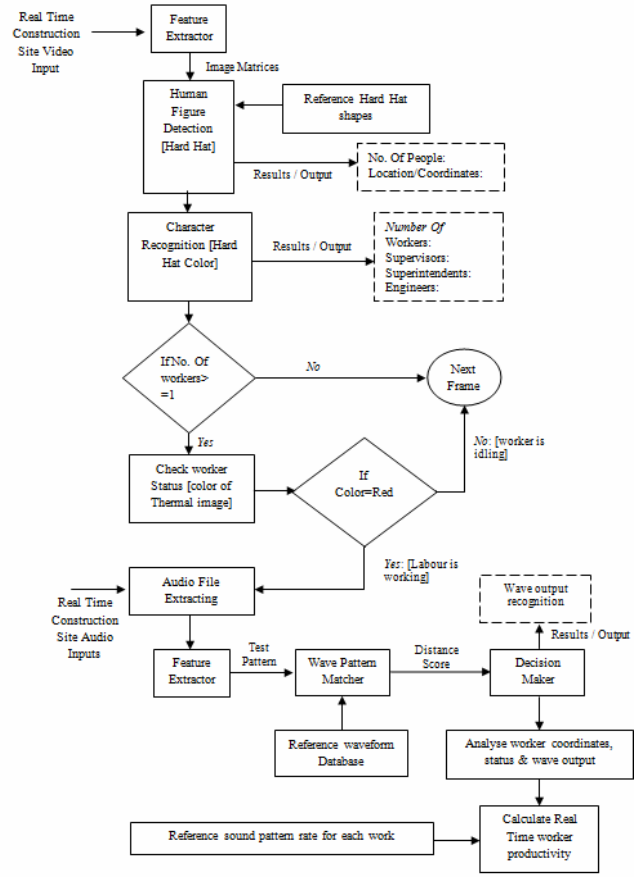


Figure 2: Research methodology flow chart

Real time videos and audio files from construction sites are extracted by onsite cameras and unidirectional microphones. Unidirectional microphones are embedded in each worker's hardhat and/or selected locations in the site. All sounds that are generated from the worker tools (i.e. hammer, drill) while the worker is working on a

particular activity can be recorded. Unidirectional microphones have the capability to filter discussions of the people and background noises. Following are the chronological order of the steps.

As the first step of this study 5m×5m×3m (length×width×height) space is selected. A camera is installed at the top corner of the selected space. The video (.avi format) which extracted from the cameras consists of colour images of 480x640 resolution (30 frames per second). The target of the camera and its zoom remained constant all the time. The system analyses each frame to extract its embedded information such as hard hat shape and colour. MATLAB7 is used for processing the images. All the images imported from the video files are stored in Red Green Blue (RGB) colour space. An RGB image is stored in MATLAB as an m-by-n-by-3 data array that defines red, green, and blue colour components for each pixel. The RGB image is then converted to gray scale and the automatic analysis is commenced as shown in figure 2. The number of people in each frame is recognized by the system. While detecting the human figures in the frame, the system records (x,y) coordinates of the humans during their movement. Then the system identifies/differentiates the characters of the image according to the hardhat color. For instance, one yellow hard hat implies that there is a construction worker/labor in that location. Different colored hard hats are given to different personnel (yellow for workers, red for supervisors and white for engineers)

The next action in the logical sequence is worker status identification. It is done by detecting the color of the worker's face extracted from the thermal image. If the major colour intensity of the face is red, the system could recognize him/her as a working/active person. After extracting the workers information in the image frame, this research study invented a new method to detect the working efficiency of labors by analysing the sounds of the worker tools which are recorded from unidirectional microphones as described under sound detection section below.

Human Figure Detection

Human detection is the most crucial component of this system as it has several algorithms to identify people and its location. Most of the constructive information of an image is enclosed in regions where a change of gray levels or colours occurs (i.e., at the edges of the objects) (Kung 2003). The information consists of the size of the transition (edge magnitude) and the direction in which the intensity changes most rapidly (edge direction). These quantities can be computed from partial derivatives of an image frame function g(x,y). The extracted edge information can be used to determine the contour of the object (Kung 2003). Following is the coding to detect the edges of an image. Figure 3 of the real time image detecting the hard hats and figure 4 is the outcome after processing the edges using the said algorithm.

```
[sizeX,sizeY]=size(Gray_Original);
dodx=Gray_Original(1:sizeX-1,1:sizeY,:)-
Gray_Original(2:sizeX,1:sizeY,:);
dodxdy=dodx(1:sizeX-1,1:sizeY-1,:)-dodx(1:sizeX-1,2:sizeY,:);
figure;imagesc(dodxdy)
```

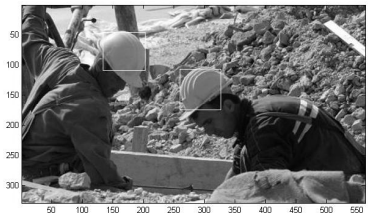


Figure 3: Original image

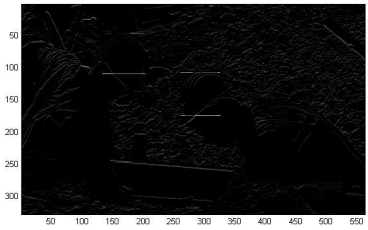


Figure 4: After detecting edges of original image

After the original image is converted into an edge map, the similarity between the original image and the reference image is identified. Correlation theory is a well-known mathematical operation for detecting two similar images. Following is a brief explanation of the correlation theory (Proakis and Manolakis 1996).

- The correlation function shows *how similar two signals* are, and for how long they remain similar when one is shifted with respect to the other.
- Correlation becomes *maximum when two signals are similar* in shape, and are in one identical space.
- Correlation is a measure of the similarity between two signals as a function of time shift between them.

Correlation function can be used to separate a reference signal embedded in a noised signal from single dimension, two-dimensional or from any number of dimensional matrices (Proakis and Manolakis 1996). Equation 1 shows the correlation function for two-dimensional matrix;

$$v[k1,k2] = \sum_{n1=1}^{N1} \sum_{n2=1}^{N2} x[n1,n2]*y[n1-k1,n2-k2]$$

.....(1)

where; x() – original function with (N1*N2) dimensions
y() – reference function with (N1'*N2') dimensions
v() –correlation function with (N1+N1'-1,N2+N2'-1)

Figure 5 shows the colour intensities of the correlation function. Two bright patches shown in the figure 5 are identified as the maximum correlation points (which are the middle point of the workers' hardhats). The minimum colour intensity level in the correlation function for the hardhat for the selected distance is determined using

equation 2. Figure 6 shows the outcome of the equation (2) which is the clear image of the midpoint of the hard hat.

f(x,y)={ 255; if g(x,y)>=T.....(2)
0 Otherwise
Where;
T=minimum colour intensity level
g(x,y)=correlation function

There are several other steps in the algorithms to detect the worker movements by counting the number of white color patches in binary images within a particular time which are not discussed in the paper due to page limitations. As an example, left indexes of the white patches in the binary image are identified using equation 3. Figure 7 shows the results of all the algorithms to track the worker figures and locations.

L(x,y) {1; f(x,y)-f(x,y-1)~=255.....(3)
0 otherwise

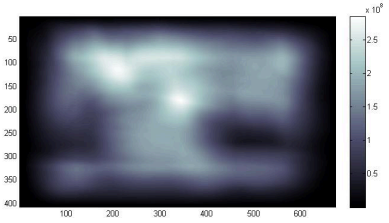


Figure 5: Correlation map

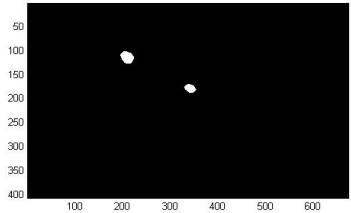


Figure 6: Binary image

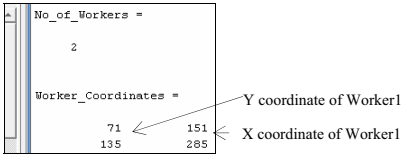


Figure 7: Result 1 (No of Workers and Coordinates)

Assess the worker status through thermal images

Ruwanpura et al (2006) defined "tool time" as the time the workers spent in producing a tangible output. Measuring tool time of a construction labor during a specific period is essential analyse the construction productivity in a given work area. It is somewhat difficult to measure the tool time by observing multiple number of workers. Therefore, a technology that can differentiate whether a worker is involved in any work or idling is a necessity to assess the tool time. In general, the worker's body emits heat while they are involved in work for a significant period of time. Therefore, the workers activity status could be identified by using infrared cameras

to detect the body temperature. This process is yet to be performed pending ethical approval from the University of Calgary and the supporting construction organizations (*at the time of writing the paper*).

Sound detection system

Construction workers use different kinds of tools for their specific construction activities and more often every single construction tool has a unique sound when it is operated (or in use). Therefore, each tool generates a unique wave signal. As a result of that, the tool's wave signal pattern could be recognized. A database of reference wave signals for each construction activity has been developed. Significant number of wave signals for a particular activity/equipment have been collected and populated in the database. This enables to determine the average wave pattern for each tool.

Dynamic Time Warping (DTW) is a well known algorithm for measuring similarity between two sequences which may vary in time or speed. Automatic speech recognition is a popular application to recognize different speaking speeds. DTW also enables a computer to find an optimal match between two given sequences (e.g. time series) with certain restrictions of feature vectors, which allows for stretched and compressed sections of the sequence (Rabiner and Juang 1993). For instance, similarities in sound patterns of construction equipment or tools would be detected using an audio file whether the construction worker is using the equipment slowly and quickly including accelerations or decelerations during the course of one observation. DTW has been applied to video, audio, and graphics indeed, any data which can be turned into a linear representation that can be analyzed with DTW (Rabiner and Juang 1993).

Construction sound recognition system commonly consists of four functional blocks as shown in figure 8. The four blocks are a feature extractor, a wave pattern matcher, a reference waveform database and a decision maker. Wave pattern matcher gate is the most critical component among all four functional gates (Kung 2003). The computation of similarity between the reference wave pattern and the test pattern is done under this functional gate. For example, in a carpentry work inspection system, the reference patterns are derived from a number of key sounds describing the parts of the carpentry work such as nailing [by using nail gun or hammer], sawing, etc. A set of characteristic parameters are extracted from the digitized waveforms of each collected key sound.The input wave form in the given time period consists of a single set of parameters extracted from an equipment sound, such as the sound of nailing. This parameter set is matched with all the reference patterns to determine the most likely key sound.

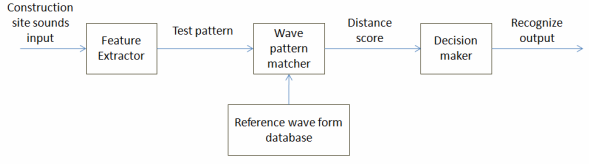


Figure 8: A complete construction site sound detection system

Conclusions

This study presented in the paper outlines the development of a real time and fully automated system to measure tool time of the workers using video, image and audio analysis techniques. High-end surveillance cameras are used to detect the humans and to differentiate different human categories in a construction site. Correlation theory in image processing aids to recognize the hard hats of the workers and to assess the worker movements. Infrared cameras are then used to assess the worker status by automatically analysing the thermal images. The sounds generated by tools of the construction workers are detected using the unidirectional microphones to verify whether the workers are working and to identify the construction activity. This is achieved through the Dynamic Time Warping algorithm to recognize the worker activity sound wave pattern of the audio files.

Although it is proposed to use different colored hard hats to differentiate the work force, deviations for the above is often observed in practice. However it is stressed that in order to acquire the benefits arising from the study the construction industry must be flexible to adhere to the prerequisites proposing by the study. Further the concepts such as work –involvement determination via body temperature do not stand as a standalone criteria yet supports a successful implementation with a reasonable accuracy. In concluding, the novel approach proposed in the study is expected to provide more precise inputs in the assessment of tool time and the worker productivity.

Acknowledgement

The authors wish to acknowledge the support and funding for this research project provided by Canadian Foundation for Innovation and CANA, PCL, Ellis Don, Graham, Ledcor, Revay & Associates, Stuart Olson, Canadian Construction Research Board, Calgary Construction Association, and the Natural Sciences Engineering Research Council under their Collaborative Research and Development Grant CRDPJ 341047 – 06. The authors also wish to thank Dr. Arjuna Madanayake from Schulich School of Engineering, University of Calgary for technical guidance.

References

Abeid, J. and Arditi, D. (2002a). “Linking Time-Lapse Digital Photography and Dynamic Scheduling of Construction Operations”. Journal of Computing in Civil Engineering, ASCE, 16(4), 269-279.

Almassi, A.N., and McCabe, B. (2008). “Image Recognition and Automated Data Extraction in Construction”, CSCE 2008 Annual Conference.

Chandan, C., Sivakumar, K., Masad, E., and Fletcher, T. (2004). “Application of Imaging Techniques to Geometry Analysis of Aggregate Particales”, Journal of Computing in Civil Engineering, ASCE, 18(1), 75-82.9

Cheung, S. O., Suen, H.C.H., and Cheung, K.K.W., 2004. “PPMS: s Web-Based Construction Project Performance Monitoring System”, Automation in Construction, 13(3), 361-376.

Gannoruwa, A., and Ruwanpura, J.Y. (2008). “Development of an efficiency model for optimum construction productivity through effective supervision on worker performances”, CSCE 2008 Annual Conference.

Ghandour, W.E. (2007). "Integrated Information based Construction Simulation System [IICSS]", A dissertation submitted to the department of civil engineering of University of Alberta for Ph.D. degree.

Hewage K.N., and Ruwanpura J.Y. (2008). "IT Usage in Alberta's Building Construction Projects: Current Status and Challenges." Journal of Automation in Const., 17 (2008), 940-947.

Kannan, G., and Vorster, M. (2000). "Development of an Experience Database for Truck Loading Operations", Journal of Construction Engineering and Management, ASCE, 126(3), 201-209.

Kim, H., Haas, C.T., and Rauch, A.F. (2004). "Automated Quality Assessment of Stone Aggregates Based on Laser Imaging and a Neural Network", Journal of Computing in Civil Engineering, ASCE, 18(1),58-64.

Kung, S.Y. (2003). "VLSI Array Processors".

Liu, L.Y. (1997). Construction Field Data Collection Using the "Digital Hardhat" Construction Congress V: Managing Engineered Construction in Expanding Global Markets. Proceedings of the Congress held in Minneapolis, Minnesota, October 5-8, 1997, 399-404.

McCabe, B., and Clarida, B. (2004). "Using Digital Images to Automate Construction Progress Reporting". Paper #234 CIBT157, CIB World Building Congress 2004, Toronto, Canada, May 3-7.

McCullouch, B. (1997). "Automating Field Data Collection in Construction Organizations", Proceeding of the Construction Congress V, Minneapolis, Minnesota, October 4-8, 1997, Published by ASCE, Reston, VA, pp.957-963.

Navon, R., and Goldschmidt, E. (2002). "Monitoring labor inputs: automated-data-collection model and enabling technologies", *Automation in Constr*., 12(2), 185-199.

Oh, J. and Leonard, J.D. (2003). "Vehicle Detection Using Video Image Processing System: Evaluation of Peek VideoTrak", Journal of Transportation Engineering, ASCE, 129(4), 462-465.

Proakis, J.G., and Manolakis, D.G. (1996). "Digital signal Processing principles, algorithms, and applications".

Rabiner, L., and Juang, B. (1993). Fundamentals of speech recognition. Englewood Cliffs, N.J, Prentice Hall.

Rojas, E.M. and Songer, A.D. (1997). "FIRS: A vision of the future of building inspection", Computing in Civil Engineering, Proceedings of the Fourth Congress. Philadelphia, PA, USA, Vol. 1, 25-32.

Ruwanpura, J.Y., Hewage, K., Da Silva, S.P. and Smith, D. (2006) "Tool Time Analysis to Improve Construction Productivity in Alberta," *Canadian Civil Engineer*, Autumn, 18-22.

Sacks, R., Navon, R., Shapira, A., and Brodetsky, I. (2002). "Monitoring Construction Equipment for Automated Project Performance Control", ISARC-19th International Symposium on Automation and Robotics in Construction.

PROJECT INFORMATION MANAGEMENT IN MEGA OIL SANDS PROJECTS

Zonghai Han[1] and Thomas Froese[2]

[1]PhD Candidate, Institute of System Engineering, Huazhong University of Science &. Technology, Wuhan, Hubei, China 430074; and PhD Candidate, Department of Civil Engineering, University of British Columbia, Vancouver, BC Canada, V6T 1Z4; PH (778) 238-6011; FAX:(604) 822-6901; e-mail: zonghaihan@hotmail.com

[2]Professor, Department of Civil Engineering, University of British Columbia, Vancouver, BC, Canada V6T 1Z4; PH (604) 822-2027; FAX:(604) 822-6901; e-mail: thomas.froese@ubc.ca

Abstract: Emerging Information and Communication Technologies offer major improvements to the practice of project management in the construction industry, yet these systems are complex and are not easily adopted into current practice. Furthermore, experiences with transformative information and communications technologies in other industries suggest that these benefits cannot be fully realized unless the overall work processes and management practices also evolve. This suggests that current work in construction project information and communications technologies cannot achieve its full potential unless we also develop our practices for managing information on projects. Project Information Management (PIM)—the practice of managing a construction project's information systems—should be developed into a more formal and explicit sub-discipline of project management. We propose an overall framework for Project Information Management, structured around four dimensions of goals and objectives, the project elements, the information system elements, and the management practices. Case studies are conducted to support our proposal.

Keywords: Project Information Management, Project Management, Construction, Protocol, Case Studies

1 Introduction

Innovation in information and communication technologies (ICT) for construction is more than a technical issue alone; it is also tightly tied to issues of work practices, culture, and technology transfer. We are interested in these issues from two perspectives: for industry practitioners, the issue is how best to take advantages of technological innovations and opportunities. For the technology research and development community, the issue is how

best to transfer their technical innovations to industry practice. To both of these, we suggest that a part of the solution is to development of the discipline of project information management (PIM).

Information and communication have always been important to construction projects, yet approaches for managing information have generally been informal and ad-hoc. We have argued that the construction industry would benefit from the development of PIM as a well-understood and formalized sub-discipline of project management. Not only would this benefit projects in general, but it seems to be a necessary pre-condition to the successful implementation of more complex emerging ICT such as Building Information Models (BIM).

PIM could be considered as very analogous to functions such as safety, risk, or quality, which have also been long recognized as important to project management in the construction industry; yet over time, these areas have evolved from loosely-defined project management objectives to distinct sub-disciplines with well-understood requirements, procedures, bodies of knowledge, and roles within the overall project management process. The same can be said for information management. For example, one chapter of the Project Management Institute's Project Management Body of Knowledge (PMI 2000) defines a communications planning framework, yet this falls well short of a comprehensive approach to PIM. Information management seems far behind the areas of cost, schedule, scope, safety, risk, or quality as a well defined and understood sub-discipline of project management.

A number of efforts have been carried out within construction ICT research related to information management practices. For example, Björk defines a formal model for information handling in construction processes. Turk explored the relationships between information flows and construction process workflows, and makes a distinction between base processes (the main value adding activities) and glue processes (that make sure that the materials and information can flow between the base processes) (Turk 2000). Betts (1999) includes much work on the role of information technologies in the management for construction, with an emphasis on strategic management of the firm. These and other works have much to offer in the area of information management practices.

In our work, however, we have taken a fairly specific perspective that has not been widely addressed—the development of information management practices as they relate to the management of individual construction projects in the context of emerging ICT. Our methodology involves condensing a wide range of PIM-related work and ideas into an overall proposed framework for PIM. With this framework as a starting point, we then intend to carry out case studies to determine best practices and to refine the framework, followed by implementation of the framework on pilot projects. We are currently in the early stages of this endeavor, focusing on the preliminary framework and initial case studies.

Previously (Froese, 2004-2006), we have argued the need for PIM, drawn analogies to quality management and ISO 9001, presented an initial conceptual framework, and discussed organizational issues and the role of a Project Information Officer. In this paper, we have further refined the conceptual framework and introduced some significant additions through reference to efforts outside of the construction domain. We also briefly discuss case study projects and get supporting points for the proposed framework.

2 The PIM Framework

As a sub-component of project management, PIM is the management of the information systems on a project to meet the relevant objectives. We suggest this definition of PIM because it emphasizes four core elements:

- The Project: PIM activities are entirely grounded in the context of the construction project. This is in contrast to much IT that is more enterprise-focused than project-focused.
- The Information Systems: In PIM, the things being managed are the information systems used on the project.
- The Management Process: PIM is a process carried out by those responsible for managing the project's information systems.
- Objectives: The purpose, goals, and success criteria of PIM are defined by various objectives that arise at the enterprise, project and information system levels.

Each of these core elements will be addressed in the following sections.

2.1 The Construction Project

PIM manages the information systems for a construction project. The focus on the project is significant for two reasons. First, it defines the business scope for PIM. Although information systems will exist and will be managed at the enterprise level, corporate information management is not sufficient to ensure that project information systems are adequately addressed. This is because the project information systems are so tightly tied into the project management practices that the management of those systems must come (at least in part) from within the project management team itself. Furthermore, projects are carried out by stakeholders from many different companies, thus project information management must be responsive to this "virtual organization" focus.

Second PIM must look to the project itself to define what information systems need to be created and managed. We suggest a "tasks/transactions/integration" approach in which PIM considers each project task in the work breakdown structure, each transaction involving information flows between tasks, and significant integration issues to arrive at a list of information system requirements.

2.2 Information Systems

Although it is something of an over simplification, we suggest that it is convenient to approach PIM as "processes" acting on "things", where the information systems are the things and the PIM are the processes. The practice of PIM, therefore, requires detailed knowledge of the information systems used on the project. These information systems can be defined largely in terms of the key information resources: information, applications, communications, information infrastructure, and people.

The linkage between these information systems elements and the project elements is evident when considering the issue of identifying the required information systems (introduced in the previous section). A review of the project tasks will identify the key computer applications required to support the work, while a review of the project transactions will identify the key project communications required. In analyzing each of these, the key information input/output requirements will be assessed. Having identified application, communication and information requirements (along with integration requirements), the infrastructure and personnel resources required to support these information systems can be identified.

Although it is reasonable to consider all of the information resources used to support a construction project as the project's information system, there will typically be several critical applications that require significant management effort, but that may be largely independent from each other. It is useful to view these as the major information sub-systems.

A detailed knowledge of the technical aspects of the project information systems is critical for PIM, but it is outside of the scope of this paper.

2.3 Information Management

Information management defines the processes used to manage the information system resources. At the highest level, this PIM involves the generic management processes of planning, executing, and monitoring the results.

However, we can define the required processes in substantially more detail. We have identified COBIT® (Control Objectives for Information and related Technology) produced by the ICT Governance Institute (IT Governance Institute 2007) as providing a very thorough framework for defining detailed information management processes. COBIT was developed as a broadly applicable standard to provide best practices for the management of information technologies in corporations.

COBIT defines four ICT management domains: plan and organize, acquire and implement the ICT solutions, deliver and support the ICT services, and monitor and evaluate the results. Within each of these domains, COBIT defines detailed ICT management processes with specific control objectives and assessment standards (in the form of maturity models). The detailed contents of the COBIT framework are very relevant for PIM, but a more extensive description is beyond the scope of this paper.

COBIT provides a comprehensive and appropriate framework for ICT management, yet we do not believe that it is directly applicable for PIM. Large portions of COBIT are likely to be ill-suited to the short-term time frame and narrow business focus of individual construction projects, while other issues that are likely to be quite common for construction projects are not included in COBIT because it is intended to apply across all industries. Rather, we suggest modifying the COBIT and incorporating substantial portions of it within a PIM framework. One of the ways in which COBIT can be modified is to define the level at which its various components are best applied: at the level of company, at the level of individual projects, at the level of the project sub-systems, etc.

2.4 Objectives

The PIM management processes are objective-driven. That is, a set of explicit objectives is used to identify the required information systems, to guide the PIM process, and to assess the results. The COBIT framework provides detailed information on appropriate ICT objectives, which should be extended for application to PIM. Like the management processes, different objectives are associated with different levels: some arise from the business goals at the enterprise level, some correspond to the project objectives at the overall project level, others are specific to individual ICT sub-systems, etc. These levels are discussed further in the following section.

3 Delivering PIM

PIM makes up a broad body of knowledge relating to the management of ICT on construction projects. To aide in the application of this knowledge to specific management actions, we propose that the information about PIM be delivered in several components:

- The PIM Body of Knowledge: To begin, any documents that provide general information about PIM (such as this paper, for example), make up the broad body of knowledge for PIM. At some point, this body of knowledge may be codified into a widely accepted standard, such as the Project Management Body of Knowledge (PMBOK), but this does not currently exist for PIM. In addition to general information about PIM, this body of knowledge may include case studies, descriptions of best practices, recommended methods, etc.
- A Protocol for PIM (PPIM): We are proposing to develop a protocol that acts as a specification for appropriate PIM practices. This will embody the practices suggested by the body of knowledge into a succinct set of basic requirements, much as the vast body of knowledge about quality management has lead to the ISO 9001 protocol.
- PIM Artifacts on individual projects: On an individual construction project, the manager responsible for PIM (e.g., the project information officer), who would be familiar with the PIM body of knowledge, would develop and document a PIM Plan that meets the specifications of the Protocol for PIM. Furthermore, for each PIM activity, a PIM methods statement would be developed and documents. The PIM Plan and PIM Methods Statement documents would make up the key artifacts that capture and communicate the PIM practices on the project.

4 The Practice of PIM in Mega Oil Sands Projects

Second only to the Saudi Arabia reserves, Alberta's oil sands deposits were described by Time Magazine as "Canada's greatest buried energy treasure," and "could satisfy the world's demand for petroleum for the next century" (Alberta Energy, 2008).

The Horizon Oil Sands project is an 11-billion-USD capital project contains over 6 billion mineable barrels of bitumen, located in Northern Alberta of Canada. The project is managed in segments and contracts to ensure a phased, measured approach to development. Project construction is underway. Horizon's synthetic crude oil (SCO) production will begin in 2008 and by 2011; 232,000 barrels of SCO will be produced daily for a period exceeding 50 years (Canadian Natural Resources, 2008).

Horizon project information systems are well defined and developed, relatively independent sub-systems under the company's enterprise level information system (IS). The Horizon IS team is a function unit of the project management organization but it is also linked/supervised by the corporate IS Department from its head office. There are information management plans and application roadmaps in place in the early stage of the project and there is a mechanism to implement, track, and evaluate the plans. Examples are the Business Applications Road Map and Work Method Statement for using SmartPlan in the project.

PIM case studies on mega oil sands projects have been conducted. The following subsections discuss PIM practices on Horizon oil sands project and lessons learned from the industry. The references are mostly from Horizon IS Documents and interviews from several different projects.

4.1 Overview of Horizon PIM

COBIT provides strategy in directing and controlling information technology and its maturity models provide a methodology for assessing management practices. Based on these models and adopted from a survey questionnaire (Mourshed 2007), interviews have been conducted to provide an overview of Horizon's project information management. Though COBIT focuses on the enterprise level and Mourshed's survey was aimed at the Manage-

ment of Architectural IT, the methodology has been used here as a preliminary assessment of the degree of PIM practice in the Horizon project. For each of the assessment management practices, there are 6 possible descriptions:

- Non-existent: Not recognized/present,
- Initial/Ad-Hoc: General awareness of the topic, the process is informal and reactive,
- Repeatable: Agreed-upon but informal and not usually revisited,
- Defined: Formal and defined,
- Managed: Increasingly defined, measurable, and
- Optimized: Continuously revisited to measure performance against goals, best examples are applied.

For each of the following PIM practices, the assessed maturity level is shown:

Planning and organization

a. The project has a strategic IT plan with the goal of striking an optimum balance of IT opportunities and IT business requirements: Defined
b. There are defined roles and responsibilities for IT management with effective communication across the project and organization: Defined
c. Human resource development (training) and management are considered for IT projects (implementation and management) : Defined
d. Compliance with external requirements (legislative and requirements of client and associate enterprises) is considered in planning for IT: Managed
e. Compliance with IT standards (layer guidelines, IFC, etc.) is considered in planning and implementation of IT: Defined
f. Risk (business and technical) are assessed and managed: Defined
g. Key goals and performance objectives are identified and integrated into the quality control procedures: Defined

Acquisition and implementation

a. Automated solutions are identified with the goal of ensuring an effective and efficient approach to satisfy user requirements. Generally the following aspects are considered: Soundness of the design, robustness of functionality, interoperability, performance, scalability, maintenance and support, sustainability: Repeatable
b. The project has control over IT process acquisition and maintenance with the goal of providing automated functions which effectively support the work/business process: Defined
c. The project proactively develops and maintains procedures with the goal of ensuring the proper use of applications and technological solutions put in place: Defined
d. The project manages changes of IT resources with the goal of minimizing the likelihood of disruptions, unauthorized alterations and errors: Defined

Delivery and support

a. The project has control over defining and managing service levels which formalize the performance criteria against which the quantity and quality of the service is measured: Repeatable
b. The project manages third party services and ensures that the roles and responsibilities or third parties are clearly defined, adhered to and continue to safety requirements: Defined
c. The project manages performance and capacity and ensures that adequate capacity is available to for the best and optimal use of IT: Defined

d. Security measures are in place to safeguard against unauthorized use, disclosure or modification, damage or loss: Optimized
e. Users are educated and trained to make effective use of technology and are aware of the risks and responsibilities involved: Managed
f. Data (drawings and other) is managed with the goal of ensuring that data remains complete, accurate and valid during its input, update and storage: Managed
g. IT operations are managed and ensured that IT support functions are performed regularly and in an orderly fashion: Managed

Monitoring

a. IT processes are monitored with the goal of ensuring the performances of the objects set beforehand: Defined
b. Independent/external assurances are obtained to increase confidence and trust across the project, participants, and associate enterprises: Repeatable

4.2 The PIOs and IM responsibilities

The PIM organization for the project was set up based on a matrix structure. In the enterprise level, a vice president (in the role of Chief Information Officer, as a member of corporate management committee) is the head of the corporate information systems department of the company. At the project level, there are three IM groups (Applications, Operations, and Standards & Practices) reporting to both the enterprise CIO and a project vice president, in the role of project information officer (PIO), who is responsible for project engineering integration and PIM. The Applications group consists of business analysts, business process analysts, business system analysts, data analysts, developers (in-home and out-source), application delivery, application sustainment, technical support, and scheduling. The Operation group is responsible for networking, servers, database and operation systems, release management, hardware and procurement, infrastructure, and client support and customers service. This structure helps to maintain alignment between the enterprise business goals, the enterprise IM strategy, the project goals, and the project IM strategy.

4.3 The PIM body of knowledge

The body of knowledge for PIM is a combination of knowledge of IM and knowledge of project management. Yet this body of knowledge does not exist as a single cohesive whole—rather, it is distributed throughout a wide variety of formal and informal practices throughout the project. A challenge, then, is to organize, categorize, and standardize these practices, leading to a more formalized body of knowledge for PIM, which is one of our research goals.

As the base of knowledge for PIM, numerous documents have been created in the course of the oil sands project's management and construction processes. These documents can be categorized into three tiers:

Tier 1 - Strategy documents: used to set up IM department-level policies, goals, and standards; describe governing structures; and define IM alignment with business objectives. Examples of these documents are mission, vision, security policy, and IM guiding principles.

Tier 2 - Knowledge documents: used to define concepts, processes, and functions; assist in decision-making; and define reporting metrics. Examples are documents describing the IT project management methodology, IS integrated process, and incident management process.

Tier 3 - Implementation documents: used to explain how to use an application, standards, or policy. These include a template that supports strategy and knowledge documents. Examples of these documents are application development standards, application/server specific installation or configuration procedures, and IM project management templates.

The PIM documents are also grouped by process areas, which are application management, availability management, capacity management, change management, configuration management, continuity management, financial management, incident management, IS governance and administration, problem management, IT project management, release management, security management, service level management, and technology management.

4.4 Sample PIM Documentation

System development life cycle (SDLC) methodology

The project developed methodologies for PIM, including an IT Project Management Methodology, System Development Life Cycle (SDLC) Methodology, Data Management Methodology, and many others.

The SDLC methodology complements and supports existing methodologies and practices such as the Project Management Methodology and the Data Management initiative. It establishes policies, processes, procedures, practices, and templates to govern each knowledge area of the SDLC. The structure of this methodology consists of governance, purpose, scope, methodologies integration, major and minor development, knowledge areas, requirements, design, development, testing, deployment, and roles and responsibilities. It defines what to do, who do what, and how to do it.

Application architecture standards

The goals of the application architecture standards are to promote efficient delivery with quality results to the business/project, promote long-term cost savings, and support the strategic goals of the business, project, and PIM. Through decomposition, a model of application layers and components was adopted to help make software reuse easier, speed up team code development efforts, and promote better management of common application operational requirements such as security, maintainability, extensibility, scalability, and robustness. Figure 1 illustrates the organization of logical layers and protocols for a 3-Tier application. A physical application architecture guideline was also proposed by the standard.

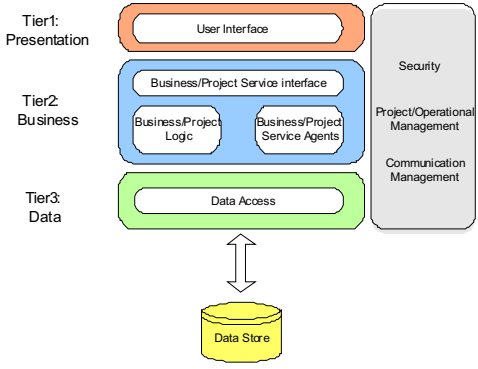


Fig. 1 Organization of Logical Layers and Protocols (Based on Ted Furuya, 2006)

4.5 Lessons Learned and the Promotion of PPIM

PIM success is driven by business. The Horizon project has defined its goals as striving for successful delivery of the project while leveraging lessons learned, utilizing proven technology and embracing innovation. It also aims to aggressively pursue innovative and synergistic technology to take the project to a new standard of economic and environmental performance (Canadian Natural Resources Limited, 2008). These goals have helped to drive the application of PIM in the Horizon oil sands projects. However, we contend that the development of the PIM discipline and the promotion of the PPIM would greatly enhance the success PIM and overall project management in the construction industry.

Lack of Industry-Wide Standards

PIM is yet not a well-defined sub-discipline of project management. There are no proven industry-wide PIM policies, standards, guidelines, methodologies, processes, procedures, best practices, statements of work, and templates (components of PPIM). Many project teams start their PIM from scratch, depending on their team (project and IM) or individual's knowledge and experience. This duplication of effort is inefficient in time and resources, and has limited potential to achieve best practices. Thus, local standards, such as the Horizon application architecture standard, may exist but they vary between projects which lead to communication problems among projects, information systems, processes, and PIM activities.

Form of PIM Knowledge

Similar to the discussion above, some of the components of the body of knowledge for PIM exist but need to be tested, formalized, and standardized.

The Need of a Protocol for PIM

Construction project information management encounters many challenges, such as the fragmented nature and distributed locations of projects, the diverse multiple participants of projects, the need to accommodate a multitude of project disciplines over the complete lifecycle of projects, the wide extent of different standards, codes, and practices, the different information requirements, the need to accommodate different legacy systems, the lack of organizational policy and mechanisms to apply information management technology in project(s) environment, and the reluctance of both industry and people to adopt IT solutions in the administrative process. In order to better manage project information, it would be valuable to establish industry-wide standards, to define the body of knowledge for PIM, and to develop a protocol that acts as a specification for appropriate PIM practices providing a policy and mechanism for understanding project information management and to measure their maturity against a comprehensive and broad-based set of project information management best practices.

5 Conclusions

We argue that emerging ICT cannot achieve its full potential to improve the construction industry unless we develop a more formal understanding of Project Information Management (PIM) as a sub-discipline of project management. We have suggested an overall framework for PIM made up of four core perspectives:

- The project, a perspective that focuses on the ICT requirements of the project's work activities.

- The Information Systems, a perspective that focuses on the elements and issues that makes up the information systems.
- The Management Process, a perspective focusing on the management activities to ensure that the project's information systems are responsive to the project's needs, well-planned, properly resourced, and producing measurable improvements.
- The goals, a perspective that fully defines the goals and requirements for the project's ICT.

We have also discussed a scope hierarchy for PIM (with levels ranging from the enterprise to individual PIM activities). We have shown that some of the key components required to implement PIM include an overall PIM body of knowledge, a PIM protocol, and a collection of PIM artifacts for each project. Finally, we have discussed the PIM practice in a major oil sands project that will serve as one of case studies in our ongoing work.

6 References

Alberta Energy. <www.energy.gov.ab.ca>. (Aug. 29, 2008)

Betts, M. (Ed). Strategic Management of I.T. in Construction, Blackwell Science, 1999.

Björk, B-C. "A formalized model of the information and materials handling activities in the construction process," Construction Innovation, 2(3), pp. 133-149.

CNRL. Horizon Project. <http://www.cnrl.com/horizon/>. (Aug. 25, 2008)

Froese, T., "Help Wanted: Project Information Officer", 5th European Conf on Product and Process Modeling in the Building and Construction Industry, Istanbul, Turkey, Sept. 8-10, 2004.

Froese, T., "Impact of Emerging Information Technology on Information Management", International Conference on Computing in Civil Engineering, ASCE, Cancun, Mexico, Paper #8890, July 12-15, 2005.

Horizon IS Doc., <http://isdocumentdelivery.cnrl.com/index.htm>, (Aug. 26, 2008)

IT Governance Institute. COBIT® 4.1, Available from [www.itgi.org]. ISBN 1-933284-72-2. 2007.

Mourshed, M. (2007). "Online survey: Management of Architectural IT." Department of Built Environment, University of Central Lancashire, Preston, UK.T. Froese, "Emerging Information and Communication Technologies and the Discipline of Project Information Management," 13th EG-ICE Workshop, Intelligent Computing in Eng. & Arch., Ascona, Switzerland, Springer Berlin / Heidelberg, Pages 230-240. June 25-30, 2006.

VALIDATION OF VISION TRACKING AT EGNATIA ODOS MOTORWAY

Francisco Cordova[1], Dimitris Sideris[2], Ioannis Brilakis[3] and Demos C. Angelides[4]

[1]PhD. Pre - Candidate. Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI. 48109-2125; PH (734) 763-2148; email: cordovaf@umich.edu
[2]M.S. Student. Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA. email: bdsideris@gmail.com
[3]Assistant Professor. Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI. 48109-2125; PH (734) 763-2148; email: brilakis@umich.edu
[4]Professor and Chairman. Department of Civil Engineering, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece; E-mail: dangelid@civil.auth.gr

ABSTRACT

Tracking applications provide real time on-site information that can be used to detect travel path conflicts, calculate crew productivity and eliminate unnecessary processes at the site. This paper presents the validation of a novel vision based tracking methodology at the Egnatia Odos Motorway in Thessaloniki, Greece. Egnatia Odos is a motorway that connects Turkey with Italy through Greece. Its multiple open construction sites serves as an ideal multi-site test bed for validating construction site tracking methods. The vision based tracking methodology uses video cameras and computer algorithms to calculate the 3D position of project related entities (e.g. personnel, materials and equipment) in construction sites. The approach provides an unobtrusive, inexpensive way of effectively identifying and tracking the 3D location of entities. The process followed in this study starts by acquiring video data from multiple synchronous cameras at several large scale project sites of Egnatia Odos, such as tunnels, interchanges and bridges under construction. Subsequent steps include the evaluation of the collected data and finally, performing the 3D tracking operations on selected entities (heavy equipment and personnel). The accuracy and precision of the method's results is evaluated by comparing it with the actual 3D position of the object, thus assessing the 3D tracking method's effectiveness.

INTRODUCTION

Real time construction site information can be a key factor in improving management processes. The data acquired provides an additional layer of control over the project and allows for enhanced decision making. However, the size and complexity of many outdoor construction projects limits the type and quality of the data that can be

acquired. The large amounts of construction-related entities, along with the high number of occlusions present, highlight certain limitations of currently used tracking methods, such as Radio Frequency Identification, Wireless Fidelity and Global Positioning Systems. These limitations include having to previously identify and install a tracking sensor on the entity (personnel, equipment and materials) to be tracked and signal interference problems with roofs and thick walls (GPS and Wi-fi respectively). These restrictions tend to reduce the flow of onsite information, and can affect productivity and lead to poor decision making, based on inaccurate information.

Vision Tracking methods (particularly 3D) have versatile applications including productivity calculations, activity sequence analysis, detecting travel path conflicts, and enhancing site safety. Travel paths can be identified by marking the location of two distinct entities in time, which allows easy recognition of route overlap (both entities at the same time in the same location). Also, by determining the location of personnel in construction sites and measuring the time needed for one person (or crew) to finish a certain activity, productivity ratings can be calculated. Tracking also allows for developing enhanced waste management tools by creating the appropriate environment for controlling on site activities and modifying site layout.

Vision tracking is also highly regarded for its high degree of automation. Automated systems improve efficiency, reducing the amount of time spent performing paperwork and monitoring activities at the project site (Gatchalian, 2001). In addition, the use of real time tracking allows for the identification of critical personnel and activities instantly which can heavily impact the project in terms of cost and time (Furlani and Stone, 2006). In general, the use of vision tracking methods can pose high advantages for its low implementation and equipment cost, high accuracy and ease of use (Caldas et al 2004).

This paper presents the application of a new vision based tracking method at the Egnatia Odos Motorway project in Thessaloniki, Greece. The method provides the 3D location of construction related entities such as personnel and equipment. Under this method, self calibrated, outdoor video cameras are placed at the construction site. The video streams collected from the cameras are simultaneously presented to the user. The user is able to select the construction related entity he wants to track in all of the views. After the entity is selected, the software automatically determines its 3D location. The 3D location is updated in every frame, as the selected entity moves throughout the camera's views.

The validation site is the Egnatia Odos Motorway. This is a complex construction site, composed of several simultaneous sites and provides the ideal testing location for validating the current vision based tracking technology. The motorway's large, outdoor construction sites allow for collecting video feeds of various construction activities in closely located diverse locations. The 3D tracking methodology was previously tested at the University of Michigan in a controlled, ideal environment. Preliminary promising results led to the necessity for large scale validation. Preliminary validation results at Egnatia Odos have also shown positive feedback in acquiring the 3D position of a construction related entity using this tracking method.

VISION BASED TRACKING

Vision tracking is a very practical method when used in outdoor construction sites due to its capability to obtain highly accurate results when measuring large areas with high number of particles (Gruen, 1997). The 3D vision tracking method (Cordova and Brilakis, 2008) used in this case study employs on site video cameras to calculate the 2D and 3D position of personnel and equipment in construction sites.

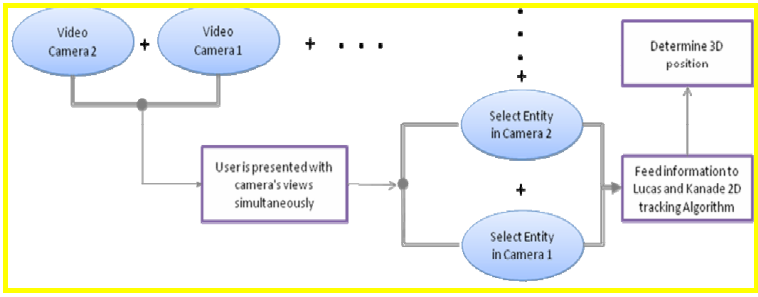


Figure 1 – 3D Tracking Methodology Overview (Cordova and Brilakis 2008)

When using this methodology, the user is presented with 2 camera's views simultaneously. The user then selects the entity to be tracked (personnel or equipment). The selection of the entire entity is not necessary, selecting a specific characteristic of the entity is sufficient. For example, hardhats are distinct characteristics of personnel in construction sites. By selecting a hardhat, the tracking information of a worker can be acquired as follows. The user selects the same entity area in both of the views by marking a rectangle on top of it. After performing the selection, the area marked is used to initialize the tracking process. This is the only action needed to be performed by the user since the remainder of the process is entirely automated. With these input points, the centroid (center of gravity) of each marked region is computed. The centroid coordinates mark the 2D location (x,y) of the entity in the image plane. These points are supplied into a 2D tracking algorithm (Baker and Matthews, 2002) based on image alignment. Image alignment consists of moving and deforming a template to minimize the sum of squared errors between two images: the template and the image. This algorithm was selected since image alignment is preferred for any application where pixels in a local area are expected to move in a way which can be modeled by a function of position; for example, for tracking rigid objects of known surface in 3D (Molton et al 2004). This algorithm provides the 2D location of the entity. After 2D coordinates are measured, epipolar geometry is used to calculate the real time 3D position of the entity. The fundamental matrix (Faugueras and Luong, 2001), based on the 8 point algorithm (Hartley and Zisserman, 2004), is used to find the epipolar lines of the image. Since the centroid of the entity is known on both camera views, the projection of that point across the epipolar plane (Shapiro and Stockman, 2001) in both of the views leads to an intersecting point in 3D space. This intersection point is the depth coordinate of the entity which provides the 3rd dimension. The 3D calculations are performed for each

frame and the results displayed are concurrently updated. Current tracking method performs tracking operations on one item at a time. Future tasks however, include tracking multiple objects simultaneously, to further the applications of the tracking method.

EGNATIA ODOS MOTORWAY

This method was originally tested in a small scale model at the University of Michigan with excellent preliminary results (Cordova and Brilakis 2008). However, large scale validation is needed in order to test the applicability of the method to real construction sites and the accuracy of the results. Validation of the presented tracking method was made at Egnatia Odos Motorway construction sites.

This project provided access to several construction sites simultaneously, which allowed the recording of various different activities in a short period of time. These sites have a large number of personnel and equipment present including excavators, trucks and drilling machines among others. The variability of the locations also permits the collection of video streams of similar activities from different angles and locations which is necessary in order to fully validate the efficiency of the method in tracking one specific activity. The sites are also in different settings, some in high populated areas in the middle of the city, other in more secluded areas, such variability is important in determining the effectiveness of our method generically in all outdoor construction sites, regardless of location complexity. Finally, the variable weather of Greece also creates the perfect challenge for out method since large amounts of sun, fog and rain can test our method's effectiveness as well as the strength and durability of our equipment. Egnatia Odos is an $8 billion 670 Km highway that connects Turkey with Italy through Greece. The road forms an integral part of European route E90 (Road-traffic technology, 2006).



Figure 2 – Egnatia Odos Motorway Route (Schwandl, 2007)

The highway includes the construction of 76 tunnels with a combined single bore length of 99 km and 1,650 bridges with a combined length of 40 km and 20% of the total project cost. These structures will feature many different designs as there are a

large variety of bridges being built: 205 bridges; 100 over-bridges; 235 underpasses and 1,110 culverts.

CASE STUDY VALIDATION PROCESS

The validation of the research is based on collecting video data from actual outdoor construction sites in Egnatia Odos and processing the data with the previously presented 3D tracking method. The objective of this case study is to validate the use of the previously researched 3D tracking method. The validation evaluated several distinctly shaped entities including construction equipment, personnel, and materials of standard sizes and shapes. The validation results are to be used to enhance current tracking methods and detect situations of utmost efficiency and inefficiency. Figure 3 explains the methodology to be followed in the validation process.

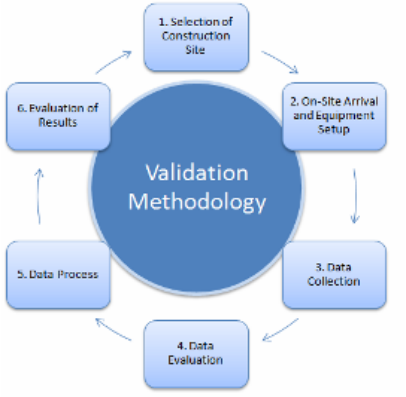


Figure 3 - Validation Methodology

Selection of the Construction Site

The selection of the construction site depends on the type and amounts of activities that are to be performed on that day. In order to perform the validation as effectively as possible, variations in construction activities, entities and locations was necessary. Video feeds were collected at each of these sites, depending on the daily activity of the sites. It was needed to collect several streams of similar activities from different points of view in order to assess the accuracy of the method. For example, more than 20 excavators and 25 hours of excavator data were collected in distinct locations and variable angles. Some of the activities recorded include: Bridge Paving, Earth movement, cconstruction of highway median barriers, rebar/formwork installation and Concrete pours.

On Site Arrival and Equipment Setup

Upon the arrival at the site, the cameras and computer equipment are set up. The set up is performed on the site, from which there is a minimum of occlusions and video feeds can be collected accurately and continuously. High vantage points were preferred for their ability to collect several activities in one concurrent shot. The setup consists of a computer receiving video feeds collected from 2 megapixel high resolution video cameras (Figure 4). Although the method can be used with several cameras connected simultaneously, for validation purposes only 2 cameras are being used. The cameras are hardwired (not wireless) for enhanced quality and collect data at a frame rate of 100 frames per second. The cameras are also equipped with zoom lenses and DC auto iris to adapt depending on weather conditions and lighting. Also, this method is to be tested under the variable weather conditions of Greece's terrain including rain, sunshine, dust and fog, in order to ensure its efficiency on real and variable weather conditions. However, no night footage was acquired since the sites were closed at this time (no work was being performed).



Figure 4 - On site Equipment Setup and Camera Detail

Data Collection and Evaluation

An average of 6 hours of recording a day was collected, depending on the type of activity and its duration. Because of the large scale of the project, the size of the construction sites and the number of activities that are being simultaneously performed all over the site, it is very important to discern which of the data that is being tracked is important and which is not. As a result the authors have chosen to record in specific and separate forms what is being tracked through the cameras. The forms are being filled out to give the reader a full description of the work that is being tracked, without the necessity of watching the entire video. For example, In Table 1 "Good" means having a clear shot of the actual activity and performing a continuous capture of high quality footage (No visible interruptions, jumps or blurs in the image). A data log was also created and updated daily containing the time, date, length of the video, the activity being performed and the quality of the stream. With this method,

both the video and the form can be easily reviewed and the validation time reduced. Proper documentation is necessary as increasing amount of data are collected, and similar activities recorded in short periods of time.

Table 1- Data log

				Duration		
File Date	Activity	Location	Quality	Hr	Min	Sec
2-Jul	People/Formwork	Egnatia Odos	Good	3	8	43
				2	11	8
3-Jul	Workers/Formwork	Egnatia Odos	Good		32	44
					12	49
	Pouring Concrete			1	45	49
	Guardrails				15	23
					13	55
					43	52
					12	43
8-Jul	Floor Rebar	Egnatia Odos	Good		34	27
					42	35
				1		15
	Concrete Placing				16	1
					3	42
					53	22
					4	35
9-Jul	Concrete Placing	Egnatia Odos	Good		19	44
					5	50
10-Jul	Tarring Bridge	Egnatia Odos	Good		27	11
					16	55
14-Jul	Excavator/Conveyor belt	Egnatia Odos	Good		1	16
	Concrete Median				21	25

Data Process and Evaluation of Results

The collected video feeds are later processed using the 3D tracking method previously described. The actual positions of the tracked personnel and equipment are calculated and compared with the results of the tracking code. This way, values of precision, recall and generality can be calculated and the method's performance evaluated. Recall is a measure of completeness. For this particular research, it is measured as the number of videos in which tracking was able to be performed divided by the total number of videos in which tracking was tried. On the other hand, precision is a measure of exactness: how close is the 3D tracking position measured to its true value.

PRELIMINARY RESULTS

Testing was performed on several construction sites at the Egnatia Odos Motorway Project. Specifically, validation was focused on personnel and heavy equipment only. Figures 5 and 6 present the tracking of the original position of an excavator in one of the sites. As can be seen, the 3D position of the bucket was constantly tracked and its position updated as the excavator moved.

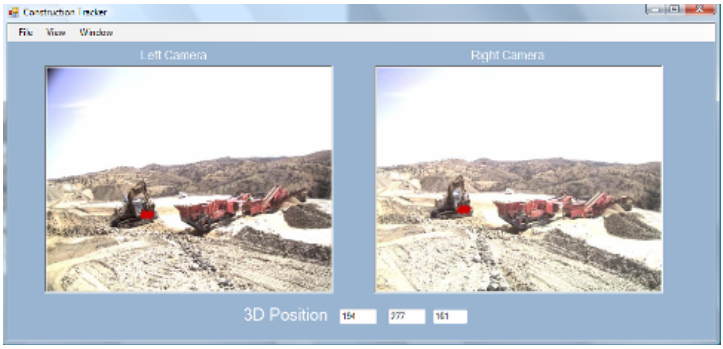


Figure 5 – Tracking of Excavator's Bucket

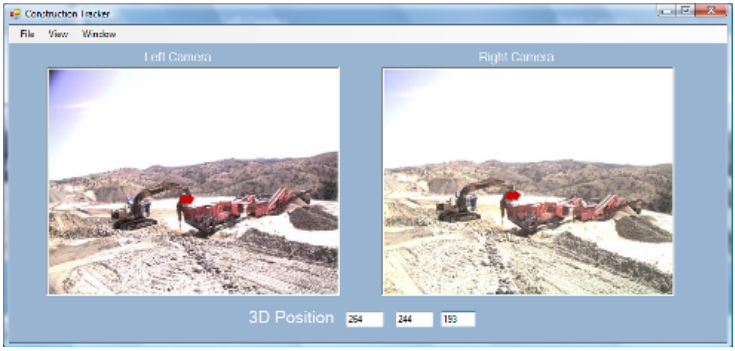


Figure 6 – Updated position of the Excavator's Bucket

Testing was also performed on construction personnel. Figures 7 and 8 show the 3D tracking of a construction worker while installing rebar on a concrete bridge.



Figure 7 – Tracking of Construction Worker at Site



Figure 8 – Construction worker tracked (Subsequent frame)

Preliminary tracking results calculated from 10 video feeds indicate recall values of 0.82 and precision values of 0.80 for personnel tracking. For heavy equipment (excavators) tracking, recall values of 0.6 and precision values of 0.76 were calculated.

CONCLUSIONS

On site tracking applications are practical tools for providing up to date project-related information. When applied to outside, large scale construction sites, this information can be used for productivity calculations, activity sequence analysis, detecting travel path conflicts, and enhancing site safety, among others.

The Egnatia Odos Motorway Project proved to be an ideal location for the validation of vision based tracking applications. The availability of multiple, simultaneous, large scale construction sites in close proximity allowed for the collection of diverse construction activity data. It also provided the opportunity to test the developed 3D tracking research under different weather and location conditions on closely spaced sites.

This vision based tracking technology can determine with high degree of accuracy the 3D location of an entity (heavy equipment and personnel) in open construction sites. Vision tracking proved to be advantageous in outdoor sites, since the required equipment is available, easy to use and inexpensive. It also allowed the tracking of multiple and dissimilar types of entities in an unobtrusive way.

The validation process required the selection of a different activity or site daily, Setting up the equipment and acquiring the construction activity data. After collecting the data, the streams were evaluated and organized. Finally the 3D tracking was used to acquire the location of heavy construction equipment (e.g. excavators, boring machines, trucks, etc.) and personnel. Preliminary results show the tracking method to be accurate and efficient in acquiring personnel and equipment tracking information (3D position).

Vision-based tracking can provide accurate real-time visual information of various construction activities in outdoor sites. The implementation of such

methodology can help increase the decision making capabilities of the construction team by providing real time information and enhancing site productivity and safety.

ACKNOWLEDGEMENTS

The presented work is based upon a research funded by the National Science Foundation Grant # 0625643. NSF's support is gratefully acknowledged. The authors would also like to thank Peter Mattes and Russell Hinkle for their help in collecting video data. Finally the authors would like to thank Professor Glykeria Kalfakakou for providing a space to work at the Aristotle University of Thessaloniki.

REFERENCES

Baker, S., and Matthews, I., (2002). "Lucas Kanade 20 Years on: A Unifying Framework".

Caldas, C. H., Torrent, D. G., and Haas, C. T. (2004) "Integration of automated data collection technologies for real-time field materials management" 21st International Symposium on Automation and Robotics in Construction, Jeju, Korea

Cordova, F. and Brilakis, I. (2008) "Automated 2D Tracking of Personnel in Construction Sites" Procedings of the 10th International Conference on Applications of Advanced Technologies in Transportation.

Faugeras, O., and Luong, Q. T. (2001)."*The Geometry of Multiple Image"*.. MIT Press. ISBN 0-262-06220-8.

Furlani, K.M. and Stonew, C.W., "Architecture for Discrete Construction Component Tracking" Construction Metrology & Automation Group, National Institute of Standards and Technology.

Gatchalian, C. (2001) "Construction Management Systems:Automated Contract Tracking" Federal Highway Administration FHWA-IF-01-022

Gruen, A., (1997) "Fundamentals of videogrammetry – A review" Human Movement Science Journal, Vol. 16 pp.155-187.

Hartley, R., and Zisserman, A. (2003)." *Multiple View Geometry in computer vision"*. Cambridge University Press. ISBN 0-521-54051-8.

Jang, W.S. and Skibniewski, M.J.(2008) "A wireless network system for automated tracking of construction materials on project sites" Journal of Civil Engineering and Management

Molton, N., Davison, A., and Reid, I. (2004) "Parameterization and probability in image alignment"

Road-traffic technology.com (2006) "Egnatia Odos Motorway, Greece" Egnatia Odos AE (state-owned company)

Schwandl, R. (2007) "Egnatia Odos" UrbanRail.Net

Shapiro, l.G. and Stockman, G.C. (2001). "*Computer Vision*" Prentice Hall, 395-403. ISBN 0-13-030796-3.

TOWARDS ESTABLISHING AN INNOVATIVENESS INDEX FOR CONSTRUCTION SITES

Dr. Andrew P. McCoy[1]

ABSTRACT: The US construction industry is often characterized as laggard in its rate of adoption (innovativeness) for innovative construction products and techniques. In contrast, European construction is often considered advanced. A trip to Spain and Portugal provides a personal lens through which to view European adoption of innovation, albeit a limited view. No current index exists to compare innovation adoption across the construction setting, though. Development of this tool would therefore benefit our understanding of adoption progress in the construction industry. This work establishes such an index and uses a student-based travel abroad program to European construction sites as the setting for better understanding its design. This work therefore acts as a development step, establishing the basis for future work.

1 Introduction

The US construction industry is often characterized as traditional and resistant to adoption of innovative construction products and techniques. In contrast, European construction is often considered advanced from this same viewpoint. A trip to Spain and Portugal in winter 2007 provided an opportunity to view European adoption of innovation, albeit a limited view. Quantifying European innovativeness through the construction setting was however difficult due to the complexity of criteria in innovation research. A simple index of innovativeness for existing structures and those in process was required if a comparison could be made across sites and countries.

While no current index exists to compare innovation adoption within the construction setting, development of this tool would be beneficial to our understanding of adoption trends in the construction industry. Innovation adoption and use in the US construction industry is commonly used as a gauge of technical and economic progress (Porter, 1980). This work aims to establish a simple survey and corresponding tool, to be tested initially in the European construction setting, for comparing innovativeness across all construction sites.

[1] Andrew P. McCoy, Assistant Professor, Virginia Tech, College of Architecture and Urban Studies, Department of Building Construction, 410B Bishop-Favrao Hall, Blacksburg, VA 24061. apmccoy@vt.edu .

This work therefore derives such a profiling tool from literature to field-test the innovativeness of construction site products and processes. Once established, this instrument for testing innovativeness is offered to US students of construction, while in the European market, as a tool for understanding innovativeness on various construction sites throughout Spain and Portugal. The author performs literature content analysis to create a list of characteristics (an index) on which to judge each site, resulting in a score for each site based on its "innovativeness." Samples of the construction setting for such a tool range from those recently under construction to mostly completed projects.

2 Literature Review

Behavioral Styles

Behavioral style is defined as an observable pattern of behaviors (Effectiveness Institute, 2004). In recent history, behavioral styles have been studied as a method for better observing individuals and their perceptions by others. Others' perceptions range from immediate to well-established through time. Immediate perceptions have nevertheless often remained a valuable gauge of prolonged behavior.

Various attempts at gauging behavior from immediate observation have resulted in limited typologies (Jung, 1923; Marston, 1928; Merrill and Reid, 1981). These typologies changed through time, but were not expanded in size, establishing basic types of social or behavioral styles. Jung (1976) established four main behavioral types: *Feeler*, *Thinker*, *Sensor* and *Intuitor*. Marston (1928) created new terms for behavioral styles: *Dominance*, *Inducement of others*, *Steadiness* and *Compliance*. Merrill and Reid (1981) separated behavior and social styles, labeling behavior styles as *Assertiveness* and *Responsiveness*, and social styles as *Driver*, *Expressive*, *Amiable* and *Analytical*. The work of the Effectiveness Institute, Inc. (2004) includes these previous categories, creating a four-quadrant tool that makes "profiling easy to use, understandable and accurate in self-perception." This four-quadrant tool, modified to the behavioral and social styles of the construction industry's settings, is the focus of this work.

Innovation in Construction

The world of construction is characterized by de-centralization of resources, knowledge and projects, which often reinforces attitudes of risk aversion. Of importance is the industry's continued resistance to new technologies due to perceived risks of adoption. McCoy et. al (2009) consolidated many risks in the industry and found the following reasons for this resistance: *site variability, one-off nature, longevity of warranties, supply uncertainty* and *uncertainty inherent in the built environment*. *Site variability* in construction refers to its project-based activities implemented by multi-party networks (Blackley and Shepard, 1996; Toole, 1998). Further, high variability in the nature of the site requires decentralized decision-making farther from the construction setting and production procedures that must be standardized to achieve efficiency and quality control (Dubois and

Gadde, 2002; Blackley and Shepard, 1996; Toole, 1998). As a construction product, the building's long lifecycle extends risks, creating longevity *of warranties* (Blackley and Shepard, 1996; Koebel, 2003). *Supply chain variability* or *uncertainty* fortifies resistance to change the processes that have worked well in the past (BTI, 2005; Toole, 1998). Further, many US construction organizational environments create an *uncertainty of technology adoption* (Koebel et. al, 2003; Ball, 1999; Slaughter, 1993). Finally, the existence of multiple standards for codes and varying degrees of enforcement on a given building site can also reinforce innovation uncertain (BTI, 2005).

Some have attempted to mitigate the risks of innovation adoption on the construction site through understanding and improving the attributes of the products. Rogers (2003) seminal work placed innovations into the following categories: *Relative Advantage, Compatibility, Complexity, Trialability and Observability*. Slaughter (1998) studied product attributes and added several for construction settings: *Incremental, Radical, Modular, Architectural, System, Timing of Commitment, Coordination, Special Resources and Nature of Supervision*. Others have expanded product attributes for the construction setting as well in an attempt to facilitate their acceptance (NAHB, 1989; Hickling, 1989; Holmen, 2001; Koebel and McCoy, 2006). This study therefore derives its definitions for characterizing product innovativeness on construction sites through the following terms:

1. *Timing of commitment* (Hickling, 1989; Holmen, 2001; Koebel and McCoy, 2006).
2. *Co-ordination within project team* (Hickling, 1989; Slaughter, 1998; Koebel and McCoy, 2006).
3. *Special resources* (NAHB, 1989; Holmen, 2001; Koebel and McCoy, 2006).
4. *Supervision competency* (Slaughter, 1998; Koebel and McCoy, 2006)
5. *Relative advantage* (Hickling, 1989; Holmen, 2001; Koebel and McCoy, 2006).
6. *Complexity* (also called *Compatibility*) (Hickling, 1989; Rogers, 2003; Koebel and McCoy, 2006).
7. *Trialability* (Hickling, 1989; Rogers, 2003; Koebel and McCoy, 2006).
8. *Observability* (sometimes called *communicability*) (Hickling, 1989; Rogers, 2003).
9. *Risk* (NAHB, 1989; Hickling, 1989; Koebel and McCoy, 2006).
10. *Regulatory Resistance* (Hickling, 1989; Koebel and McCoy, 2006).

There is also consensus in the industry about the importance of successfully overcoming resistance to the adoption of innovative processes (Koebel, 2004). This work therefore attempts to understand and mitigate risks for innovative processes that might further traditional methods and facilitate successful promotion of new technologies. Many of these risks involved in process innovation nevertheless remain unlisted for the construction setting. Some consider risks specific to construction sites without listing them (Fisk and Reynolds, 2006). Koebel et al. (2003) placed sources of risk affecting the adoption and diffusion of innovation, albeit in residential construction, into several broad categories. The National Association of Home Builders Research Center (NAHB, 2005) studied industry risks specific to commercialization process. The Toolbase website of NAHB (www.toolbase.org), categorized innovative process in response to an initiative of

the Partnership for the Advancement of Housing (PATH). Koebel et al. (2003) and NAHB (www.toolbase.org) together included broad categories of organizational, marketing, technical, supply chain, operational, environmental, financial and legal uncertainties for construction site process. Many have recently argued for the benefits of information technology on construction sites (Vaidyanathan and O'Brien, 2003; Thomas et. al, 2004, Koebel and McCoy, 2006) and the emerging trend of sustainability (Pulaski and Horman, 2005). The US Department of Energy (DOE) also has lists criteria for innovativeness of process in the construction setting through its Solar Decathlon competition. This study therefore distills previous criteria and derives its definitions for characterizing process innovativeness on construction sites through the following terms:

1. *Economic attributes* (Koebel, 2005).
2. *Human resources* (Koebel et al., 2003).
3. *Market Viability* (DOE, 2007).
4. *Information Technology (*Vaidyanathan and O'Brien, 2003; Thomas et. al, 2004; Koebel and McCoy, 2006)
5. *Comfort Zone* (DOE, 2007).
6. *Accessibility* (Koebel et al., 2003; DOE, 2007).
7. *Resource Management* (Koebel et al., 2003).
8. *Sustainability* (Pulaski and Horman, 2005).
9. *Architectural Firmness, Commodity and Delight* (DOE, 2007).
10. *Engineering Design, Implementation and Energy Analysis* (Koebel et al., 2003; DOE, 2007).

Research Steps

This research bases its quantitative methodology on Creswell (1994), using previously accepted terms (meanings) that contain specific, accepted characteristics. Attempting to explain existing phenomena, Figure 1 illustrates the research steps of this work. Accepted terms form the basis for a survey instrument that explains relationships among variables in the construction setting, specifically product and process innovativeness. The overall goal of this research is to create a tool that will validate theories specific to the relationship among such survey variables.

The process for this work began in previous research on innovation in the construction industry and behavioral studies, both in psychology and diffusion literature. Previous work in innovation and diffusion created disparate definitions of behavior styles for the construction industry, as explained previously. Psychology studies, to the contrary, have historically narrowed their focus to consistent sets of behavior or social types (Effectiveness Institute, 2004). These two strands of previous work set the stage for this work's hypotheses.

The first stage of the research consisted of a literature review which served to operationalize the hypotheses through the identification of effective instruments for behavioral analysis and an assessment of innovativeness criteria relevant to this work. This review was not confined to US-based literature and these data are later summarized and discussed in regard to the survey instrument construction.

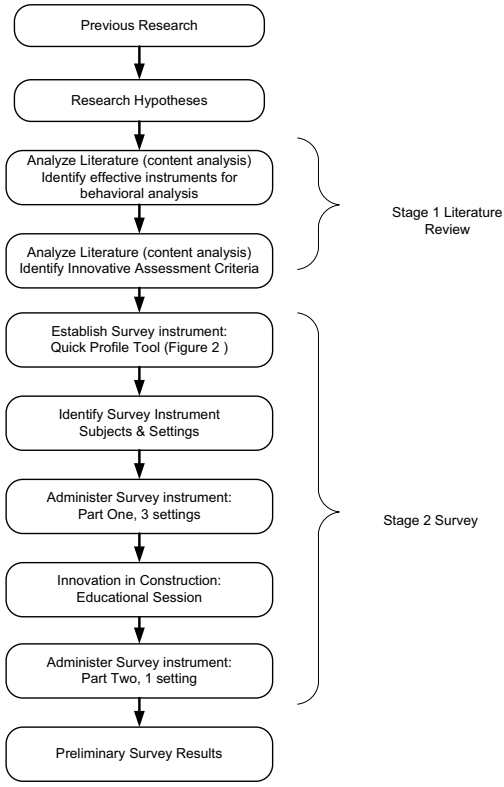


Figure 1: Research Steps

The second stage of the research identified a quick profiling template for behavioral styles. This tool was deliberately limited to a simple set of types that directly correlated to Rogers' (2003) categories of innovativeness: *Innovator*s defined as "rash, the daring and the risky;" *Early Adopter*s defined as "a more integral part of the local social system (that) has the highest degree of opinion leadership in most systems (and) can trigger the critical mass when they adopt an innovation; " The *Early Majority* defined as "adopting new ideas just before the average members of a system (and) interact frequently with peers but seldom hold positions of opinion leadership; " The *Late Majority* defined as "adopting ideas just after the average member of a system; their adoption may be both an economic necessity and a result of increasing peer pressure; " and *Laggards* defined as "possessing almost no opinion leadership; their point of reference is the past. "

Once the quick profile tool and its categories were established, the next stage of the research derived a set of questions that were appropriately tied to the four main

categories of the tool. Literature review offered many facets of behavioral style within the construction industry that might determine the traditional or innovative behavior of a specific setting. Each question contained a yes or no answer and placed, in parentheses, the appropriate designation of traditional or advanced.

The subjects for this work were 10 students attending a travel abroad program during break holiday of Virginia Tech. Each student, as a requirement of the trip, was at a minimum academic level of Junior and a member of the Building Construction (BC) department. As members of the BC department, their exposure to materials, methods and concepts of innovation in construction was appropriate for this study.

The four settings used to gauge innovativeness were all existing structures. Construction sites were not able to be accessed due to the difficult logistics of gaining permissions before arriving overseas. Nevertheless, each project consistently contained common materials to the students' education, used them in both traditional and non-traditional applications and required both traditional and non-traditional methods in construction. All materials were available for a construction setting in the US as well.

The sites were further divided into two categories: those viewed prior to a lecture on innovativeness in construction and those viewed after. Before the lecture, the students had three possible sites, as it would offer maximum flexibility for a tight trip schedule. These sites were: Toledum in Toledo, Spain; *Salamanca Museum of Modern Art* in Salamanca, Spain; and *Casa de Musica* in Porto, Portugal. The *Toletum* building sits at the gateway to the modern city of Toledo. The building serves as a chamber of commerce, museum, interactive media building, and café and gift shop for visitors to the city. The museum and interactive media tell the history of the area and describe local culture. The building is a modern design with materials including: cast-in-place concrete, cortens steel rain screening, curtain wall glass storefronts and a metal-clad roofing system. The Salamanca Museum of Modern Art sits in the former industrial area of the city. The building serves as a museum, interactive media building, café and gift shop for visitors to the museum and this part of the city. The museum and interactive media are part of permanent installations and temporary installations are also housed in this facility. The building is a modern design within an older construction setting with materials including: cast-in-place concrete, masonry, curtain wall glass storefronts, exposed metal structure and a metal-clad roofing system. The *Casa de Musica* building sits within the economically depressed region of Boavista in Porto. The building serves as a concert hall for local citizens and as an attraction for visitors to the city. The building contains interactive media displays that create music for its visitors. The building is a modern design meant to engage the local vernacular with materials including: cast-in-place concrete, curtain wall glass storefronts and stamped-metal interior surfaces. No walls within the structure are perpendicular to each other, creating the feeling of a "tilted" experience.

Following the lecture, the setting was the *Oriente Station* in Lisbon, Portugal, which we all visited together. The *Oriente* building sits at the gateway to the Expo

'98 area of Lisbon and was built specifically for this event. The building serves as a transportation hub, retail center and gateway for visitors to this part of the city. The upper portion of the building houses trains to other parts of Portugal, the lower part contains a local bus terminal and the underground portion contains Lisbon's underground system as well as retail leading into a nearby shopping mall. The building is a modern design with materials including: cast-in-place concrete, hollow structural steel and curtain wall or glass storefront systems for the roof and walkway borders.

3 Construction Site Innovativeness

Establishing the Quick Profiling Tool for Innovativeness

Rogers' (2003) listed five categories of innovativeness: *Innovator*, *Early Adopter*, *Early Majority*, *Late Majority* and *Laggards.* The four-quadrant organizational limits of the quick profiling tool (Effectiveness Institute, 2004) required the combination of *Late Majority* and *Laggards* categories, as shown in Figure 2.

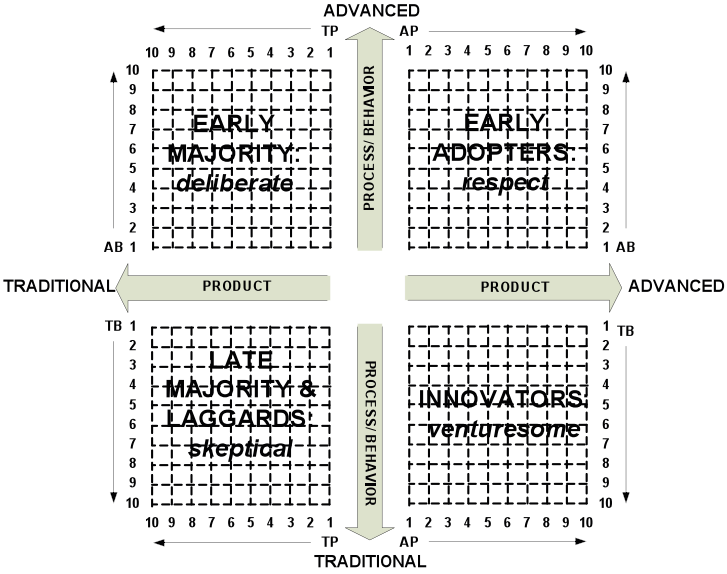


Figure 2: Innovativeness Quick Profile

As these categories of adopters represent a market share above 50%, many existing research studies consider these categories less or consider them less "critical" to the acceptance of an innovation. The scale for products and behaviors within the tool was determined as either more-or-less traditional or more-or-less advanced in an effort to remove the varying definitions of "innovativeness." A more-traditional process or product remains less innovative (advanced) and the

same reasoning applies to less-advanced designations. Product use was therefore designated "advanced products" (AP) or "traditional products" (TP) and Process/Behavior was designated as "advanced behavior" (AB) or "traditional behavior" (TB). Process innovativeness used "behavior" as its term to limit confusion of AP & TP for both products and process. While *innovators* constitute the leading edge of adopters, they are often driven by instinct and therefore exhibit a "tradition" to their behavior. For this reason, *early adopters* exist as the culmination of advanced products and advanced behavior.

The quick profiling tool contains a ten by ten grid in each quadrant, allowing for a total quadrant score between one and ten for behavior and products. The score between one and ten is determined by the answers recorded in the survey regarding the setting's innovativeness. For example, if all ten questions pertaining to product and process innovativeness are recorded as "advanced behavior" (AB) and "advanced product" (AP), the profiling tool will have all lines of the early adopter category shaded.

Product Innovation Criteria

Once the format of the tool was determined, the tool required an instrument, in the form of a survey, for collecting data. Previous literature terminology in behavior of and innovation in the construction setting served as the basis for all survey questions. This study therefore derived its definitions for characterizing product innovativeness on construction sites through the following terms, as previously outlined in literature review. Each term is written exactly as presented in the survey instrument.

1. *Timing of commitment:* refers to when the innovation must be introduced into project schedule, including design and construction. The commitment is the degree to which resources are assigned to the implementation of the innovation when an organization may publicly acknowledge its use of the innovation.
2. *Co-ordination within project team:* The degree to which an innovation requires communication among the members of a project team, including clients, designers, contractors, subcontractors and all contractual parties. Increased co-ordination will act as a barrier.
3. *Special resources*: Exist when the use of an innovation may require special resource (special equipment or trained personnel) and these resources will only exist within specialty companies. If the resource is difficult to obtain then this factor will act as barrier.
4. *Supervision competency:* Considers the nature of the supervision activities, including the organizational level at which the supervision is required. Since some innovation may require supervision only at the level of the performance task this characteristic will be an accelerator to diffusion of innovation.
5. *Relative advantage:* Reflects cost, labor, time, and energy savings. Adoption of an innovation is not only related to the existence, size and type of advantage, it is also related to how concrete and how immediate the advantages are. Relative advantages impact directly on the economic, social and psychological risk.

6. *Complex* (also called *Compatibility*): Innovations are seen as too risky and incompatible. Simplicity (the opposite of complex) contributes or detracts from a potential adopter's understanding of how the innovation works or of the scientific or engineering principles upon which it is based. Complex products require extensive research and product trials upfront. High or low compatibility (a variable of complexity) refers to changing or not changing work habits of builders, trade people, or contractor and end-users. If product does change working habits then product is not considered as compatible and in such case compatibility will impede the process of diffusion. Low compatibility directly affects the risk assessment component of the diffusion process.
7. *Trialability* is directly related to risk perception. Trying a product allows an adopter to evaluate the practical risks involved. If the product performs to the expectations then it facilitates the process of adoption.
8. *Observability* (sometimes called *communicability*): The visibility of an innovation to potential adopters. This refers to ease of seeing and explaining an innovation. An observable innovation is seen on the home's exterior. Non-visible products (more integrated into a structure or system of construction) act as barriers (Hickling, 1989; Rogers, 2003).
9. *Risk*: Contractors, owner's, designers and other construction team members have low tolerance for risk. They will stay away from any innovation that carries a market risk, a competitive risk and especially a financial risk.
10. *Regulatory Resistance*: The approval of any product in the market depends upon the approval from the regulatory bodies, which in turn determines the pace of diffusion. It reflects the government's need to set standards in product performance and testing or secondary or delayed effects of product.

Process Innovation Criteria

Again, previous literature terminology in behavior of and innovation in the construction setting served as the basis for all survey questions. This study therefore derived its definitions for characterizing process innovativeness on construction sites through the following terms, as previously outlined in literature review. Each term is written exactly as presented in the survey instrument.

1. *Economic attributes*: For each site, the viability of a community developing such a structure to provide an economic benefit to the area and its inhabitants.
2. *Human resources*: For each site, the amount of labor required to support the project.
3. *Market Viability*: For each site, whether the building has market appeal and is well suited for everyday living—and if it could be built easily and accommodate a variety of potential inhabitants. Please consider livability, build-ability, and flexibility.
4. *Information Technology*: For each site, the use of information technologies on-site or contained in the existing structure.
5. *Comfort Zone*: For each site, the comfort of the space with regard to lighting and temperature.

6. *Accessibility*: For each site, the ease of maneuvering on-site during construction or access to the building within its existing setting.
7. *Resource Management*: For each site, the quantity of waste, systems used to mitigate or reduce this waste and systems used to store waste.
8. *Sustainability*: For each site, the use of technologies that do not adversely affect the current environment while making future environments better.
9. *Architectural Firmness, Commodity and Delight*: For each site, does the design seem: strong in its form, suitable and appropriate in its materials for the context; architecturally strategic in its use of technologies required to run the building; and generous and sufficient in space; surprising in an unusual use of ordinary materials, or use of extraordinary materials.
10. *Engineering Design, Implementation and Energy Analysis*: For each site, does the engineering involved seem advanced or standard, easily implemented or complex, highly energy conscious or unconcerned.

Construction Site Innovativeness Instrument

Due to the length requirements of this publication, the instrument derived from these previous criteria cannot be presented. Nevertheless, the survey instrument was created to be answered by students to determine the innovativeness of the products or processes in all settings based on previous criteria. For example, questions regarding innovative products were based on a previously established definition, while using basic language to avoid bias. A similar process was used for all questions regarding innovative process.

4 Conclusions and Future Work

This research attempts to create a prescriptive tool for quickly establishing resistance towards innovative products and processes in the construction setting. In order to make innovativeness more accessible, the specific objectives of this work were to establish this simple survey for students of construction and develop a resultant tool for comparing innovativeness across all construction sites. It is the aim of this work to better define the current and past role of innovative products and processes in unfamiliar construction settings through student involvement.

Without some education in the topic of innovation and construction, confusion would exist about basic terms of innovation and students might not properly understand the profiling tool and the survey as a support mechanism for such a tool. The purpose of this tool would therefore be inaccessible to student comprehension. Such a tool offers a comparison of many settings in which students may work. The survey, not the tool, and its explanation seem to need the most attention and clarification for future studies. Future work should include all survey comments for survey effectiveness and continue to develop the profiling tool to gain quick views of the behavior of the construction industry with regard to innovation.

EVALUATION OF WORK ZONE CAPACITY MODELS

Carolyn Hicks[1], Brenda McCabe[2], and Susan Tighe[3]

[1]Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, Ontario, Canada, M5S 1A4; FAX (416)978-6813; e-mail: c.hicks@utoronto.ca
[2]Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, Ontario, Canada, M5S 1A4; PH(416)978-3505; FAX(416)978-5054; e-mail: mccabeb@civ.utoronto.ca
[3]Department of Civil Engineering, University of Waterloo, 200 University Avenue West, Waterloo, Ontario, Canada, N2L 3G1; e-mail: sltighte@civmail.uwaterloo.ca

Abstract

Due to aging highways, roadwork on Southern Ontario is becoming increasingly important and increasingly frequent. Lane closures that ensue from this work must be managed appropriately in order to diminish user delay costs and maintain the quality and productivity of work. The ability to predict the capacity of freeway work zones is important in this analysis. Using multiple work zones in the region, this study evaluated six models that were used to estimate capacity. The models were based on data from Texas, Maryland, South Carolina and Ontario. After comparing each model to the observed capacities on five sites across South Western Ontario, the resulting conclusion was that region specific models are required in order to account for local driving practices.

Introduction

Southern Ontario freeways service well over a million vehicles on a daily basis [Traffic Volumes, 2005]. These highways are aging, making repairs and maintenance of these critical arteries increasingly important. The Ontario government has begun to recognize this and close the infrastructure gap. In 2006, the Ontario government committed to investing 3.4 billion dollars in highway construction in the five year project called “Southern Ontario Highways Program” [SOHP, 2007]. A significant portion of this funding is aimed towards road rehabilitation creating many highway work zones across the province.

Performing road maintenance and rehabilitation requires road closures which cause reduced traffic throughput, often resulting in traffic backups and queuing. To avoid excessive queuing and, in turn, user delay costs, construction contractors are forced to keep lanes open during peak hours and work only at night. Having a limited work schedule can not only extend a project, but can decrease both productivity and quality of work. To find the right balance between keeping the lane open for users and closing it for extended work hours, an accurate prediction of the site capacity is needed.

A number of studies have been performed with the aim of formulating a model that will predict the capacity of a freeway work zone. Based on the idea that driver behaviour and practices vary between socio-demographic groups [Dobson 1999], this study set out to determine if driver behaviour variations caused by being in different geographic regions might affect work zone capacity. As such, this study set the null hypothesis to having work zone capacity models be accurately applied to all regions and the alternative hypothesis to these models not applying in regions different to the one it was developed in.

Models for predicting work zone capacity can employ a number of different tactics to arrive at their final vehicle count. They can generally be classified as mathematical (M), simulation (S) or artificial intelligence (AI) models. The type most often used in the determination of the capacity of a work zone is the mathematical model. This study highlights those models and evaluates them to determine their appropriateness for the Southern Ontario region.

Models for Analysis

Models for predicting work zone capacity were identified from previous research. Each model included different site characteristics in their analysis. Table 1 summarizes the characteristics deemed statistically significant in the models. The models would have considered other characteristics prior to finalizing their choice of the ones to use in the final model. For example the Kim et al. [2000] model initially included eight characteristics but determined that only two were statistically significant (P value less than 0.05).

Of these, four models were chosen for possible application to Southern Ontario data.

	Models								
	Rouphail and Tiwari 1985	Sarasua et al 2004	Krammes and Lopez 1994	Kim et al. 2000	Al-Kaisey and Hall 2003	Karim and Adeli 2003a	Adeli and Jiang 2003	Zhang et al. 1996	Karim and Adeli 2003b
Model Type	M	M	M	M	AI	AI	AI	S	S
Work Activity	x	x	x	x	x	x	x	x	x
Heavy Vehicle	x	x	x	x	x	x	x		x
No. of Open Lanes	x	x	x	x		x	x	x	x
Light Conditions					x	x	x	x	
Lane Width					x	x	x		x
Total No. of Lanes						x	x	x	x
Lateral Distance				x					
Length of Closure				x		x	x		x
Driver Population					x		x		x
Side of Closure				x	x	x			x
Ramps			x		x	x	x		
Work Zone Speed						x	x		x
Work Duration							x		x
Weather					x		x		
Crossover					x		x		
Grade				x		x	x		
Traffic Manag'nt				x					x
Work Zone Location							x		
Pavement Condition							x		
Site ID (on database)									x
Start Time									x
Construction Cost									x
Maintenance Cost									x
Flow Rate									x

Table 1 - Summary of Previous Work Zone Capacity Models

Krammes and Lopez (1994)

The model developed by Krammes and Lopez starts with a base capacity (C_b) and then makes adjustments for work intensity (I), heavy vehicles (f_{hv}) and ramps within or near to the work zone (R) [Equation 1]. This model used 45 hours of data collected from 33 work zones in Texas between 1987 and 1991.

$$C = (C_b + I - R)*f_{hv}*N \qquad \text{Equation 1}$$

Where: C = Capacity (in passenger cars per hour per lane [pcphpl])
C_b = Base Capacity = 1600
I = Work Intensity Factor
R = Ramps in the Work Zone
f_{hv} = Heavy Vehicle Factor
N = Number of Lanes

The presence of work activity was accounted for using the work intensity factor, I. Mathematically it represents an addition or subtraction of 10% of the base capacity (160passenger cars), which is determined based on the amount of activity occurring in the work zone.

Krammes and Lopez predicted that the presence of ramps within 152m (500ft) of the end of the work zone could decrease the capacity of the work zone. While they did not specify how to determine where on the spectrum each site should be, they did say that R should never be greater than 50% of the determined capacity of the lane.

The heavy vehicle factor (f_{hv}) is defined by the Highway Capacity Manual (HCM). As heavy vehicles not only take up more space on a roadway, accelerate at slower speeds and generally leave more space for braking, a passenger car equivalent (PCE) is employed. This value is used to convert the number of heavy vehicles into an equivalent passenger car count. The PCE is used in the calculation of the impact of heavy vehicles on capacity, as seen in Equation 2.

$$f_{hv} = 1/[1 + [HV*(PCE - 1)]] \quad \text{Equation 2}$$

Where: HV = Percentage of heavy vehicles on the road
PCE = Passenger Car Equivalent

Kim, Lovell and Paracha (2000)
The Kim et al. model included a wider range of site characteristics. Using data collected from 12 work zone sites in Maryland, the model is geared towards lane closures on highways which normally have 4 lanes open in one direction. As shown in Equation 3, this model starts with a base capacity and adjusts for seven different site characteristics.

$$C = 1857 - 168.1*(NUMCL) - 37.0*(LOCCL) - 9.0*(HV) + 92.7*(LD) - 34.3*(WL) - 106.1*(WI_H) - 2.3*(WG)*(HV) \quad \text{Equation 3}$$

Where: C = Capacity (in vehicles per hour per lane [vphpl])
NUMCL = Number of closed lanes
LOCCL = Location of closed lanes (right = 1, left = 0)
HV = Percentage of heavy vehicles on the road
LD = Lateral distance to the open lanes
WL = Work zone length
WI = Work intensity (heavy = 1)
WG = Work zone grade

Although the model includes all of these site characteristics, the equation shows that some have little effect on the overall capacity. Additionally, a further assessment of the study shows that some of the characteristics have a relatively low level of statistical significance.

Al-Kaisy and Hall (2003)

The study performed by Al-Kaisy and Hall took two approaches to determining work zone capacity. Unlike previous studies, this research collected data from a long term closure, located within close proximity to the downtown core of the city of Toronto, Ontario. The study resulted in two different models to account for the different site characteristics, one additive and one multiplicative.

The additive and multiplicative models used similar general formats, shown in Equation 4 and Equation 5, respectively.

$$C = C_b + I_1 + I_2 + I_3 + ... + I_n \quad \text{Equation 4}$$

Where: C = Capacity (in passenger cars per hour per lane [pcphpl])
C_b = Base Capacity = 1600
I_i = Impact from various factors

$$C = C_b * f_1 * f_2 * f_3 * f_4 * ... * f_n \quad \text{Equation 5}$$

Where: f_i = Adjustment factors

Starting with a base capacity, the additive model specified five significant characteristics that affect capacity. These were heavy vehicle factor, day of week, work zone configuration (right vs. left lane closed), weather and work activity. The model also accounted for any interactions between these variables, shown in Table 2.

Characteristic	Value/Adjustment (pcphpl)
Base Capacity	1964
Heavy Vehicle	-20.7*(HV)
Weekday	-82
Weekend	-352
Left Lane Closed	-121
Rain	-71
Work Activity Present	-172
Interactions	
Left Lane Closed and Weekday	+55
Weekend and Work Activity	+185
Left Lane Closed and Rain	+58
Weekend and Rain	+107

Table 2 - Impacts from factors in Al-Kaisy and Hall additive model

Similarly, the multiplicative model includes these same characteristics, but instead of altering the capacity value with a lump sum adjustment, it alters the value as a percentage of its original. Adjusting the base capacity of 2000pcphpl, Table 3 shows the factors applied in Equation 5 to determine the work zone capacity.

Element	Characteristic	Value (pcphpl)
Capacity	Base Capacity	2000
Heavy Vehicle	Heavy Vehicle - Uses f_{HV} formula with different PCE values	
	Level Ground	PCE = 2.4
	3% Grade or more	PCE = 3.0
Driver Population	Weekday Peak Hours	1.0
	Weekday Offpeak Hours	0.961
	Weekend	0.825
Light Condition	Daytime	1.0
	Night time with Illumination	0.96
WZ Configuration	Right Lane Closed	1.0
	Left Lane Closed	0.94
Weather	No Rain	1.0
	Light to Moderate Rain	0.95
	Heavy Rain	0.90
Work Activity	No Work Activity	1.0
	Work Activity	0.943
Variable Interactions	No Interactions	1.0
	Left Lane & Weekday off peak	1.03
	Weekend & Work Activity	1.08
	Left Lane & Rain	1.02
	Weekend & Rain	1.05

Table 3 - Impacts from factors in Al-Kaisy and Hall multiplicative model

Sarasua, Davis, Clarke, Kottapally and Muluktla (2004)

Almost identical to the model created by Krammes and Lopez, the Sarasua et al. model employs the same equation with exception of the impact of ramps. This model was formed using values from highways in South Carolina and accounts for removing the ramp variable by altering the starting (base) capacity. By doing this, it eliminates the need to assign an impact of the ramp (which, according to the previous model could affect the capacity by up to 50%). Equation 6 shows the model resulting from this study.

$$C = (C_b + I) * f_{hv} * N \quad \text{Equation 6}$$

Where: C = Capacity (in passenger cars per hour per lane [pcphpl])
C_b = Base Capacity = 1460
I = Work Intensity Factor
f_{hv} = Heavy Vehicle Factor
N = Number of Lanes

MTO Estimates

In addition to evaluating published capacity models, the analysis shown in this paper also evaluated the values currently used in design in the region. The Ministry of Transportation of Ontario (MTO) maintains a list of suggested capacity values for work zone capacities. Found in the Generic Lane Closure Times manual [TPISS 2003], capacity values are held for three different types of road ways (Table 4).

Type of Roadway	Capacity (vphpl)
Two Lane Highway (Alternating Flow)	850
Multi-Lane Highway	1400
Freeway	1800 (1600 on weekends)

Table 4 - MTO Design Capacity Values

Discussion

Data were collected from a number of sites in Southern Ontario that exhibited full lane closures and traffic queuing over the course of two construction season (Fall 2007 and Summer 2008). While it was often difficult to find the desired work zone characteristics, data were collected from 5 site locations on 11 different days, resulting in 34 hours of data. Factors recorded included the percentage of heavy vehicles, presence of work activity, presence of ramps, number of lanes, number of lanes closed, side of road closed (right or left), distance to open lanes, work zone length, work zone grade, day of week, time of day and weather.

Under queued conditions, vehicle counts were performed over 15 minute intervals. According to the Highway Capacity Manual (HCM) [2000] a heavy vehicle is any vehicle with more than 4 tires touching the pavement. The capacity counts (both passenger and heavy vehicles) combined with the site characteristics allowed the models to be evaluated to determine their appropriateness on Southern Ontario freeways.

Table 5 shows site code, visit date and type of work performed at each data collection location. Collecting data at these different locations resulted in a wide range of vehicle per hour per lane values. Figure 1 shows how the data from each site varied along with the 95% Confidence Interval. Please note that matching data counts are denoted by only one line on the graph.

Site Code	Type of Work	Visit Dates	Capacity (vphpl)		
				95% Confidence Interval	
			Mean	Low	High
Site A-1	Rehabilitation of ramp	20-Sep-07	1755	1706	1804
A-2		21-Sep-07	1714	1693	1759
A-3		24-Sep-07	1625	1561	1689
Site B-1	Road surfacing and widening	02-Oct-07	1148	1084	1252
Site C-1	Road resurfacing and	27-Sep-07	1190	1116	1265
C-2	construction of interchange	09-Oct-07	1296	1231	1365
C-3		12-Oct-07	1209	1151	1315
C-4		10-Jul-08	1134	1060	1207
C-5		13-Jul-08 day	1141	1024	1257
C-6		13-Jul-08 night	1155	1027	1284
Site D-1	Rehabilitation of ramp	26-Jun-08	1564	1528	1600
Site E-1	Road widening for HOV lane	07-Jul-08	971	961	1076

Table 5 - List of Sites Visited and Site Information

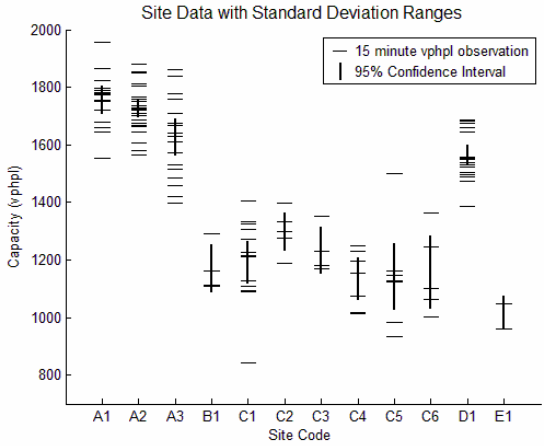


Figure 1 - Data Observed at all Sites and their Corresponding Standard Deviations

Model Evaluations

Existing models were evaluated for each site visit to calculate the predicted capacity for that roadway and then compared to the observed capacity on site (vphpl). Results of the comparison of the models can be found in Table 6. The Texas model by Krammes and Lopez [1994] resulted in a range of 0-54% error between the calculated and observed capacities, with an average absolute error of 20%. Comparatively, the Kim et al. model [2000] which included numerous site characteristics yielded 2-36% error and an average absolute error of 15%.

Site		Krammes & Lopez		Kim et al.		Al-Kaisy & Hall – Add.		Al-Kaisy & Hall – Mult.		Sarasua et al.		MTO Design Values	
	Act.	C	Err (%)	C	Err (%)	C	Err (%)	C	Err (%)	C	Err (%)	C	Err (%)
A-1	1755	1624	7	1508	14	1587	10	1587	10	1490	15	1800	-3
A-2	1726	1624	6	1508	13	1587	8	1587	8	1490	14	1800	-4
A-3	1625	1624	0	1508	7	1587	2	1587	2	1490	8	1800	-11
B-1	1168	1507	-29	1583	-36	1640	-40	1364	-17	1389	-19	1800	-54
C-1	1190	1450	-22	1374	-15	1706	-43	1339	-12	1339	-13	1800	-51
C-2	1298	1415	-9	1425	-10	1639	-26	1256	3	1309	-1	1800	-39
C-3	1233	1458	-18	1330	-8	1706	-38	1349	-9	1347	-9	1800	-46
C-4	1134	1386	-22	1319	-16	1704	-50	1263	-11	1284	-13	1800	-59
C-5	1141	1574	-38	1361	-19	1502	-32	1356	-19	1447	-27	1600	-40
C-6	1155	1525	-32	1360	-18	1501	-30	1248	-8	1405	-22	1600	-39
D-1	1564	1525	2	1590	-2	1586	-1	1459	7	1405	10	1800	-15
E-1	1019	1574	-54	1230	-21	1642	-61	1445	-42	1447	-42	1800	-77
Abs error			20%		15%		29%		12%		16%		36%

Table 6 - Calculated Model Values (C) and their %Error with respect to Actual Values

The Al-Kaisy and Hall models were based on data collected in a similar area to the current sites. More specifically Site A and Site D were collected within 15km of the Al-Kaisy study, just on the border of Toronto city limits. The remaining sites range between 40 and 110km away from the Al-Kaisy and Hall Toronto site. The similarity in the geographic region shows through the analysis of the capacities. In the two sites that were within a reasonable range of the model's data, the average error in values was from 1 to 8%. However, the overall average absolute error for the additive model was 29% and for the multiplicative model was 12%. The final two models by Sarasua et al. and the Ministry of Transportation's yielded average absolute error values of 16% and 36% respectively. The comparisons show that neither represent a suitable model to use in capacity approximations.

Conclusions

After visiting a number of different freeway work zones, it was apparent that there is a wide variation in the number of vehicles per hour per lane that can pass through. Knowing this, an evaluation of existing models was performed. This evaluation saw that the models were, in general, unable to accurately predict the capacity observed on the Southern Ontario freeways.

One of the models, which was based on data collected close to downtown Toronto, was able to closely predict the values of the two sites that were within 15km of the downtown core. However, when the model was compared to sites that were further outside the city, errors increased.

The resulting conclusion of these evaluations is that a region specific model is required to best predict work zone capacity values. Although characteristics can be similar in different sites across the continent, the variation in results shows that each geographic area should determine their own coefficients to account for local driving practices.

Bibliography

Adeli, H. and Jiang, X. (2003) "Neuro-Fuzzy Logic Model for Freeway Work Zone Capacity Estimation". Journal of Transportation Engineering Vol. 129 #5, 484-493

Al-Kaisey, A. and Hall, F. (2002) "Guidelines for Estimating Free Capacity at Long-Term Reconstruction Zones". Paper submitted to the Transportation Research Board 81st Annual Meeting, 13-17

Dobson, A., W. Brown, J. Ball, J. Powers, M. McFadden (1999) "Women Drivers' Behaviour, soci-demographic Characteristics and Accidents". Accident; analysis and prevention, England.

"Geometric Design Standards for Ontario Highways; Chapter B Update". (2002) GDM Chapter B Content Revisions, Ministry of Transportation of Ontario

HCM (Highway Capacity Manual) (2000) Transportation Research Board, National Research Council, National Academy of the Sciences, Washington D.C. USA

Karim, A. and Adeli, H. (2003a) "CBR Model for Freeway Work Zone Traffic Management". Journal of Transportation Engineering Vol. 129 #2, 134-145

Karim, A. and Adeli, H. (2003b) "Radial Basis Function Neural Network for Work Zone Capacity and Queue Estimation". Journal of Transportation Engineering Vol. 129 #5, 494-503

Kim, T., D. Lovell and J. Pracha. (2000) "A new Methodology to Estimate Capacity for Freeway Work Zones". Submitted to the 2001 Transportation Research Board Annual Meeting, Washington D.C., January 2001. Paper No. 01-0566

Krammes, R. A. and G. O. Lopez. (1994) "Updated Capacity Values for Short-Term Freeway Work Zone Lane Closures". Transportation Research Record 1442, TRB, Transportation Board of the National Academies, 49-56

Lee, E.B., C.W. Ibbs, J.T. Harvey, J.R. Roesler, (2000) "Constructability and Productivity Analysis for Long Life Concrete Pavement Rehabilitation Strategies", Report Prepared for California Department of Transportation Report No. FHWA/CA/OR-2000/01

Lee, E.B., L. Hojung, J.T. Harvey, (2004) "Fast-track Urban freeway Rehabilitation with 55-hour Weekend Closure: I-710 Long Beach Case Study", Technical Memorandum Prepared for California Department of Transportation and National Asphalt Paving Association, Technical Memorandum TM-UCB-PRC-2004-4

Rouphail, N. M. and G. Tiwari. (1985) "Flow Characteristics at Freeway Lane Closures". Transportation Research Record 1035, TRB, Transportation Board of the National Academies, 50-58

Sarasua, W., W. Davis, D. Clarke, J. Kottapally and P. Mulukutla (2004) "Evaluation of Interstate Highway Capacity for Short-Term Work Zone Lane Closures". Transportation Research Record 1887, TRB National Research Council, 85-94

SOHP, "Southern Highways Program; 2007-2011", (2007) Ministry of Transportation of Ontario, Government of Ontario, Canada, <http://www.mto.gov.on.ca/english/pubs/shp2007/shp.html> (Aug. 18, 2008)

Tighe, S, and McCabe, B. (2006) "Evaluation of Work Zone Strategies" Report Number ESB-001, prepared for the Ministry of Transportation Ontario, Highway Infrastructure Innovation Funding Program

TPISS (Traffic Planning and Information Services Section). (2003) "Generic Lane Closure Time for Central Region Highways 2003/2004". Ministry of Transportation of Ontario, Government of Ontario, Canada

"Traffic Volumes (AADT Only); Provincial Highways – Kings Highways, Secondary Highways, Tertiary Highways". (2005) Ministry of Transportation of Ontario, Highway Standards Branch, Traffic Office

Zhang, J., L. Leiman, and A. D. May. (1989) "Evaluation of Operational Effects of Freeway Reconstruction Activities". Transportation Research Record 1232, TRB, Transportation Board of the National Academies, 27-39

THE RELATIONSHIP BETWEEN INFORMATION TECHNOLOGY AND CONSTRUCTION PRODUCTIVITY: A VIEW FROM COUNTRY-LEVEL DATA

Dong Zhai[1] and Paul M. Goodrum[2]

[1]PhD Student, Department of Civil Engineering, University of Kentucky, 151D Raymond Building, Lexington, Kentucky, 40506-0281; PH (859)257-8033; dzhai0@engr.uky.edu

[2]Associate Professor, Department of Civil Engineering, University of Kentucky, 151C Raymond Building, Lexington, Kentucky, 40506-0281; (PH) (859)257-5416; FAX (859)257-4404; pgoodrum@engr.uky.edu

Abstract: With the increasing application of information technology (IT) in almost all industries, understanding the relationship between IT and productivity is useful in order to help improve the effectiveness of IT in improving productivity. Although previous research has identified the effects of IT on productivity in other industries, the general relationship between IT application and construction productivity is less clear. The evidence that overall costs have been reduced or project performance has been improved with IT in construction is limited and mostly focused on specific IT applications. This article investigates the general relationship of national IT investment level to construction productivity in various countries. The data is from Organisation for Economic Co-operation and Development (OECD) and Eurostat. By examining the trends of construction productivity and information and communication technology investment, the authors found positive relationship between these two trends among the 13 sampled European countries.

Key Words: Information Technology, Construction Productivity, Investment, Trend, Relationship, Country Level Analysis

INTRODUCTION

Information technology (IT) can be defined as the use of electronic machines and programs as the use of electronic machines and programs to process, store, transfer and present information (Björk 1999). The development and application of IT has contributed much to the improvement of many industries' productivities, such as the manufacturing, retail and service industries (Siegel 1994, Diewert and Smith 1994, Brynjolfsson and Hitt 1993).

The relationship between the usage of IT and productivity performance in the construction industry is less clear. Unfortunately, the construction industry has

traditionally been viewed as technologically stagnant in comparison with other industries (Rosefielde and Mills 1979). Furthermore, within the industry, a lack of information and some healthy skepticism regarding technological net benefits has contributed to the construction industry's reluctance to implement new technologies (O'Connor and Yang, 2004). Nonetheless, most researchers and construction practitioners would acknowledge that IT may eventually have a significant net positive impact on construction projects, yet little evidence exists. For example, one vision predicts that future construction sites will become more "intelligent and integrated" as materials, components, tools, equipment, and people become elements of a fully sensed and monitored environment (Wood and Alvarez, 2005). In such an environment, the construction industry will be required to process and share larger volumes of data across multiple systems and will therefore necessitate the application of IT. What remains uncertain is whether there has been or will be an improvement in productivity as a result of increased IT usage.

The primary objective of this research is to examine the general relationship of national IT investment level to construction productivity among various countries. This country-level analysis has the potential to identify if nations with advanced IT development and application in their respective construction industries experienced greater construction productivity improvement than construction industries in other countries with relatively less IT usage.

BACKGROUND

Information technology not only includes computers and related software, but it also includes advanced electrical devices like GPA, telephone, photocopies, and fax machines (Björk 1999). Many previous researchers have identified specific IT applications on construction as well as their effects, but the general relationship between IT application and construction productivity is less clear. Griffis et al. (1995) found that 3D model usage was positively related to improvement of cost and schedule performance and reduction of rework. Balli (2002) showed handheld computers in conjunction with wireless networking technologies could provide accurate, reliable and timely information to construction foremen at locations where it is needed. Thomas et al. (2004) indicated that design/information technology was positively related to project performance, especially cost and schedule. O'Connor and Yang (2004) found that increased automation and integration usage may contribute significantly to project performance in terms of cost and schedule success. Ergen et al. (2007) indicated that automated tracking and locating technology using RFID combined with GPS technology could eliminate the deficiencies in existing manual methods of identifying, tracking and locating highly customized prefabricated components.

Meanwhile, researchers focusing on other industries have investigated a more general relationship between information technology and productivity. Brynjolfsson and Hitt (1993) found that for the service firms sampled in their research return on investment of information technology averaged over 60% per year. Siegel (1994) found a significant positive relationship between manufacturing productivity growth and firm-level investments in computers.

Dewan and Kraemer (2000) performed a country-level analysis. They found significant differences between developed and developing countries with respect to their structure of returns from capital investments. For the developed countries in their sample, returns from IT capital investments were estimated to be positive and significant, while returns from non-IT capital investments were not commensurate with relative factor shares. The situation was reversed for the developing countries, where returns from non-IT capital were quite substantial, but those from IT capital investments were not statistically significant. Unfortunately, there has been no similar research that has focused on the construction industry.

METHODOLOGY

Data source

The data used in this research are from Organisation for Economic Co-operation and Development (OECD) and Eurostat. OECD provides the Information and Communication Technology (ICT) investment as the percentage of non-residential gross fixed capital formation in each of the OECD countries in 1980, 1990 and 2000. Eurostat is the official statistical bureau of the European countries, where the authors collected data in regards to the annual construction GDP and workers employed, and then calculated the construction productivity as the construction GDP per worker per year. The study's estimate of construction labor productivity implies that all workers are full-time employed in construction, which is clearly not the case. Furthermore, other concerns regarding the accuracy of construction output at an industry level exist (Rosefielde and Mills 1979, Stokes 1981, Pieper 1990, and Gullickson and Harper 2002), so the authors acknowledge this to be one weakness of the study. There are 13 European countries included in this research. The criteria for choosing these countries are as follows and (1) the country must appear in both OECD and Eurostat; and (2) the indicators are available in the designated years. For the purpose of this research, the ICT investment from the OECD was required in 1980, 1990 and 2000, and the construction GDP and total workers employed were required to be available in Eurostat in 2005 and 1999.

IT Development Measurement

To benchmark the development, application and impact of information and communication technology, the EU launched a program in 2005, named the i2010, which identified a list of key indicators to measure IT usage within specific EU countries. The indicators are grouped under nine themes: (1) Developments in broadband, (2) Advanced services, (3) Security, (4) Impact in relation to the overall Lisbon objectives of growth and employment, (5) Investment in ICT research, (6) Adoption of ICT by businesses, (7) Impact of adoption of ICT by Business, (8) Inclusion, and (9) Public services. Unfortunately, the i2010 research is relatively new, and cannot be used in the historical analysis conducted in this paper. Therefore, the authors used the ICT investment as the percentage of non-residential gross fixed capital formation as the indicator of IT development in one country as previous researchers have done (Dewan and Kraemer, 2000). The authors acknowledge that the ICT investment described herein is not limited to just construction but across all industries among the sampled countries.

Analysis Procedure

The hypothesis is that greater improvement of construction productivity occurred in the countries with large ICT investment as the percentage of non-residential gross fixed capital formation among the sampled countries.

To begin, the authors analyzed the trend of construction productivity between 1999 and 2005 through the percentage of productivity improvement between the two years (Equation 1).

$$\%\ Productivity\ Improvement = \frac{Productivity\ 05' - Productivity\ 99'}{Productivity\ 99'} \times 100\% \quad (1)$$

Next, the authors identified the trend of ICT investment. For the purpose of this research, the ICT investment in this paper denotes the percentage of ICT investment in none-residential gross fixed capital formation. Similarly, the authors also calculated the percentage of ICT investment improvement between 1980, 1990 and 2000 (Equation 2).

$$\%\ ICT\ Investment\ Improvement = \frac{ICT\ Investment\ (year\ a) - Productivity\ (year\ b)}{Productivity\ (year\ b)} \times 100\% \quad (2)$$

Next, the authors tested the hypothesis by plotting the percentage of productivity improvement and ICT investment. As examined by others (Brynjolfson 1993), IT investments can require a longer return period of approximately five to fifteen years before the full benefit of the investment is realized. Therefore, the authors investigated productivity improvement in the sampled countries' construction industries from 1999 to 2005 and ICT investment from 1980 to 2000.

RESULTS OF ANALYSES

The Trend of Construction Productivity

As shown in Figure 1, all of the sampled countries experienced an improvement in construction productivity from 1999 to 2005, except Greece with a 44.77% decrease. The average improvement in all of the 13 countries was 18.88%. Ireland, United Kingdom and Spain experienced the greatest improvement by 50.74%, 49.52% and 41.52%, respectively. Besides Greece, the countries experienced the least improvement in construction productivity were Sweden (0.14%), Germany (6.48%) and Portugal (10.67%).

The Trend of ICT Investment

From 1980 to 2000, all of the 13 sampled country experienced remarkable growth in ICT investment (Figure 2). The average ICT investments are 6.5%, 11.5% and 17.4% in 1980, 1990 and 2000 respectively. In the 20 years, Sweden, Ireland and United Kingdom experienced the largest improvement, while Spain, Austria and Portugal experienced the least improvement. In the first decade (1980-1990), all of the 13 countries experienced remarkable ICT investment improvement, with an average of 75.7%. United Kingdom, Greece and Spain experienced the largest improvement, while Netherland, France and Austria had the least improvement.

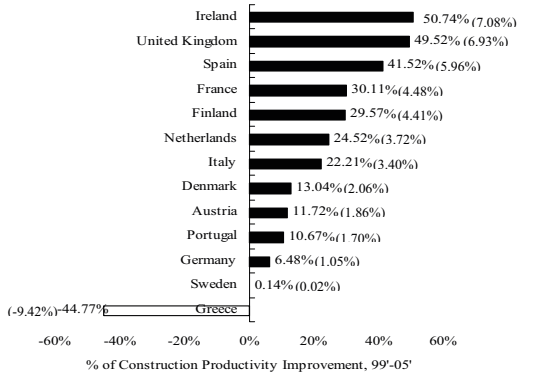


Figure 1: The Percentage of Construction Productivity Improvement, 99'-05 (Note: compound rates are shown in parentheses), Data from Eurosta

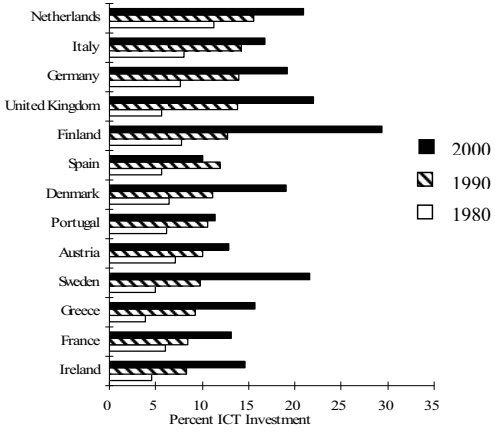


Figure 2: The ICT Investment as a Percentage of None-residential Gross Fixed Capital Formation, Data from OECD

In the second decade (1990-2000), all of the countries still had improvement on ICT investment with the exception of Spain, the average improvement (51.6%) was less than the first decade. Finland, Sweden and Ireland had the largest improvement, while Spain, Portugal and Austria had the smallest improvement.

The Relationship between Construction Productivity Improvement and ICT Investment Improvement

The authors plotted the construction productivity improvement in 1999 to 2005 versus the ICT investment improvement in the periods 1980-2000, 1980-1990, and 1990-2000 (Figures 3, 4 and 5).

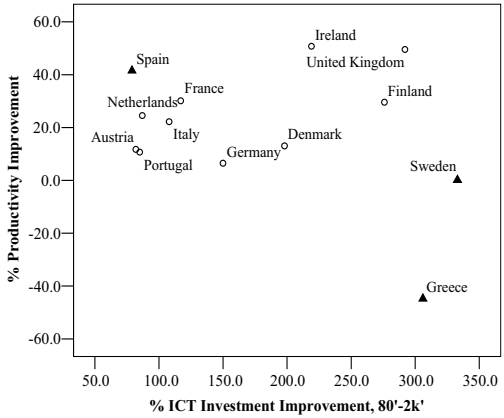


Figure 3: Scatter plot of Productivity Improvement (1999-2005) Vs. ICT Investment Improvement 1980-2000 (Note: outliers are solid black triangles)

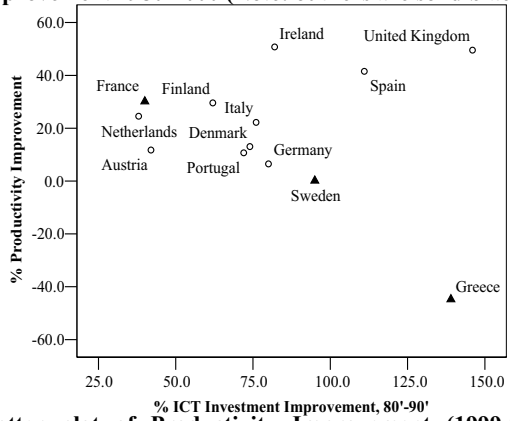


Figure 4: Scatter plot of Productivity Improvement (1999-2005) Vs. ICT Investment Improvement 1980-1990 (Note: outliers are solid black triangles)

In Figure 3, Ireland, United Kingdom and Finland had large productivity improvements with large ICT investment improvements, while Austria and Portugal had small productivity improvements with small ICT investment improvements. Sweden, Greece and Spain appear to be the "outliers" in this plot, where productivity improvement cannot be observed to have any positive relationship to the ICT investment improvement from 1980 to 2000. Herein the outlier is defined as the point that does not support the hypothesis in this paper. The authors knowledge that there are statistical methods that can identify outliers, but they were not used in this paper due to the small sample size. In Figure 4, the scatter plot of productivity

improvement versus ICT investment improvement from 1980 to 1990 showed a similar pattern as Figure 3, with Greece, Sweden and France as the outliers.

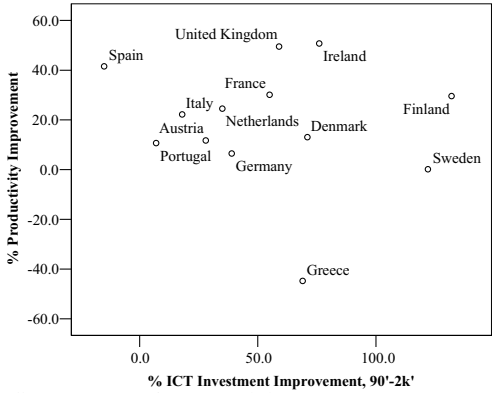


Figure 5: Scatter plot of Productivity Improvement (1999-2005) Vs. ICT Investment Improvement 1990-2000

It is noted that in Figure 4, Spain had a large improvement on construction productivity with a large improvement on ICT investment from 1980 to 1990. This may indicate that the Spanish construction productivity improvement from 1995 to 2005 was impacted by the ICT investment improvement in the period of 1980 to 1990 rather than 1990 to 2000. In fact, from 1990 to 2000, the ICT investment decreased in Spain as described above, which could explain why Spain was the Outlier in Figure 3.

In Figure 5, no pattern can be observed in regards to the relationship of construction productivity improvement to ICT investment improvement from 1990 to 2000. This apparent lag in ICT investment and any relation with construction productivity improvement demonstrate the necessary prolonged return period with ICT investment as described previously in the paper.

It may be worthy to investigate why Sweden and Greece were outliers in Figures 3 and 4. Obviously, there are other factors that may have impacted these countries' construction productivity improvement outside of IT usage. Since no other factors were investigated in this study, the authors plotted the productivity improvement versus ICT investments in 1980, 1990 and 2000 rather than the ICT investment improvement over consecutive time periods (Figures 6, 7 and 8). No patterns can be observed in Figure 6 and 8, which plotted the construction improvement versus ICT investment in 1980 and 2000. This may indicate that the ICT development levels in 1980 or 2000 were too far or too near to impact the construction productivity in the period from 1999 to 2005. An encouraging pattern can be observed in Figure 7 where Greece and Sweden are no longer the outliers in this figure. The two countries had low construction productivity improvements, along with low ICT investments in 1990. This may indicate that although the two countries experienced large ICT investment improvement in 1980-1990, the improved ICT investment was not high enough to boost the country's construction

productivity. But in Figure 7, Ireland and France became new outliers, which cannot be explained by the analysis in this paper.

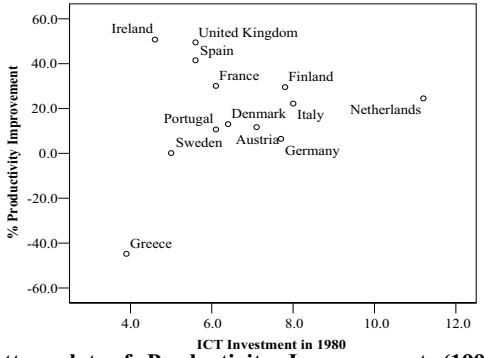


Figure 6: Scatter plot of Productivity Improvement (1999-2005) Vs. ICT Investment in 1980

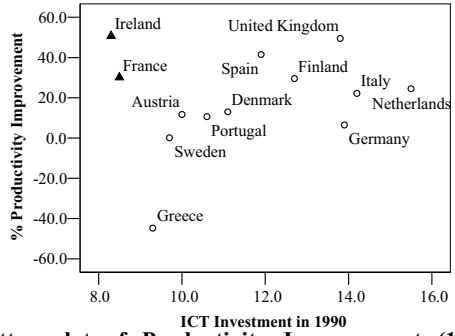


Figure 7: Scatter plot of Productivity Improvement (1999-2005) Vs. ICT Investment in 1990 (Note: outliers are solid black triangles)

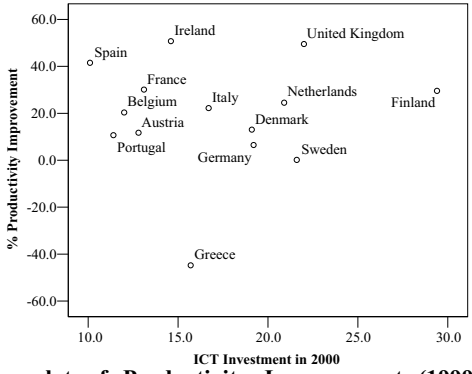


Figure 8: Scatter plot of Productivity Improvement (1999-2005) Vs. ICT Investment in 2000

CONCLUSIONS

These analyses and discussion contribute to the body of knowledge with regard to the relationship of construction productivity to information technology development in two areas:

1. A simple positive relationship of construction productivity to information and communication technology investment can be observed in the country-level, although the relatively small sample size of the sampled countries prevented any robust statistical analysis of this finding.

2. A gap between construction productivity improvement and information technology investment existed, which was observed to be in 10 year time frame in this research (Figure 7).

RECOMMENDATIONS

Future research is needed to investigate more indicators to develop a comprehensive assessment of information technology application and development. In addition, the national IT development level cannot fully represent IT application in the construction industry with the data herein, but the methods of analysis could be applied elsewhere if a larger dataset could be obtained. To examine the more precise relationship of information technology to construction productivity, more construction-specific data is needed and warranted in future research efforts.

REFERENCES

Balli, N.A.. (2002). "Handheld Computer Applications for the Tier II Construction Worker" MS Thesis, The University of Texas, Austin, Texas.

Brynjolfsson, E. and Hitt, L (1993), "Is Information Systems Spending Productive? New Evidence and New Results", The Proceedings of the 14th International Conference on Information Systems, Orlando, FL

Björk B. (1999). "Information Technology in construction: domain definition and research issues." International Journal of Computer Integrated Design and Construction, SETO, London, May 1999, Vol.1, No. 1, pp. 3-16.

Dewan, S and Kraemer, K.L.(2000) "Information Technology and Productivity: Evidence from Country-Level Data," Management Science, Vol. 46, No. 4, pp. 548-562

Diewert, W. E and Smith, M. A., (1994), "Productivity Measurement for a Distribution Firm," National Bureau of Economic Research Working Paper, No. 4812, (July).

Ergen, E., Akinci, B., and Sacks, R. (2007). "Tracking and Locating Components in a Precast Storage Yard Utilizing Radio Frequency Identification Technology and GPS", Automation in Construction, ASCE, Vol. 16, Issue 3, May 2007, pp. 354-367

Griffis, F.H., Hogan, D. B., and Li, W. (1995). " An Analysis of the Impacts of Using Three Dimensional Computer Models in the Management of Construction." Research Rep. No.106-11, Construction Industry Institute (CII), Autin, Texas.

Gullickson, W. and Harper, M. (2002). "Bias in Aggregate Productivity Trends Revisited." Monthly Labor Review. U.S. Bureau of Labor Statistics. March 2002. pp. 32-40.

Eurostat, http://epp.eurostat.ec.europa.eu, 2008

O'Connor, J. and Yang, L., (2004), "Project Performance versus Use of Technologies at Project and Phase Levels", Journal of Construction Engineering and Management, ASCE, Vol. 130, No. 3, May/June 2004, pp. 322-329

OECD, http://www.oecd.org, 2008

Pieper, P. (1990). "The Measurement of Construction Prices: Retrospect and Prospect" in Berndt, E. and Triplet, J. Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth. The University of Chicago Press. Chicago, Illinois.

Rosefielde, S. and Mills, D. (1979). "Is Construction Technologically Stagnant?" in Lange, J. and Mills, D. The Construction Industry: Balance Wheel of the Economy. Lexington Books. Lexington, Massachusetts.

Siegel, D. (1994), "The Impact of Computers on Manufacturing Productivity Growth: A Multiple-Indicators, Multiple-Causes Approach," SUNY at Stony Brook Working Paper, (May).

Stokes, H. (1981). "An Examination of the Productivity Decline in the Construction Industry." The Review of Economics and Statistics. The MIT Press. 63(4), pp. 495-502.

Thomas, S., Lee, S., Spencer, J., Tucker, R., Chapman, R. (2004). "Impacts of Design/Information Technology on Project Outcomes" Journal of Construction Engineering and Management, ASCE, Vol.130, No.4. pp 586-597

Wood., C., and Alvarez., M. (2005). "Emerging Construction Technologies", A FIATECH™ Catalogue

CONSTRUCTION INDUSTRY PRODUCTIVITY: OMITTED QUALITY CHARACTERISTICS IN CONSTRUCTION PRICE INDICES

Bryan D. Dyer[1] and Paul M. Goodrum[2]

[1]Doctoral Student, Department of Civil Engineering, University of Kentucky, Lexington, KY 40506-0281, fax 270-393-7308, bryan.dyer@uky.edu
[2]Associate Professor, Department of Civil Engineering, University of Kentucky, Lexington, KY 40506-0281

Abstract
A fundamental challenge to the U.S. construction industry is the establishment of an accurate measure of the industry's productivity. The inability to accurately measure construction inflation is cited as a primary reason why the U.S. Bureau of Labor Statistics does not maintain an official productivity measure for construction (Dacy 1965, Gordon 1968, Rosefielde and Mills 1979, Pieper 1990, Gullickson and Harper 2002). Macroeconomic studies have shown a decline in construction productivity (Stokes 1981, BRT 1983, Allen 1985, and Teicholtz 2000), while micro studies have shown an increase (Allmon et al 2000 and Goodrum et al 2002). One theory to explain these opposing results is that current measurements of construction inflation do not adequately consider the change in quality and amenities provided in today's structures as compared to when the measurements were first established. An inflation index that is considered to be one of the industry's major measurements of construction inflation is the U.S. Census Bureau New One-Family Houses under Construction Price Index. In this paper, the writers present initial results of a larger study to examine the current hedonic regression model used by the Census Bureau to estimate this price index, which is used to help measure a significant proportion of the industry's real output. This study will compare the current hedonic model with a proposed model, which will include quality variables that are not part of the Census' current hedonic model. Previous research suggests that omitted quality variables in the Census' price index potentially leads to omitted variable bias which overestimates construction inflation leading to both an underestimate of construction industry output and productivity. However, previous research has not formalized necessary changes to the Census index to avoid this bias nor has the bias been actually measured in order to quantify its direction or magnitude. For this paper, price and quality data of new homes was collected from Multiple Listing Service data from Warren County, Kentucky for years 2002 through 2007, which was provided by the local Board of Realtors. The data was compiled to determine the frequency of additional quality characteristics currently not measured by the Census Bureau. By

identifying quality characteristics that occur at a high frequency that are also not included in the current Census index for new homes, these results serve as a starting point for further research to determine if additional quality characteristics should be included in the model.

Introduction

In order to determine productivity growth in any field, an accurate measure of output is required. Heterogeneity in the construction industry creates a large problem when trying to develop a reliable form of output measurement. When construction productivity has been measured at the aggregate level, research has shown a decline in productivity by 0.72% annually compounded from 1968 to 2000 Teicholtz (2001). This finding was also supported in research conducted by Stokes (1981) and Allen (1985). Opposite results were found when productivity was measured at the activity level. Goodrum et al (2002) collected data on 200 activities using the Means, Richardson and Dodge estimation manuals from the years 1976 and 1998 and found an increase in construction productivity of 1.2% compounded annually. Along with other research that highlighted several of the weaknesses of existing industry measures of construction industry output (Rojas and Aramvareekul 2003), the need for additional research to understand how to accurately measure construction productivity at a macro level has been revitalized..

This paper examines the U.S. Census Bureau New Single Family Houses Under Construction Index and the variables it uses for measurement. The Census index is used to adjust the value of construction put in place to constant dollars (i.e. real value) on all residential buildings (Department of Commerce 1998). It is also used in conjunction with other indexes to measure real value on other non-residential building. If the index is not accurately measuring output relative to changes in quality over time it may potentially overestimate inflation and significantly contribute to a potential bias that suggests a decline in the industry productivity measures. Unfortunately, any potential bias in the measure of construction output, resulting from biases in the price indices, impacts a broad swath of construction. As a result of strong growth in residential and commercial construction, the Census Single-family Home index was used to adjust over 50% of industry output in 2007 which increased from 44% in 1979. As a starting point of examining a potential bias in the Census index, this paper examines the frequency of other quality characteristics which are currently not included. Many features in current homes were not common in homes built in 1963, the year the index was established. Since that time, the Census Bureau has made revisions to quality characteristics integrated into the model in 1974. However, today still over half of the new home characteristics in the Census index are based upon size and geographic location. To what extent the quality of new homes has changed since 1974 and the implications that these changes have on the Census index is the focus of this paper.

Lack of Quality Measurements in Construction Industry's Output

The primary measure of construction output is the Value of Construction Put in Place, which is maintained by the U.S. Census Bureau and used by other agencies such as the U.S. Bureau of Economic Analysis. The Census uses a variety of input

cost and output price inflation indices in order to measure industry real output. The input cost index deflates output on the assumption that a constant relationship exists between input and output; therefore, it also assumes that productivity is constant. If productivity increased, then the index would be biased upward (Pieper 1990). Many have found evidence that input cost indices in construction have overestimated construction inflation, therefore have underestimated real output, and have also understated labor productivity (Dacy 1965, Gordon 1968, Rosefielde and Mills 1979, and Allen 1985). Although the Census' use of input cost indices has diminished over time, 23% of total industry output was controlled for inflation using input cost indices in 2003.

Being the preferred price index, the Census Single-Family Houses Under Construction index still potentially ignores changes in the quality of construction. The Census annually collects data on the sales price, lot value, and house characteristics of approximately 19,000 speculatively built single-family homes. Based on a hedonic regression model, the index is calculated when the sales price less the estimated lot value is regressed on thirteen housing characteristics(square feet of floor area, number of bedrooms, number of bathrooms, type of parking facility, type of foundation, number of fireplaces, presence of a deck, presence of a patio, construction method, primary exterior wall material, type of heating and air condition type, metropolitan location, and geographical location) which is shown in equation 1. Most of the characteristics were based on a 1963 model home. In the 1963 model index only 8 variables (floor area, number of stories, number of bathrooms, presence of central air conditioning, type of parking, type of foundation, geographic region, and metropolitan area) were used in the regression index and then were revised in 1974 with the addition of lot size and presence of a fireplace. Since that time, the Census Bureau has made some effort to refine the model by dividing it into two indexes: the Single-Family Under Construction and Single-Family House Sold index. The difference between the two indexes is the lot value, which is removed from the Under Construction index but is included in the Sold index. In addition, the characteristic divisions have been modified to accommodate the larger homes built today but the basic characteristics remain the same.

$$P_t = b_0 + b_{i,t}x_{i,t} + b_{i,t}x_{i,t} + \ldots\ldots + b_{n,t}x_{n,t} + u_1 \quad (1)$$

where:

P_t = price of house at time t (minus land value in the Under Construction index)

b_0 = constant variable

$b_{i,t}$= regression coefficient of variable i in year t (which would include $b_{\text{sft t}}$, $b_{\text{bedroom t}}$, $b_{\text{baths t}}$, $b_{\text{parking t}}$, $b_{\text{basement t}}$, $b_{\text{fireplace t}}$, $b_{\text{deck t}}$, $b_{\text{patio t}}$, $b_{\text{cont. method t}}$, $b_{\text{exterior wall t}}$, $b_{\text{type of heat and AC t}}$, $b_{\text{metro t}}$, and $b_{\text{geographic t,}}$)

u_1 = is the residual error term

Next, the regression coefficients are used to form three indexes. The first is the Laspeyres price index(constant quality). The Laspeyres price index is formed by multiplying the regression coefficients by the base year averages of the house characteristics thereby creating a ratio of what the average base year house(b) would cost in year(t) as shown in equation 2.

$$PI = \sum b_{i,t}\, q_{i,b} / \sum b_{i,b}\, q_{i,b} \quad (2)$$

Where:

LPI= Census Laspeyres price index:

$b_{i,t}$= regression coefficient of variable i in year t (as defined for equation 1);

$b_{i,b}$= regression coefficient of variable i in base year b (as defined for equation 1); and

$q_{i,b}$= mean of the independent variables in the base year(which would include $q_{\text{sft b}}$, $q_{\text{bedroom b}}$, $q_{\text{baths b}}$, $q_{\text{parking b}}$, $q_{\text{basement b}}$, $q_{\text{deck b}}$, $q_{\text{exterior wall b}}$, $q_{\text{type of heat and AC b}}$, $q_{\text{metro b}}$, $q_{\text{geographic b}}$)

The theory behind the Laspeyres price index is that it can be used to determine how much price increases are due to quality changes and how much are due to inflation. This is accomplished by keeping the housing qualities constant. Unfortunately, there are potential problems with this index. The first one is also its greatest strength, constant quality. As stated previously, since its conception in1963 very little change has been made to the qualities measured. If typical home characteristics change due to buyer preference or financial reasons, their effects will not be reflected in the index. The index also assumes that the same percent distribution of new home sales by geographical region as the base year. This assumption is based on the belief that all markets are relatively strong or weak at the same time, but in reality this is not the case. This index additionally does not account for adjustments in the market due to consumer overspending and market adjustments, as experienced in the last two years.

The second price index, which is not published, is the Paasche Index (Output Deflator). While the Laspeyres index tries to answer the question "How much is the sales price today for the same quality house as in the base year?" The Paasche index try's to answer the question "What is the difference in price in today's house in today's dollars versus the price for the same house in the base year dollars?" It differs from the from the Laspeyres index by using the mean value of the current year with the regression coefficients from the base and current year as shown in equation 3.

$$PPI = \sum b_{i,t}\, q_{i,t} / \sum b_{i,b}\, q_{i,t} \qquad (3)$$

Where:

PPI= Census Paasche price index

$b_{i,t}$ and $b_{i,b}$ are defined as before; and

$q_{i,t}$= mean of the independent variables in the year t (which would include $q_{\text{sft t}}$, $q_{\text{bedroom t}}$, $q_{\text{baths t}}$, $q_{\text{parking t}}$, $q_{\text{basement t}}$, $q_{\text{deck t}}$, $q_{\text{exterior wall t}}$, $q_{\text{type of heat and AC t}}$, $q_{\text{metro t}}$, $q_{\text{geographic t}}$)

The potential problem with the Paasche Index is that it does not hold quality constant between the base year and the *t* year. If cheaper options are chosen to make the house cost more affordable or if there is a correction in the market house prices, either change will not be reflected in the index. This in turn will have a tendency to underestimate inflation.

The Census Bureau attempts to remove the potential bias created by the two above mentioned indexes by publishing a third index called the Fisher Ideal Index (Price Deflator). The Fisher Ideal Index is a geometric average of the Laspeyres and Paasche Indexes. This is shown in equation 4.

$$(\text{Laspeyres} \times \text{Paasche})^{\wedge 1/2} = \text{Fisher} \qquad (4)$$

The Fisher index is intended to reduce the potential upward inflation bias of the Laspeyres index and at the same time, minimize the potential understated inflation of the Paasche index. It is based on the premise that the first two indexes are measuring the correct quality characteristics. Another problem with this index is that it cannot determine how much of the change in price is due to inflation and how much of the change is due to quality, since quality measures are not directly linked to the base year in both indexes (Census Bureau 2005a).

When a closer look is given to each of the three indices, the independent variables used to measure quality are not necessarily true quality variables. Over half of the variables are based upon size and geographical location. The Census index does not include measures for the quality of materials or design amenities (e.g., appliances); flooring; energy efficiency improvements (e.g., heat pumps, air circulation systems, heated floor slabs); code-mandated improvements in electrical system, seismic and windstorm resistance, sustainability enhancements (e.g., environmentally friendly materials, pollution reduction, landscaping), and improvements in indoor air quality. In theory, regression coefficients in the hedonic model (equation 1) will measure the price of the independent variable plus the value of correlated omitted quality characteristics. Ultimately, this omitted variable bias may produce overestimates of inflation by Laspeyres price index and likewise underestimates of construction output. This is especially true if there is extensive growth in omitted quality characteristics, which does appear to be the case. The Census Bureau itself only claims to account for 60 to 80 percent of the variation in the logarithm of the price through its indices (Census Bureau 2005b). If it is 60 percent, then unmeasured qualities could make up a portion of the additional 40 percent.

Data Source

Research data was collected from the Multiple Listing Service (MLS) from the board of realtors in Bowling Green, Kentucky. The MLS is a computer-based service that provides real estate professionals with detailed listings of most homes currently on the market. When a realtor signs a contract to sell a house, an MLS data sheet is completed so the property being sold will be advertised on the national level via the Internet. On a standard MLS data sheet, general information about the house is reported which includes: bonus room, basement, lot size, school district, number of bedrooms with sizes, presence of a master bedroom with dimensions, living room, family room and kitchen with dimensions, number of stories, number of full and half baths, and above and below ground square footage. In addition to this information, the MLS data also reports featured information which includes: style of home, exterior finish, storm doors/windows, roof type, foundation type, type of heat and air conditioning, source of water and wastewater, fireplace, type of flooring, window treatments, kitchen features including appliances, bathroom features, and type of garage. Additional interior features include: smoke alarms, garage door openers, walk in closets, attic storage, bookshelves, closet lights, and presence of a pantry. Finally, additional exterior features are also listed including: type of drive, presence of a patio, landscaping, exterior lighting, pool or hot tub as well as others.

While the MLS data is recorded for all houses sold, this study focuses only on newly constructed houses. The purpose for this is to stay consistent with the Census Bureau. Information gathered from the data also includes the standard information gathered by the Census Bureau, as well as other quality characteristics. These include the following: presence of porch, thermal pane windows, type of roof, type of sewer, type of floor coverings, list of kitchen appliances, presence of whirlpool tub and separate shower, walk- in closets, smoke alarms, tray or vaulted ceilings, pantry, landscaping, exterior lighting, security system, concrete or asphalt drive, surround sound wiring, computer wiring, cable, fence, pool or hot tub, additional energy features and school district. All of the above mentioned would add additional cost to the house, many of which were not options when the Census Bureau identified its criteria.

Assumptions are being made regarding the overall accuracy of the MLS data. One assumption is that the realtors have the incentive to list as many quality features available in new homes in order to sell the home; therefore, if it was not listed, it was not present. Another assumption is that homes listed in the MLS are speculative built homes. Custom built homes typically will not have an MLS data sheet, due to the fact the home owner will go directly to the home contractor to purchase the home, without the use of a realtor. Custom built homes are predominantly the more expensive homes. This is represented in the results (Tables 1 and 2), which shows very few homes over $300,000.

Results

Table 1 reports the characteristic frequencies from homes sold between the years of 2002-2004. Table 2 reports the characteristic frequencies from homes sold between the years of 2005-2007. Tables 1 and 2 report the frequencies based upon price range of homes. The home prices are separated as follows: <100k, 100-200k, 200-300k, 300-400k and > 400k. This was compiled in an effort to see if certain characteristics are more prevalent in certain price range homes. Table 2 also reports the overall frequency of these characteristics from the entire data sample. The characteristics currently measured by the Census Bureau are on the upper portion of each table and the additional characteristics are on the lower portion of each table. The characteristics the Census Bureau measures (house square foot, number of bedrooms, number of bathrooms, number of garages, presence of a fireplace, presence of deck and or patio, exterior wall type, number of stories, and type of heating and air-conditioning) occur frequently among the homes in the sample data. Some vary with price while others remain consistent among all price range homes. For example, lower price range houses tend to have vinyl siding while the more expensive homes tend to have brick. Other quality characteristics, for example air conditioning, remain relatively consistent across all price ranges. More than 80% of all homes were equipped with central heat and air conditioning. The heating type from natural gas to electric tends to vary with price range. Other frequency characteristics measured, which are included in the Census indices, may vary in other geographical regions. For example, Bowling Green is located in an extremely Karst geographical area, therefore rock is relatively close to the surface. Many homes are

placed on a crawl space rather than basements due to the cost of rock removal as shown in the data.

Some interior features not currently measured by the census bureau tend to increase with price, while others are consistent in all price ranges. Dishwashers are reported in 83.1 % of all of the homes surveyed. This supports previous research published data from the Census Bureau which reported that in 1990, 92% of all new homes included dishwashers, where as in 1974 only 65% of all new homes had contractor installed dishwashers (U.S. Dept. of Commerce). Other kitchen appliances such as stoves, garbage disposals and microwaves are all prevalent in the study but tend to vary with home prices. A far less frequent kitchen appliance was the refrigerator. Refrigerators were only installed in 9% of the homes in the sample.

Table 1: New Home Characteristics: 2002-2004

Year	2002					2003					2004				
Price Range	**<100k**	**100-200k**	**200-300k**	**300-400k**	**>400k**	**<100k**	**100-200k**	**200-300k**	**300-400k**	**>400k**	**<100k**	**100-200k**	**200-300k**	**300-400k**	**>400k**
Number of homes	18	45	4	1	3	10	109	6	2	0	49	271	77	7	1
Census Bureau Quality Characteristic															
Average SQFT	1282	1723	2975	4600	4600	1310	1557	2533.33	3900		1316	1704	2624.35	3592.86	4000
Bedrooms															
2 or less	0%	0%	0%												
3 bedroom	100%	80%	25%			100%	90%				98%	81%	33%		
4 bedroom	0%	20%	50%	100%	67%		9%	100%	100%		2%	19%	64%	100%	100%
more than 4	0%	0%	25%		33%		1%						4%		
Full Bathrooms															
1	6%	0%	0%								2%	0%	0%		
2	94%	93%	50%			100%	94%	17%			96%	89%	47%	14%	
3	0%	7%	50%		33%		6%	83%	50%		2%	10%	53%	71%	100%
4	0%	0%		100%	67%				50%			0%	0%	14%	
Half Bathrooms															
1	6%	9%	25%		67%	10%	3%	17%	50%		0%	8%	52%	71%	
2	0%	0%			33%		1%					1%	1%		
Fire Place	11%	73%	100%	100%		20%	66%	100%	100%		4%	66%	86%	100%	
Garages															
0	28%	0%				40%	1%				53%	0%	3%		
1	28%	11%				40%	2%	17%			37%	3%	84%		
2	44%	87%	50%	100%		20%	95%	67%	100%		10%	95%	13%	57%	
3 or more	0%	2%	50%		100%		2%	17%						43%	
Foundations															
full basement	28%	4%									2%	2%	1%	14%	
partial basement	6%	2%			33%		2%	17%				0%	4%		
crawl	67%	84%	100%	100%	67%	90%	91%	83%	100%		78%	92%	82%	86%	
slab	0%	0%					5%					70%	0%		
Deck	44%	11%	0%	0%	67%	40%	17%	33%	0%		35%	15%	16%	29%	
Patio	39%	67%	75%	100%	67%	30%	62%	83%	100%		27%	68%	60%	86%	
Exterior walls															
wood	0%	0%					2%				2%	0%	1%		
brick	11%	40%	100%	100%	100%	10%	47%	83%	100%		19%	41%	87%	100%	
AL. siding	0%	0%									2%	0%	1%		
Stucco	0%	0%									2%	1%	0%		
vinyl siding	72%	51%				80%	48%				61%	52%	0%		
stone	0%	0%											0%		
cement board	0%	0%						17%					0%		
Stories															
1	89%	89%		100%		100%	86%				92%	79%	8%	14%	
1.5		11%	75%				11%	50%	50%		4%	16%	62%	57%	
2			25%		100%		2%	50%	50%			1%	17%	29%	
Heating															
electric	44%	11%	100%	100%	100%	60%	12%	17%	100%		51%	24%	12%	14%	
natural gas	33%	80%				30%	84%	83%			20%	68%	77%	86%	
propane	6%											2%	0%		
Central Air	89%	91%	100%	100%	100%	80%	97%	100%	100%		76%	94%	88%	100%	
Unmeasured Quality Characteristic															
Thermal Windows	83%	91%	75%	100%	100%	90%	94%	83%	100%		70%	93%	90%	100%	
Carpet	89%	91%	100%	100%	67%	90%	95%	100%	100%		76%	92%	90%	100%	
Vinyl	78%	36%	100%	100%	0%	70%	45%	0%	0%		63%	42%	4%		
Hardwood	0%	67%	100%	100%	67%	0%	69%	100%	100%		10%	56%	87%	100%	
Ceramic Tile	0%	53%	75%	100%	67%	10%	49%	83%	100%		6%	52%	88%	100%	
Refregirator	6%	9%	0%	0%	100%	10%	2%	17%	50%		10%	4%	1%	29%	
Stove/oven	89%	89%	100%	100%	100%	70%	94%	100%	100%		65%	91%	87%	100%	
Dishwasher	89%	80%	100%	100%	100%	90%	95%	83%	100%		55%	88%	86%		
Garbage-disposal	17%	67%	100%	100%	100%	20%	66%	67%	100%		18%	59%	61%	71%	
Microwave	33%	82%	100%	100%	100%	30%	83%	83%	100%		29%	82%	84%	86%	
Whirlpool tub	0%	56%	75%	100%	100%	0%	59%	67%	100%		6%	63%	90%	100%	
Separate Shower	0%	51%	75%	100%	100%	10%	55%	33%	100%		2%	58%	81%	86%	
Smoke alarms	72%	84%	100%	100%	100%	80%	88%	67%	100%		59%	86%	81%	57%	
Tray/vaulted ceiling	56%	67%	75%	100%	67%	40%	73%	50%	100%		22%	74%	82%	71%	
Landscaping	28%	80%	100%	100%	1000%	30%	84%	67%	100%		22%	73%	77%	71%	
Exterior-lighting	56%	68%	100%	100%	100%	10%	79%	33%	100%		16%	77%	68%	71%	
Cable	56%	87%	100%	100%	100%	50%	91%	83%	100%		51%	80%	84%	71%	

Frequency of type of interior finish varied with price. In the lower-priced homes, floor coverings tended to be predominantly carpet and vinyl while the higher-priced homes had hardwood and tile. Additional framing features also had a higher frequency in the higher-priced homes. In 2006, homes price above $200k had walk

in closets 97% of the time, while homes less than $200k had walk in closets only 70% of the time. Likewise with tray or vaulted ceilings, homes priced over $200k had them 78% of the time and homes less than $200k had them 60% of the time. Other interior features were also more prevalent as the price increased which included: whirlpool tubs, separate showers, and pantries.

Table 2: New Home Characteristics: 2005-2007

Year	2005					2006					2007					
Price Range	<100k	100-200k	200-300k	300-400k	>400k	<100k	100-200k	200-300k	300-400k	>400k	<100k	100-200k	200-300k	300-400k	>400k	Overall
Number of homes	45	296	115	13	11	43	309	108	16	10	27	286	94	15	7	2019
Census Bureau Quality Characteristic																
Average SQFT	1211.11	1632.09	2505.87	3232.69	4006.52	1100	1523.06	2412.73	3046.88	3770.05	1033.33	1538.99	2374.2	3078.33	4535.71	1825.1
Bedrooms																
2 or less	4%	1%				30%	1%				44%	1%	4%			2%
3 bedroom	87%	89%	40%	15%	9%	70%	93%	46%	31%		56%	94%	49%	40%		75%
4 bedroom	7%	10%	57%	85%	64%		6%	52%	56%	100%		5%	46%	47%	43%	22%
more than 4	2%	1%	3%		27%		0%	2%	13%				1%	13%	57%	1%
Full Bathrooms																
1	20%	1%				33%	0%				56%					2%
2	80%	93%	52%	31%		67%	96%	60%	19%		44%	98%	63%	53%		81%
3		7%	48%	54%	73%		3%	40%	81%	40%		2%	36%	40%	57%	15%
4				15%	27%					60%			1%	7%	43%	1%
Half Bathrooms																
1	4%	6%	38%	62%	91%	2%	7%	44%	44%	70%	19%	5%	43%	67%	100%	16%
2			1%	8%	9%				6%			0%		7%		1%
Fire Place	9%	54%	92%	100%		0%	36%	91%	94%	70%		31%	88%	80%	86%	55%
Garages																
0																7%
1	31%	11%				40%	10%				56%	9%				9%
2	7%	85%	84%	69%	36%		86%	88%	50%	10%		87%	89%	67%	14%	78%
3 or more		1%	15%	31%	64%		1%	12%	50%	90%		0%	9%	33%	86%	6%
Foundations																
full basement	2%	3%	9%	8%	36%		2%	3%	13%	20%		2%	3%	13%	14%	3%
partial basement	2%	1%		8%			1%	1%	6%	20%		0%		7%		1%
crawl	91%	90%		85%	55%	77%	92%	95%	75%	50%	85%	87%	83%	67%	86%	88%
slab		0%	85%				0%				15%	3%	5%			1%
Deck	49%	17%	14%	39%	46%	42%	21%	7%	44%	10%	67%	25%	12%	20%	14%	20%
Patio	22%	64%	66%	62%	73%	7%	49%	69%	88%	70%	15%	48%	60%	53%	100%	56%
Exterior walls																
wood	7%	1%					0%						2%			1%
brick	11%	35%	72%	100%	73%		30%	71%	88%	80%	4%	29%	66%	73%	100%	42%
AL. siding	7%		1%				1%									0%
Stucco																10%
vinyl siding	69%	53%	4%			79%	54%	2%			93%	57%	3%			42%
stone																0%
cement board								1%								0%
Stories																
1	80%	72%	12%	8%		100%	88%	23%	13%		100%	80%	17%	7%		65%
1.5	11%	13%	61%	46%	55%		4%	57%	13%	20%		8%	26%	40%		19%
2		2%	19%	31%	27%		4%	13%	56%	40%		2%	38%	47%	71%	8%
Heating																
electric	62%	35%	10%	23%		74%	48%	11%	19%	10%	85%	53%	14%	27%	29%	33%
natural gas	24%	56%	79%	69%	91%	5%	37%	75%	38%	70%	4%	33%	67%	40%	71%	54%
propane	3%	1%											2%			1%
Central Air	84%	92%	90%	92%	82%	79%	89%	88%	56%	80%	96%	87%	85%	73%		89%
Unmeasured Quality Characteristic																
Thermal Windows	80%	90%	90%	100%	91%	77%	11%	84%	81%	50%	85%	90%	85%	80%	86%	88%
Carpet	91%	91%	92%	85%	91%	77%	85%	95%	81%	80%	93%	84%	89%	87%	86%	89%
Vinyl	87%	42%	4%	8%	9%	70%	44%	4%	0%	0%	74%	38%	3%			35%
Hardwood	9%	57%	90%	92%	91%	12%	48%	94%	81%	80%	30%	56%	89%	93%	100%	60%
Ceramic Tile	4%	50%	87%	100%	91%	9%	43%	95%	81%	80%	11%	52%	86%	93%		55%
Refrigirator	16%	9%	2%	15%	46%	21%	11%	6%	13%	50%	48%	8%	7%	7%	57%	9%
Stove/oven	80%	88%	89%	92%	91%	70%	85%	94%	81%	70%	89%	85%	87%	80%	86%	87%
Dishwasher	80%	85%	90%	92%	91%	61%	82%	90%	50%	70%	82%	81%	76%	73%	100%	83%
Garbage-disposal	20%	45%	72%	77%	82%	14%	44%	68%	56%	70%	37%	36%	62%	33%	71%	50%
Microwave	31%	74%	89%	100%	91%	30%	71%	84%	50%	70%	63%	77%	80%	67%	71%	74%
Whirlpool tub	0%	51%	87%	77%	82%	0%	30%	74%	44%	60%		28%	75%	60%	71%	49%
Separate Shower	0%	43%	80%	54%	64%	5%	27%	60%	44%	60%		29%	62%	53%	57%	44%
Walk-in closet	44%	74%	92%	100%	91%	35%	70%	97%	81%	70%	48%	75%	89%	93%	100%	76%
Smoke alarms	71%	77%	84%	92%	91%	40%	75%	84%	75%	80%	52%	78%	83%	67%	100%	79%
Tray/vaulted ceiling	29%	66%	77%	85%	64%	23%	60%	78%	69%	50%	33%	64%	63%	60%	57%	64%
Landscaping	31%	71%	79%	69%	82%	21%	60%	71%	50%	70%	48%	54%	68%	53%		64%
Exterior-lighting	24%	61%	70%	54%	73%	26%	50%	57%	25%	60%	33%	54%	48%	53%	71%	58%
Cable	56%	73%	76%	77%	91%	35%	71%	58%	44%	40%	82%	66%	60%	33%	57%	72%

From the homes listed, 70.4% of the homes had cable TV, which indicates theses homes contained structural wiring to support the use of cable television. This percentage is higher than a previous report by Koebel et al 2004 which estimated it to be in 38% of all new single family homes. Other wiring features, such as security system, computer wiring and exterior lighting also increased in frequency as the price increased. The frequencies for computer wiring did not appear in any price range until 2005. This suggests the items being measured must be revisited on a frequent basis because home characteristics continue to change. Many of the features such as microwaves and whirlpool tubs were not in existence when the index was created in the 60's.

In all, the following unmeasured quality characteristics were the ten most frequent characteristics in new homes over all years and therefore are prime

candidates for further investigation regarding their inclusion into the Census' price indices: 1) Thermal windows, 2) Floor coverings, 3) Kitchen appliances, 4) Whirlpool tub, 5) Walk-in closets, 6) Smoke alarms, 7) Trey/vaulted ceiling, 8) Landscape, 9) Exterior lights, and 10) Cable. An ANOVA analysis was conducted on the top ten most frequent unmeasured characteristics as an initial step and the results are shown in Table 3. From the ten characteristics listed above only thermal windows, dishwasher, carpet, and cable television where not significant when mean home prices were compared for homes with and without the said characteristic. The remainder of the characteristics were statistically significant, thus more analysis is warranted to determine if they should be included the model the Census uses to adjust construction output.

Table 3: Anova Analysis of Home Characteristic vs Home Price

Variable	Mean Price With	Mean Price Without	Significance Level
Termal Windows	$ 167,886	$ 175,908	.137
Floor Covering			
Carpet	$ 169,478	$ 163,474	.267
Vinle	$ 120,647	$ 194,918	7.751E-107
Hardwood	$ 196,167	$ 127,273	4.016E-94
Tile	$ 202,018	$ 128,000	1.274E-114
Kitchen Appliances			
Refregirator	$ 183,664	$ 167,398	.011
Stove/Oven	$ 170,360	$ 158,783	.022
Garbage Disposal	$ 185,009	$ 152,348	5.174E-22
Dishwasher	$ 170,271	$ 161,486	.055
Microwave	$ 176,831	$ 145,642	6.944E-15
Wirlpool Tub	$ 200,976	$ 138,088	3.748E-82
Walk-in Closets	$ 179,543	$ 133,613	1.160E-29
Smoke-Alarms	$ 172,705	$ 154,525	.000
Trey/Vaulted Ceilings	$ 176,502	$ 154,783	1.096E-09
Landscape	$ 178,318	$ 151,473	3.774E-13
Exterior Lights	$ 176,126	$ 158,684	4.601E-07
Cable Television	$ 168,752	$ 172,634	.503

Conclusions

Some level of bias in the construction industry indices is known; however, the amount and source of bias is unknown. Not knowing the magnitude of this bias creates measurement problems in a number of areas in construction and construction productivity. Quality characteristics examined in this study, as well as others not listed, have not been measured to determine the impact on the bias current construction price index models. In 2007, the Census Single-Family Homes under construction index was used to deflate 51% of the value of construction put in place. Given the fact that in 2006 the construction industry comprised 4.9% of the gross

domestic product (Chapman et al 2008 and BEA 2008), it is important to have an accurate measurement of output. The characteristics listed in this study may or may not change the current index models accuracy. However, with the high frequency of quality characteristics reported, research efforts are warranted to determine if they create omitted variable bias in published aggregate output data.

REFERENCES

Allen, Stephen G. (1985), "Why Construction Industry Productivity is Declining." The Review of Economics and Statistics. The MIT Press, 117(4), pp. 661-665.

Allmon, E., Haas, C., Borcherding, J., Goodrum, P. (2000) "U.S. Construction Labor Productivity Trends, 1970-1998." Journal of Construction Engineering and Management. ASCE, 126(2). pp. 97-104.

Bureau of Economic Analysis (BEA). (2008), "Gross-Domestic-Product-(GDP)-by-Industry Data." Industry Economic Accounts, Bureau of Economic Analysis, Washington.

Business Roundtable (BRT). (1983) "More Construction for the Money: Summary Report of the Construction Industry Cost Effectiveness Project" (1983). The Business Roundtable. New York, New York.

Chapman, Robert E., Butry, David T.(2008) "Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities" Buildings and Fire Research Laboratory, National Inst. of Standards and Technology, Gaithersburg, MD

Dacy, D. (1965). "Productivity and Price Trends in Construction since 1947". Review of Economics and Statistics. Vol. 47. (November).

Goodrum, P., Haas, C., and Glover, R. (2002). "The Divergence in Aggregate and Activity Estimates of U.S. Construction Productivity." Journal of Construction Management and Economics. E. & F. N. Spon. 20(5). pp. 415-423.

Gordon, R. (1968). "A New View of Real Investment in Structures, 1919-1966. *Review of Economics and Statistics*. 50(4). pp. 417-428.

Gullickson, W. and Harper, M. (2002). "Bias in Aggregate Productivity Trends Revisited." *Monthly Labor Review*. U.S. Bureau of Labor Statistics. March. pp. 32-40.

Pieper, P. (1990). "The Measurement of Construction Prices: Retrospect and Prospect" in Berndt, E. and Triplet, J. *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth*. The University of Chicago Press. Chicago, Illinois.

Rojas, M., and Aramvareekul, P. (2003). "Labor Productivity Drivers and Opportunities in the Construction Industry," *Journal of Construction Engineering and Management*, ASCE, 19(2), 78-82.

Rosefielde, S. and Quinn Mills, D. (1979). "Is Construction Technologically Stagnant?" in Lange, J. and Mills, D. *The Construction Industry: Balance Wheel of the Economy*. Lexington Books. Lexington, Massachusetts.

Stokes, H. (1981). "An Examination of the Productivity Decline in the Construction Industry." *The Review of Economics and Statistics*. The MIT Press. 63(4), pp. 495-502.

Teicholtz, P. (2000). "Productivity Trends in the Construction Industry." Presentation to the 2000 AISC Annual Convention. San Francisco, California. October, 2000.

U.S. Census Bureau(2005a) "General Information About The Price Index" U.S Department of Commerce, Bureau of Census Washington, DC.

U.S. Census Bureau(2005b) "Definitions, Limitations, and Miscellaneous Statistical Methodology" U.S Department of Commerce, Bureau of Census Washington, DC.

U.S. Department of Commerce Characteristics of New Housing, Construction Report Series C25, US Department of Commerce, Washington, DC.

MEASURING CONSTRUCTION PRODUCTIVITY USING THE WRITE SYSTEM

Seonghoon Kim[1]; Yong Bai[2]; Luke Huan[3]; and Abhinav Peddi[4]

ABSTRACT

To overcome the limitations of existing on-site construction productivity measurement techniques, a **w**ireless **r**eal-t**i**me produc**t**ivity m**e**asurement (WRITE) system was developed. Major components of the WRITE system include a digital camera, a video camera, a data processor, an AC transformer, a computer, and wireless modems. Researchers developed the framework of the WRITE system first. Then, a prototype of the system was built in the laboratory. Finally, the prototype system was tested for accuracy in three highway projects. Statistical analysis results proved that the developed system generated identical productivity measurements compared to the stopwatch method. The WRITE System has several unique advantages. First, there is no disruption to construction operations. Second, the on-site construction productivity can be determined in real-time so that the project manager will be able to take action immediately if necessary. Third, the collected data can be shared by all parties in the construction project via the Internet at any time and at any location. These advancements help to enhance the contractors' capability of managing construction projects.

INTRODUCTION

[1] Ph.D. Candidate, Department of Civil, Environmental, and Architectural Engineering, University of Kansas, 2160 Learned Hall, Lawrence, KS 66045; PH (785) 864-2598; FAX (785) 864-5631; E-mail: steve072@ku.edu

[2] Associate Professor, Department of Civil, Environmental, and Architectural Engineering, University of Kansas, 2135-B Learned Hall, Lawrence, KS 66045; PH (785) 864-2991; FAX (785) 864-5631; E-mail: ybai@ku.edu

[3] Assistant Professor, Department of Electrical Engineering and Computer Science, University of Kansas, 2034 Eaton Hall, Lawrence, KS 66045; PH (785) 864-5072; FAX (785) 864-3226; E-mail: jhuan@ittc.ku.edu

[4] Research Assistant, Department of Electrical Engineering and Computer Science, University of Kansas, 2001 Eaton Hall, Lawrence, KS 66045; PH (785) 864-4620; FAX (785) 864-3226; E-mail: abhinav@ku.edu

Productivity has been widely used as a performance indicator to evaluate construction operation throughout the entire phase of construction. Construction companies must continuously track productivity in order to gauge their performance to maintain profitability and to prepare future biddings (Ghanem and Abdelrazig 2006). Over the years, several productivity measurement techniques have been developed, including stopwatch study, photographic, time-lapse, and others (Fondahl 1960; Oglesby et al. 1989; Abudayyeh 1997; Everett and Halkali 1998; Noor 1998; Abeid and Arditi 2002; Peyret and Tasky 2002; Memon et al. 2005; and Navon and Shpatnitsky 2005). Stopwatch study, also known as time study, has been used as the fundamental approach to measure productivity since its invention in 1880 by Frederick W. Taylor, the father of scientific management (Meyers 1992). This is the oldest and most simple measurement method of productivity for recording the duration of various construction activities (Oglesby et al. 1989).

All available productivity measurement methods have some common limitations. First, these methods are unable to provide data for engineers and project managers to analyze the on-site construction productivity in real-time. Thus, actions to address the on-site productivity problems cannot be taken just in time. Second, current methods do not provide a platform to share the real-time productivity data among owner, engineers, contractors, and material suppliers. As a result, opportunities to improve construction operations are lost. To address these shortfalls, there is an urgent need to develop new technologies to measure the on-site construction productivity.

RESEARCH OBJECTIVES AND METHODOLOGY

The primary goal of this research project was to develop a **w**ireless **r**eal-**t**i**m**e produc**t**ivity m**e**asurement (WRITE) system that is capable of collecting on-site construction productivity data without interfering with construction operations and sending the collected data via a wireless network to a project manager or engineer miles away from the job site for analysis. The data can also be shared by the owner, engineers, contractors, and material suppliers as long as they have Internet service at their locations. This goal was realized through achieving the specified research objectives that are described as follows:

1. To build the WRITE System by identifying the key components and their connections.
2. To design field experimental procedures to test the accuracy of the WRITE System.
3. To conduct field experiments including data collection and analysis.
4. To identify the needs for future research.

The specified research objectives were accomplished in the manner explained below. The first phase of this research project was an extensive literature review. The literature survey included construction productivity measurement methods and statistical theories. The second phase of this project was to develop the WRITE System. Researchers first identified the necessary hardware and software that were

required to build the WRITE System. Then, a framework that showed the connection of components was developed. Finally, researchers purchased the required hardware and software and built the system. The developed WRITE System was tested to determine its accuracy in the construction sites, which was the third phase of the project. Productivity measurements produced by the WRITE System were compared with productivity measured by a stopwatch. Researchers were trying to determine whether the measurement results produced by these two methods were statistically the same. In order to make the comparison, researchers designed field experiments which included experimental site selection, experimental layout, data collection procedure, and data analysis methods. Based on the procedure developed at the experimental design stage, field experiments were conducted at three highway construction sites. Productivity data was collected using the WRITE System and the stopwatch method simultaneously. Researchers utilized the Statistical Analysis System (SAS®) to analyze the collected data. Statistical analysis methods, such as the hypothesis test, the paired t-test, and the Wilcoxon Signed Rank Test, were conducted to systematically compare experimental data collected by these two methods.

The rest of the paper is organized as follows. First, the writers will describe the development of the WRITE System. Second, the field experiment design will be outlined, followed by data collection and data analyses. Finally, conclusions, contributions, and recommendations for the future will be presented.

DEVELOPMENT OF WRITE SYSTEM

The WRITE System can provide pictorial data via a wireless network so that anyone in the construction field office or home office can monitor construction activities and analyze productivity in real-time as long as there is an Internet service available at the location. The WRITE system is composed of four major components that are shown in Figure 1. Their functions are briefly described as follows:

1. Pan/Tilt Camera Housing (upper right in Figure 1): This steel box contains a digital camera and a video camera which are connected to the data processor. The video camera can take up to 30 pictures every second, and the digital camera can take high-resolution pictures of seven mega pixels. The camera housing is weatherproof and vandalism-resistant. It is mounted on a rugged 360° outdoor pan/tilt unit which can be attached to a pole, wall, or pedestal mount.
2. Data Processor (the second item from the left in the first row in Figure 1): The data processor, also known as a biscuit computer or mini computer, contains a program called VM95 that can control the camera housing movement, the number and duration of shots, and the zooming.
3. AC Transformer (the first item from the left in the first row in Figure 1): This device transfers electric energy to other circuits. The transformer unit should be mounted close to the AC power source. One end of a phone line plugs into a jack inside the transformer box, and another end of the phone line plus the low voltage AC line pass through the transformer to the data processor box.

The maximum length of cable is 100 meters. The transformer box can be mounted indoors or outdoors and can be mounted to a wall or pole.

4. Computer: This is a necessary item for anyone who wants to view the pictorial data at a different location via a wireless modem or a local area network (LAN). If the computer is equipped with VW View software, the cameras can be controlled with such adjustments as zoom in and zoom out.

Besides these major components, additional items are also required to operate the system. They include wireless modems, a generator to provide electricity at the job site, a steel pole to mount the camera box, and cables to connect the components.



Fig. 1. Major components of the WRITE System

Figure 2 presents the framework of the WRITE System that was developed during the process of this research project. Once the video camera takes pictures from the construction site, the data processor immediately saves the pictorial data into files. Then, these files are transmitted in real-time via a wireless modem. An engineer or a project manager can access the data files via a wireless modem or a LAN with the IP address at another location to conduct productivity analysis using a computer with VM View software. After finishing the data analysis, productivity data and live pictures are presented in a website so that other users such as the owner, engineers, contractors, and material suppliers can share the information.

FIELD EXPERIMENTS

After building the WRITE System, researchers conducted field experiments to test the developed system in three highway construction projects. The objective of these experiments was to determine whether the WRITE System is an accurate tool for measuring on-site construction productivity. To accomplish the objective, productivity data were collected simultaneously using a stopwatch and the WRITE System. The results of the two techniques were compared using statistical methods to determine if there was a significant difference between them. Due to the resource constraints, the system was only tested in the highway construction projects.

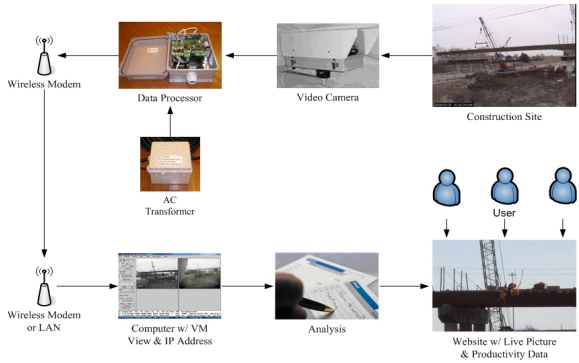


Fig. 2. Framework of the WRITE System

Three highway projects were selected with the help from engineers at the Kansas Department of Transportation. One project was a hot-mixed-asphalt (HMA) overlay project and the other two were hot-in-place recycling (HIR) projects. The HMA overlay project was carried out by paving a net length of 14.8 kilometers with a thickness of 3.8 centimeters and a width of 9.4 meters on US 36 near Washington, KS. Major construction operations included milling, bituminous overlay, and shoulder rock. Productivity data were collected on the overlay operation for four days from June 18 to June 21, 2007. Two HIR asphalt rehabilitation projects were carried out on K-192 near Winchester, KS and K-16 near Tonganoxie, KS. Total length of highway was 38.3 kilometers. Productivity data were collected for ten days from July 9 to July 20, 2007.

DATA COLLECTION

Two different data collection methods were employed: the stopwatch method (shown in Figure 3) and the WRITE System method (shown in Figure 4). The stopwatch method was used to measure the cycle times of construction operations, and the results were immediately recorded onto the data collection form at the job sites. Then, data were converted to productivity data in the office. The WRITE System recorded construction operations in video pictures, and then the researchers converted picture data to productivity data.



Fig. 3. Time study using a stopwatch



Fig. 4. Time study using the WRITE

DATA ANALYSES

Three statistical analysis methods were employed for the data analyses. First, data normality tests were performed to determine whether data had a normal distribution since data normality was a required assumption for the hypothesis test. Second, a paired t-test was conducted as a parametric test to compare two dependant variables (two productivity measurements) when data had a normal distribution, and a nonparametric test, the Wilcoxon Signed Rank test, was carried out where data did not have a normal distribution. Finally, the variability of the two productivity measurements was compared by using the t-statistic (only for HMA overlay data analyses).

HMA Overlay Operations

In the paired t-test, an important assumption is that sample means follow a normal distribution. Four normality tests (Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling) were conducted to determine normality. As shown in Table 1, all computed p values were greater than the significance level of 5%: the null hypothesis that the sample follows a normal distribution was accepted. This means at the significance level of 5%, the differences of cycle times for the HMA overlay operations measured by the stopwatch and the WRITE System were normally distributed. Therefore, it was concluded that the paired t-test could be conducted to analyze the data.

Table 1. Tests for Normality for HMA Overlay Operations

Test	Statistic		p Value
Shapiro-Wilk	W	0.9506	0.6966
Kolmogorov-Smirnov	D	0.1878	0.1500
Cramér-von Mises	W-Sq	0.0491	0.2500
Anderson-Darling	A-Sq	0.2902	0.2500

Note: W (Shapiro-Wilk statistic); D (Kolmogorov-Smirnov statistic); W-Sq (W^2: Cramér-von Mises statistic); A-Sq (A^2: Anderson-Darling statistic).

Productivity data collected using two time-study methods on the HMA overlay operations were compared to determine whether means of these two groups of data were the same. The null hypothesis and alternative hypothesis for this analysis are as follows:

H_0: $\mu_1 = \mu_2$

H_1: $\mu_1 \neq \mu_2$

where μ_1 and μ_2 are means of cycle times for the HMA overlay operations measured by the stopwatch and the WRITE System, respectively. A cycle time is the sum of working time (applying hot mix asphalt to the desired width and thickness) and nonworking time (idle or waiting) of an asphalt paving machine. A total of nine

cycles was observed for the HMA overlay operations at the construction site. The standard deviation s_d is equal to 90.807 seconds, as shown in Table 2. $\bar{d} = 0.667$ and $t_{(0.025,8)} = 2.306$ were estimated.

$$t\ statistic = \frac{\bar{d} - 0}{s_d / \sqrt{n}} = \frac{0.667}{90.807 / \sqrt{9}} = 0.022$$

Table 2. Results of Paired t-test

Difference	D.F.	S.D.	S.E.	t value	$t_{critical}$	Pr. > |t|
Cycle Time	8	90.807	30.269	0.022	2.306	0.983

Note: D.F. (Degree of Freedom); S.D. (Standard Deviation); S.E. (Standard Error); Pr. (Probability).

Using the two-tail t test, the null hypothesis cannot be rejected at the significant level of 5% ($|t| = 0.022 < t_{(0.025, 8)} = 2.306$). This result indicated that statistically there was no difference between productivity measurements taken by the WRITE System and the stopwatch.

The concept of linear correlation was used to compare variances of paired measurements because two sample standard deviations were not statistically independent or they were linearly correlated. The sums and differences of the pairs are linearly correlated if the standard deviations are not equal (Bradley and Blackwood 1989). The statistical significance of the sample correlation was assessed using a t-statistic that tested the following hypothesis: H_0: $\rho = 0$ vs. H_a: $\rho \neq 0$, where ρ is the correlation coefficient for a population of pairs. The t-statistic for the two measurements was t = -0.998, as shown in the calculation below.

$$t = \frac{r(n-2)^{1/2}}{(1-r^2)^{1/2}} = \frac{-0.353(9-2)^{1/2}}{(1-0.353^2)^{1/2}} = -0.998$$

where the Pearson correlation coefficient r was –0.353.

Using a two-tail t test, the null hypothesis cannot be rejected at the significance level of 5% ($|t| = 0.998 < t_{(0.025, 7)} = 2.365$). This result indicated that statistically there was no difference between standard deviations of the productivity measurements taken by the WRITE System and the stopwatch.

HIR Operations

Four normality tests (Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling) were conducted to determine if differences in working time

follow a normal distribution. As shown in Table 3, all computed p values were lower than the significance level of 5%. Thus, the null hypothesis that samples follow a normal distribution was rejected at the significance level of 5%. This means at the significance level of 5%, the differences of cycle times for the HIR operations measured by the stopwatch and the WRITE System were not normally distributed. Therefore, it was concluded that a nonparametric test, the Wilcoxon Signed Rank Test, should be selected to analyze the data.

Table 3. Tests for Normality for HIR Operations

Test	Statistic		p Value
Shapiro-Wilk	W	0.2513	0.0001
Kolmogorov-Smirnov	D	0.5356	0.0100
Cramér-von Mises	W-Sq	4.3760	0.0050
Anderson-Darling	A-Sq	20.8139	0.0050

Note: W (Shapiro-Wilk statistic); D (Kolmogorov-Smirnov statistic); W-Sq (W^2: Cramér-von Mises statistic); A-Sq (A^2: Anderson-Darling statistic).

Productivity data collected using two time-study methods from two HIR projects were compared to determine whether means of these two groups of data were the same. The null hypothesis and alternative hypothesis for this analysis are as follows:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

where μ_1 and μ_2 are means of cycle times for the HIR operations measured by the stopwatch and the WRITE System, respectively. For HIR operations, a cycle time was defined as one hour of time of construction operation. A total of 60 cycles (hours) was observed for the HIR operations in two highway projects. Researchers determined the sum of working time and nonworking time (idle or waiting) for each cycle.

A nonparametric test, the Wilcoxon signed rank test, was utilized as an alternative to the paired t test. As shown in Table 4, test results indicated that the null hypothesis was accepted at the significance level of 5% because the computed p-value was greater than *a* value of 0.05. Thus, statistically, there was no difference in the means of two productivity measurements collected using the stopwatch and the WRITE System.

Table 4. Results of the Wilcoxon Signed-Rank Test

Test	Statistic		p Value
Signed-Rank	S	-4	0.2500

Note: S (Signed-Rank statistic)

CONCLUSIONS, CONTRIBUTIONS, AND RECOMMENDATIONS

Existing construction productivity measurement methods take longer time to transmit data and pose difficulties for sharing and communicating data among participants involved in construction operations. To address these shortfalls, the WRITE System has been developed using advanced technologies. Field experiments were conducted on three highway construction projects to determine the system's accuracy as an on-site construction productivity measurement tool. The WRITE system was compared with the classic productivity measurement method using the stopwatch. Statistical analysis results prove that the WRITE System produced identical productivity measurements compared to the stopwatch method on three highway construction projects. Thus, an advanced on-site construction productivity measurement method was invented using the wireless technologies and can be utilized by the construction professionals.

This research project made several major contributions to the advancement of knowledge in the construction industry. First, it advances the applications of wireless technologies in construction operations. Second, the developed WRITE System is capable of continuously collecting on-site construction productivity data so that engineers and/or project managers can determine productivity in real-time. Third, productivity data gathered by the WRITE System can be sent to a website so that owners, engineers, contractors, and material suppliers are able to share data and make necessary actions in real-time as long as they have Internet access at their locations. With these advancements, communication and coordination will improve at the construction site. Thus, the WRITE System will enhance the contractors' capability of managing construction projects.

This research can be extended in several ways. First, although the WRITE System is more advanced than the current productivity measurement methods employed in construction industry, engineers or project managers still need to interpret the live images acquired from the WRITE System to determine which actions are working. Because the process of determining working status is time-consuming and subject to human errors and biases, there is a need to develop an algorithm to automatically classify working or non-working actions based on human poses that are associated with construction activities so that misinterpretation can be reduced. Second, it is necessary to install several cameras at different locations at some construction sites in order to cover the entire project site. Thus, there is a need to develop a user interface and algorithms that can be used to collect, store, retrieve, manipulate, transform, and display the data that are sent by the different cameras.

ACKNOWLEDGEMENTS

This research project was funded by the Kansas University Transportation Research Institute, Kansas Department of Transportation, Federal Highway Administration, and National Science Foundation. The financial support from these agencies is greatly appreciated.

REFERENCES

Abeid, J. and Arditi, D., (2002). “Time-Lapse Digital Photography Applied to Project Management”. J. of Constr. Eng. & Manage., 128(6), 530-535.

Abudayyeh, O. Y. (1997). "Multimedia construction delay management system." Microcomputers in Civil Engineering, 12(3), Blackwell Publishers, 183-192.

Bradley, E. L., and Blackwood, L. G. (1989). "Comparing Paired Data: A Simultaneous Test for Means and Variances." The American Statistician, 43, 234-235.

Everett, J. G., and Halkali, H. (1998). "Time-Lapse Video Applications for Construction Project Management Schedule." J. of Constr. Eng. & Manage., 124(3), 2004-2009.

Fondahl, J. W. (1960). "Photographic analysis for construction operations." Journal of the Construction Division, 86(C2, Part 1), ASCE, 9-25.

Ghanem, A. G., and Abdelrazig, Y. A. (2006). "A framework for real-time construction project progress tracking." Earth and Space 2006 – Proc., the 10th B. Int. Conf. on Engineering, Construction, and Operations in Challenging Environments, League City/Houston, TX, ASCE, Reston, VA, 112-119.

Memon, Z. A., Majid, M. Z. A., and Mustaffar, M. (2005). "An Automatic Project Progress Monitoring Model by Integrating Auto CAD and Digital Photos." Computing in Civil Engineering 2005, ASCE, Cancun, Mexico, 151-151.

Meyers, F. E. (1992). "Motion and Time Study: Improving Work Methods & Management." Prentice-Hall, Inc.

Navon, R., and Shpatnitsky, Y. (2005). "Field Experiments in Automated Monitoring of Road Construction." J. of Constr. Eng. & Manage., 131(4), 487-493.

Noor, I. (1998). "Measuring construction labor productivity by daily visits." AACE Int. transactions of the Annual Meeting, Cincinnati, OH, USA, AACE Inc., Morgantown, WV, USA, 6 p.

Oglesby, C. H., Parker, H. W., and Howell, G. A. (1989). "Productivity Improvement in Construction." McGraw-Hill, Inc., New York, N.Y.

Peyret, F., and Tasky, R. (2002). "Asphalt quality parameters traceability using electronic tags and GPS." Proc., 19th Int. Symp. on Automation and Robotics in Construction, NIST, Gaithersburg, MD, 155-160.

CONSTRUCTION STUDENT TECHNOLOGY SKILL ASSESSMENT: A SURVEY INSTRUMENT

Thuy Nguyen[1], William O'Brien[2], Kathy Schmidt[3]

Abstract

The purpose of this paper is to describe the design and initial results of a data collection instrument developed to assess student technology skills. These baseline data are believed to be important for the educators in the construction industry to incorporate technology knowledge into the academic curricula. The instrument is a questionnaire that assesses the subject's level of technology skills in five dimensions: Attitude, Operational Skills, Interactions, Active Learning, and Cooperative Learning. Each of these dimensions has five developmental stages or maturity levels: Functional and Perceptual Knowledge, Pluralist Awareness, Synthetic Awareness, Competence, and Proficiency. The instrument is designed and will be validated using the Structural Equation Modeling method. The paper will present the process of initial design and data collection, the method for validation of the original instrument, and its refinement process. The original survey was distributed to 117 students in 4 Civil Engineering departments in America and initial results were used to explore the validity method of the instrument. These preliminary results and exploratory analyses suggest that with a sufficiently large sample size, it is likely that the model can be validated to satisfactorily meet the validity requirements of a well-designed measurement instrument. The data collection and validation process is still ongoing and will be feeding the design cycle of this presumably valuable instrument.

1. Introduction

With increased use of information technology in the engineering and construction workplace comes demand for increased education about how to use and deploy this

[1] Construction Engineering and Project Management Program, Department of Civil, Environmental and Architectural Engineering, 1 University Station C1752, TX 78712. Phone: 512 653 2973. Email: thuyttnguyen@mail.utexas.edu
[2] Construction Engineering and Project Management Program, Department of Civil, Environmental and Architectural Engineering, 1 University Station C1700, TX 78712. Phone: 512 471 4638. Email: wjob@mail.utexas.edu
[3] Faculty Innovation Center, Cockrell School of Engineering, 1 University Station C2200, TX 78712. Phone: 512 232 1536. Email: k.schmidt@mail.utexas.edu.

technology. Unfortunately, there is limited knowledge about how to best incorporate such pedagogical goals into academic curricula. There is a need to acquire baseline knowledge about the technology skills of our students and workers to help guide such curriculum development. The understanding of their current status of knowledge in this field is critical to identifying the areas of technology education to focus on and to select the pedagogy that is most effective. Although there have been several quick check-lists available for organizations to determine their employees' skills of technology, these tend to be rather application-specific or provide simplistic Yes/No answers that are not significantly helpful in yielding insightful understanding about how an individual perceives, understands and evaluates technological concepts in the process of learning and self-improvement. More importantly, these check-lists do not establish a scale of technology skills and knowledge that can be used as a benchmark to facilitate accurate evaluation of technology educational tools or programs. Furthermore, as educators in a college environment, we have a strong desire in studying the students' intellectual development process when technology is involved. Thus, it is desirable to have a valid instrument that can measure such ability with reliability.

2. Description of the Technology Skill Assessment model

The technology skill measurement instrument developed in this research was adopted from a technological literacy development model called the Technology Arc created by Langer and Knefelkamp (2008). This Technology Arc describes a model for understanding the students' progress in advancing their technological skills in college years. It is built upon the developmental models established by William Perry and Douglas Heath in the 1960s. It defines the developmental progress of a learner in five stages from low to high levels of intellectual development: Functional and Perceptual Knowledge, Multi-Tasking, Synthetic Awareness, Competence, and Multi-Dimensional. Five skills or literacies under consideration can be assessed against these scales to determine an individual's current status of knowledge; these are: Information/Computer Literacy, Interactions Literacy, Values Literacy, Ethical Literacy, and Reflective Literacy. Our baseline technology skills assessment tool is built upon the concepts of Langer and Knefelkamp's model. However, we modified the specific definitions of the developmental stages and replaced their five literacies by five different skill and knowledge areas that were more relevant to our student audience as described below. This is a linear model, which means that if one has reached a higher stage of development, one has acquired the skills and knowledge that are characteristic to the lower stages.

Descriptions of developmental stages

- ***Stage 1: Functional and Perceptual Knowledge.*** The learners with functional and perceptual knowledge understand the basic concepts and have the basic knowledge and skills of technology, including hardware recognition, software functions and the usage of Internet-based applications. They can also communicate what they know with others effectively.

- ***Stage 2: Pluralist Awareness***. Learners with technology awareness are aware of technical and non-technical (social, economic) benefits, constraints and limitations of technology. They are capable of developing multiple perspectives: being aware of the merits of technology and non-technology solutions in a certain context, and accepting the fact that others might have different perspectives on a solution or technology.
- ***Stage 3: Synthetic Awareness***. Learners who are synthetically aware know how to integrate both technology and non-technology benefits in solutions. They become more coordinated and flexible at using technology. They are capable of updating and adjusting their values and beliefs as they develop new knowledge and skills of technology.
- ***Stage 4: Competence***. Competent learners are able to evaluate the validity and credibility of technological products (such as information and feedback). Their knowledge, habits and skills of using technology have strengthened and become stable and readily accessible, which gives them the resilience to overcome and recover from unexpected problems.
- ***Stage 5: Proficiency.*** Proficient learners are motivated to apply and capable of using technology in contexts different from the original context in which the knowledge was acquired. They are able to judge independently and critically in any context, and hence become more willing to take risks. This ability encourages the learners to use technology for creative purposes.

Once the developmental stages had been established, we chose the literacies or intellectual development areas that we wanted to measure. Among those used in Langer and Knefelkamp's Technology Arc, we retained the Interactions literacy, and slightly modified the Information/Computer literacy description to fit it under the umbrella of Operational Skills. We added three new literacies that are more relevant to technology-enabled instructional design; these are: Attitude (towards Technology), Cooperative Learning, and Active Learning.

Descriptions of literacy/skill variables

- ***Literacy 1: Attitude (towards Technology).*** This literacy variable is concerned with learners' awareness of various available technologies that could be used to improve their work as well as their social life and self-improvement. It also reflects the willingness to explore and adopt technology. Mature students become aware of state-of-the-art technologies relevant to their professional domain and personal needs. They are also receptive to change in their existing ways of doing things as well as to the adoption and adaptation of new technologies for better work performance.
- ***Literacy 2: Operational Skills.*** This literacy variable reflects the understanding of learners about the purposes and functionality of various technologies, the ability to use these features to perform the tasks at hand and develop more abstract knowledge. As learners mature, they can operate devices or use applications with ease to serve their specific purposes. They also learn through reflecting on the process, the system and the conceptual rationale behind these specific functions to form more integrated and

comprehensive knowledge of how to maximize operational benefits of technology.

- ***Literacy 3: Interactions.*** This literacy variable relates to how cyber-infrastructure, including the world of mobile technologies and Internet-based applications, can influence students' relationships with others in terms of communication and respect for individual differences in the virtual world. The mature learners understand differences between asynchronized and real-time communication, and face-to-face and distant communication. They adapt well, both cognitively and emotionally, with this new form of communication that technology brings about, and develop tolerance for others' habits and methods of communication.
- ***Literacy 4: Cooperative Learning.*** This literacy variable is associated with the ways learners use technology collaboratively to complete a common task that serves both a common goal and individual needs. Mature individuals can use technology to maximize the learning of self and help others achieve their goals, in addition to the common goals. They are capable of using technology to make everyone a better resource for others. Maturing individuals become increasingly aware of the benefit of investing in others for their own intellectual achievement, and committed to cooperation for realizing that potential.
- ***Literacy 5: Active Learning.*** This literacy variable reflects the awareness, willingness and ability of learners to make use of available technology to actively involve in various intellectual activities with self and others. Mature individuals can retain knowledge for long-term, are motivated for further learning, confident and effective in applying current knowledge as well as acquiring new knowledge with minimal instruction.

From these high level conceptual definitions of developmental stages and literacies, 25 specific descriptions were developed to classify the behaviors and skills corresponding to every literacy at one particular stage. This acts similarly to a taxonomy for assessment. For example, one is considered to have acquired Perceptual Knowledge in the skills of Interactions if one "understands the potential of technologies such as email, web pages, handheld devices, collaborative software in communication with others" and "understands these tools' feasibility and applicability." Similarly, Competence in Operational Skills reflects the ability to "demonstrate knowledge of technology that is concrete, accurate, precise, broad, and are able to diagnose problems or evaluate the validity of technology's products" and "able to trouble shoot effectively."

A sample graphical representation of the Technology Arc resulted from our baseline technology skill assessment tool is shown in Figure 1. In this example, the student has acquired synthetic awareness in the Attitude and Interactions literacies, pluralist awareness in Cooperative Learning, and has reached competence in Operation Skills and Active Learning.

Maturity Stages					
Proficiency (Stage 5)					
Competence (Stage 4)					
Synthetic Awareness (Stage 3)					
Pluralist Awareness (Stage 2)					
Functional and Perceptual Knowledge (Stage 1)					
Literacy Variables	Attitude	Operational Skills	Interactions	Cooperative Learning	Active Learning

Figure 1. Technology Arc for Baseline Technology Skill Assessment

This figure is the output of the assessment tool, which can be used to identify areas that need to be focused on when designing and/or conducting instruction. The shaded cells reflect the knowledge the student has gained, and the white cells reflect the learning to be achieved. The input data for this Technology Arc model come from a survey questionnaire that has 42 statements about technology use. For each of these statements, the participants are asked to rate, using a 5-point Likert scale, its relevance to their field, their understanding about specific applications mentioned in the statement, and their experience in using such applications. The questions are classified into five groups; each group is believed to measure a certain set of skills (or a literacy). The total score for any literacy comes from the questions in that group, weighted by the factor loadings determined through the statistical analysis of the model. This process is described in more detail in the next section on validation.

The complete design of the instrument

The questionnaire has three main parts: Demographic and Background Information, Technology Exposure Checklist, and Technology Skill Assessment. Part 1 captures the basic information about the participants, such as age, gender, academic background, construction experience, and English proficiency. Part 2 is a check-list of 16 popular technologies to determine the participants' awareness of the existence of these technologies and corresponding levels of use. Part 3 is the main part of the questionnaire which consists of the 42 statement questions described earlier. Apart from the Arc which is the high level output of the instrument, the survey also provides a great amount of specific information on level of technology use and experience that can be extracted from Part 2 and some questions in Part 3. The anticipation is that if the instrument can reliably capture the information it is supposed to capture, we will have a very rich database that contains valuable information about our audience in terms of specific technology skills and knowledge and some important abstract and high level traits related to learning and cognition.

3. Validation method

The questions in the instrument are designed based on extensive literature review in technology education, technology assessment and the researchers' own judgment on the subject. This design has to go through an iterative validation process that might take years to complete and requires rigorous statistical analysis. For this particular instrument, the confirmatory factor analysis (CFA) is the technique chosen for instrument validation. This was also the method used to validate the original Technology Arc model of Langer and Knefelkamp (2008). However, as we adopted their model, slightly modified the developmental stages and replaced their questions by our own questions, we have to completely revalidate our model. The ultimate goal of this validation process is to perform the CFA on an appropriate sample to determine the factor loadings (or weights) for each of the questions in the survey. In other words, the CFA analysis will help determine how relevant and influential each question is to the literacy it is trying to measure. This process might also result in a reduction of the model size if certain questions are proved to have no correlation or effect on the outcome to be measured.

In general the CFA is a technique to study the linear relationship between the measured (observed) variables and some unmeasured variables that are believed to be the important underlying factors influencing the observations. The measured variables are called the indicators (in our case, these are the skills measured in survey questions); while the unmeasured constructs are called factors or latent variables (these are the literacies in our instrument). A CFA model reflects the causal relationships between factors and indicators. For our model, there are a total of 126 indicators (42 questions times three aspects explored in each questions: relevance, understanding, experience) and five factors. Figure 2 illustrates the causal relationships in the Technology Arc model. Please note that for the clarity of presentation, only some indicators (questions) are shown. In Figure 2, rectangles represent the measured variables, while circles or ellipses represent unmeasured or latent variables. The small circles pointing toward the indicators represent the causes affecting the indicators but not accounted for in this model. Double-arrow curves between factors indicate that these are free to covary with each other (Amos 2007).

It should be noted that such model in Figure 2 requires a very large sample size (500 plus data points, Kline (2005)) for the analysis to be statistically valid. Given that we are early in this process, it yielded bad fit indexes for the batch of 109 data points we have collected so far. At this stage in the design cycle, it is more beneficial to carry out some exploratory analysis for the subsets of variables to diagnose any early correlation problems among the indicators. The "exploratory analysis" term is used loosely here. It is not the same as the exploratory factor analysis (EFA) technique that is in the structural equation modeling (SEM) family with CFA. By "exploratory", we still used the same model (with the factors covarying) but just used a subset of variables to preliminarily observe the effect of scale reduction of the model.

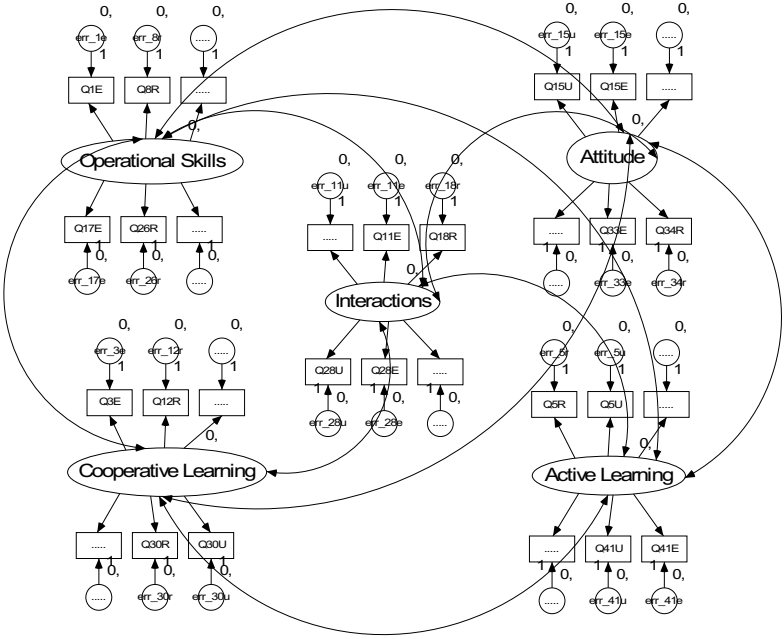


Figure 2. CFA model for the Technology Arc

As every question in the survey asks about the subject's understanding and experience with a technology and its relevance to their field, it was of interest to see how well the questions did in each of these aspects. We first ran the model with just scores concerning one of the three aspects: relevance, understanding or experience. Each of these exploratory models had 5 latent variables (same as the overall model) but only 42 indicators (not 126). While the results from these three analyses gave some insight into the inappropriateness of a few questions in the survey, it only suggested that these questions might need special attention when analyzing the model. Any final conclusion about the value of each question has to be drawn from an analysis of an appropriate sample size. The details of these preliminary observations will be provided later in the paper.

Model validity criteria and fit indexes

The following validity criteria will be assessed in the design of this technology arc. The definitions of criteria are taken from Coffield et al (2004).

- **Face validity**. Support for an assessment tool based on common-sense judgment that the test items appear to measure what they are claimed to measure.
- **Internal consistency (reliability)**. The degree to which the items in a test measure the same thing, measured by the average correlation between each item and the other items.

- **Construct validity**. How far test scores can be interpreted as measuring only what they are intended to measure
- **Test–retest reliability**. The stability of test scores as indicated by retesting the same group and calculating a correlation coefficient using the two sets of scores

The following fit indexes are used to evaluate the goodness of fit for the model. This is the minimal set of fit indexes that have to be reported according to Kline (2005).

- **Model Chi-square.** The ratio of Chi-square and model's degree of freedom is smaller than or within the range from 2 to 3.
- **Root Mean Square Error of Approximation** (RMSEA) equal or smaller than .08
- **Comparative Fit Index** (CFI) equal or greater than .90
- **Standardized Root Mean Square Residual** (SRMR) equal or less than .10

4. Preliminary Results

The first version of the survey instrument was distributed to 117 undergraduate civil engineering students at the University of Texas at Austin, University of Kentucky, University of Florida and University of Washington. Among these 8 records were removed as the result of incomplete data. The remaining 109 data points were used in the exploratory analysis of the sub-models of the CFA described in Section 3 created and run in Amos 16.0.

The first three rows in Table 1 are the fit index results from the analysis of experience scores, understanding scores and relevance scores using data of all the original 42 questions of the technology arc instrument. Based on the results, 12 questions were found to have significantly low factor loadings on the literacies. These were then removed from the sub-models and analysis was carried out on the new sub-models. The fit indexes for these new runs are shown in the last three rows of Table 1. It can be seen that the goodness of fit was improved for all three sub-models when the questions in doubt were removed across the three criteria (Chi2/df, RMSEA, CFI). While the chi-square/degrees of freedom ratio and the RMSEA indicated that there was a good fit in the sub-models (criteria defined above), the CFI was significant lower than desired for all of them. This finding is understandable given the small sample size used in the analyses. And this is the reason why these results cannot be used to immediately remove any questions from the survey. As discussed earlier, only conclusions from a sufficiently large sample can be reliable. These preliminary results, however, suggest that there is a high chance that with more data obtained from our ongoing collection process, the overall model can be validated and the instrument refined to result in a good fit.

Apart from the model fit indicators, some preliminary results from some questions provide interesting information in specific areas of interest, such as the Technology Exposure Checklist. In this part, 16 popular technologies were put in to four groups:

Hardware Devices, Office Document Tools, Domain Specific Tools, and Web-Based Tools. The preliminary results are shown in Table 2.

Table 1. Model fit indexes for exploratory models

Model	Chi-Square	df*	Chi^2/df	RMSEA	CFI
Experience – 42 questions	1595	809	1.97	0.089	0.414
Understanding – 42 questions	1483	809	1.83	0.082	0.517
Relevance - 42 questions	1504.7	809	1.86	0.086	0.406
Experience – 30 questions	615	367	1.68	0.074	0.622
Understanding – 30 questions	532.3	367	1.45	0.077	0.653
Relevance – 30 questions	593.9	367	1.62	0.071	0.614

*df = degrees of freedom

Table 2. Technology Exposure Checklist Results

Technology	Never	Rarely	Monthly	Weekly	Daily
Basic hardware (e.g. computers, printers, fax machines, scanners, digital cameras, projectors)	1%	1%	1%	7%	88%
Handheld devices (e.g. labtop, tabletPCs, PDAs, cell phones, pagers, iPhones, iPods)	1%	0%	3%	9%	87%
Sensing technologies (e.g. RFID, sensors)	46%	31%	15%	6%	3%
Office document tools (e.g. word processors, spreadsheets, presentations)	0%	0%	4%	25%	71%
Graphic and web design tools (e.g. Photoshop, Paintbrush, Fireworks, CorelDraw, FrontPage, DreamWeaver)	6%	32%	34%	24%	4%
Email and Time/Task management tools (e.g. MS Outlook, desktop organizers)	1%	10%	10%	21%	57%
Knowledge and Data management tools (e.g. MS Access, EndNote)	37%	34%	25%	4%	0%
Structural & Architectural design tools (e.g. SAP2000, ADINA, STAAD-Pro, ArchiCAD)	68%	22%	7%	3%	0%
2D- & 3D-CAD (e.g. AutoCAD, AutoDesk, MicroStation)	15%	29%	28%	16%	12%
4D- and nD-CAD (e.g. Design + Schedule + Cost/Others)	85%	12%	1%	0%	1%
Email & Instant messaging (e.g. Yahoo Messenger, AOL, MSN)	3%	4%	10%	15%	68%
Search engines (e.g. Google, Yahoo)	0%	0%	1%	7%	91%
Social networks (e.g. Facebook, MySpace, LinkedIN)	19%	7%	9%	15%	50%
Online forums/Wikis/Blogs	15%	18%	24%	21%	24%
Web/Video conferences (e.g. Webinar)	66%	18%	10%	3%	3%
Electronic Resources (e.g. online publications, online libraries, YouTube)	0%	9%	21%	44%	26%

5. Conclusions

The technology skill assessment instrument designed in this research is comprehensive and covers several aspects of technology skills, including specific measures such as technology familiarity and use, as well as more abstract constructs such as attitude and interactions. The validation framework developed, when completed will ensure that the instrument satisfies several validity requirements for a measurement tool. Preliminary deployment of the survey for data collection at four different civil engineering schools has triggered significant interest in the instrument from the faculty. It is anticipated that a sufficiently large database will be collected in the next year or two, and with such a database, this instrument can be appropriately validated for mass deployment to collect industry-wide data. Such long-term database of technology skills will be valuable in the support pedagogical design and promotion IT innovations in construction. The instrument can then be expanded to accommodate the intellectual differences between construction students and workers so that it can be used across the board of the construction workforce.

6. Acknowledgements

We would like to acknowledge the support of the National Science Foundation, the University of Kentucky, the University of Florida, the University of Washington and several students at the University of Texas at Austin who have participated in our survey development and testing.

7. References

Amos Development Corporation (2007). "*Amos 16.0's user's guide*." Published by SPSS.

Coffield, F., Moseley, D., Hall, E., Ecclestone, K. (2004). "*Learning styles and pedagogy in post-16 learning: A systematic and critical review*." Learning and Skills Research Center.

Gravetter, F. J., Wallnau, L. B. (2007). "*Statistics for the Behavorial Sciences*." Seventh Edition. The Thomson Wadsworth Press. California, USA

Kline, R.B. (2005). "*Principles and Practice of Structural Equation Modeling*." Second Edition. The Guilford Press. New York, USA.

Langer, A. and Knefelkamp, L. (2008). "Technological Literacy Development in the College years: A Model for Understand Student Progress". To be published in the J*ournal of Theory to Practice*, 2008.

3D-GIS BASED EARTHWORK PLANNING SYSTEM FOR PRODUCTIVITY IMPROVEMENT

Sang Hyeok Kang[1], Jong Won Seo[2], and Kyeong Geun Baik[3]

[1] Graduate Research Assistant, Department of Civil Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, Korea, Tel.: +82-2-2220-4481, Fax.: +82-2-2220-4480, e-mail: lifesine@yahoo.co.kr
[2] Associate Professor, Department of Civil Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, Korea, Tel.: +82-2-2220-1482, Fax.: +82-2-2220-4480, e-mail: jseo@hanyang.ac.kr, Corresponding Author
[3] Graduate Research Assistant, Department of Civil Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, Korea, Tel.: +82-2-2220-4481, Fax.: +82-2-2220-4480, e-mail: sowon999@hanmail.net

Abstract
This paper proposes a GIS-based planning system for improving earthwork productivity. The system takes two planning steps considering 3-dimensional topographical conditions and other necessary information of the construction site and surroundings: 1) internal earthwork planning for earthmoving within construction site and 2) external earthwork planning for importing and exporting soil to and from construction site. Useful functions such as dissecting and grouping earth volumes for detailed task order creation, 3-dimensional analysis of haul routes, and assembling geographical and non-geographical information for equipment selection and earthwork process design are provided. Example analysis of the system is demonstrated in the paper and the analysis proves that 3-dimensional spatial manipulation and objectification of unstructured topographical data such as cut/fill mass (features) can be effectively used for earthwork planning.

1. INTRODUCTION

A construction project is composed of many activities and tasks. Earthworks are engineering works created through the moving of massive quantities of soil or unformed rock. Earthworks usually occupy around 20% of total amount of construction cost. Especially the haul task occupies about 6% of the project cost and 30% of the whole earthwork cost. Therefore, improvement of earthwork productivity

can contribute to cost and time savings of the whole project.

Earthmoving planning on linear type of construction projects such as roadway construction projects uses mass curve. However, the usage of mass curve has limitations in that planners cannot consider surroundings of the site and 3-dimensional topographical conditions in detail. In addition, planners mainly depend on subjective knowledge acquired and experienced in practice. Therefore, the planners have difficulties in evaluating alternatives eventually decreasing productivity and increasing project cost and time.

There have been various efforts to improve earthwork productivity. The conducted studies can be classified into two types: 1) performance enhancement of earthmoving equipment and 2) improvement of construction management techniques including effective planning and scheduling. This paper focuses on the latter. Peurifoy and Schexnayder (2002) plotted haul speed of various dump trucks depending on rolling resistance and grade resistance, which provided construction planners with more accurate information about truck speed. Smith (1999) and Marzouk and Moselhi (2004) conducted quantitative analysis on the factors that affect haul speed. Christian and Xie (2006) identified factors affecting earthwork productivity based on practical knowledge through questionnaire survey and expert interviews. Also, AbouRizk (1988) and Halpin and Riggs (1992) conducted research on methodology and tools for measuring and analyzing productivity using process modeling and simulation. Application programs such as MicroCyclone are now widely used as effective construction productivity analysis tools as a result.

Previous work mentioned above made contribution to improvement of earthwork productivity through systematic and reasonable planning. However, authors believe that earthwork planning may be more rigorous by considering earthmoving operation within the construction site (internal earthwork) and importing/exporting soil to and from construction site (external earthwork) simultaneously with a comprehensive planning tool based on well assembled geographical and non-geographical information. Therefore, this study aims to develop a system with which construction planners can conduct internal/external earthmoving planning comprehensively in one system as shown in Figure 1.

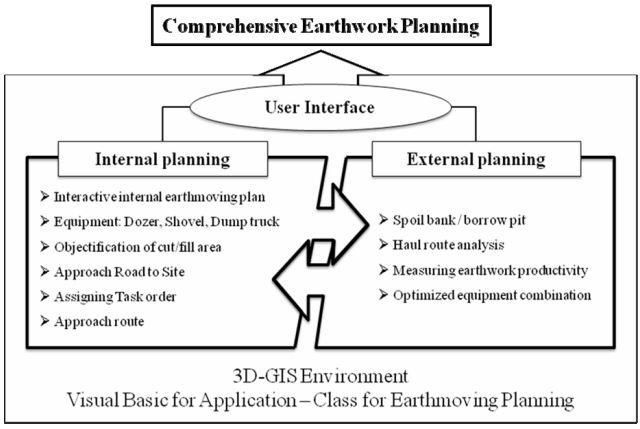


Figure 1. Objectives and Contents of the Study

2. EARTHWORK PLANNING

The system takes two steps for their comprehensive earthwork planning as shown in Figure 2. The first step is internal earthwork planning on which planners divide the site three dimensionally into pieces to assign task order based on the geometry and the soil characteristics as well as the pre-programmed heuristics based on skillful operators' knowledge. These heuristics are applied to 3-dimensional geographic information of the site and earthwork design data in the form of divided solid model of digital terrain map so that the effective earthwork task order could be created or the possible alternatives could be visually examined. After finishing internal earthwork planning, users may conduct external earthwork planning continuously, if required. In this step planners analyze various haul routes connecting the construction site to borrow pit or spoil bank. When planners cannot find any appropriate haul routes among existing roads, they can draw temporary roads directly through the interface provided by the system. The system, then, analyzes the route based on the haul speed and productivity of various trucks and excavators combination. Through this process planners can finish both internal and external earthmoving planning comprehensively. In other words, the productivity of various alternatives of earthwork within and outside of the construction site can then be analyzed and the best alternatives including the task orders, haul routes and equipment combinations could be selected.

2.1 Internal Earthwork Planning

Construction planners usually use a mass curve for earthwork planning on linear type of construction projects such as roadway, railway, and riverbank. It is very effective to plan based on the curve for deciding appropriate equipment and average haul distance on the site. However, it is difficult to create detailed plan that considers equipment travel routes, access roads to the site, and the surroundings of the site

based on the mass curve. It becomes more difficult to plan earthwork in case of areal construction site where movement of soil and equipment within the site should be considered in two directions (X and Y). In this case GIS can be an effective tool in that it is possible to consider 3-dimensional topographical information around the site and connect feature data such as lines or polygons representing roads or paths with related attributes.

Internal planning module of the proposed system help planners select appropriate equipment and capacities considering the shape of original ground and design information three-dimensionally by identifying cut/fill regions and boundaries and considering equipment characteristics and soil information. Based on the selected equipment, the 3-D model of earth volumes that need to be moved are dissected and grouped to create task orders and equipment passes. To do so, object-oriented classes are implemented within GIS. These classes are based on the heuristics that are drawn from the skillful equipment operators' knowledge. Class implementation and the heuristics are explained in section 3 and 4.

Task planning of earthmoving equipment involves many kinds of information on the conditions of the site. For example, an access road may be required within the site in case haul equipment cannot approach to the construction site. Moreover, there are several factors to be considered such as drainage and ground conditions when designing an access road. Construction planners may also have to consider the following factors: 1) the region of cultural assets, 2) environmentally sensitive region, 3) drainage, 4) the volume of traffic etc. This kind of factors can be easily input and displayed on a GIS as features such as polygons, lines, and points, meaning planners can inspect many factors overall on one system.

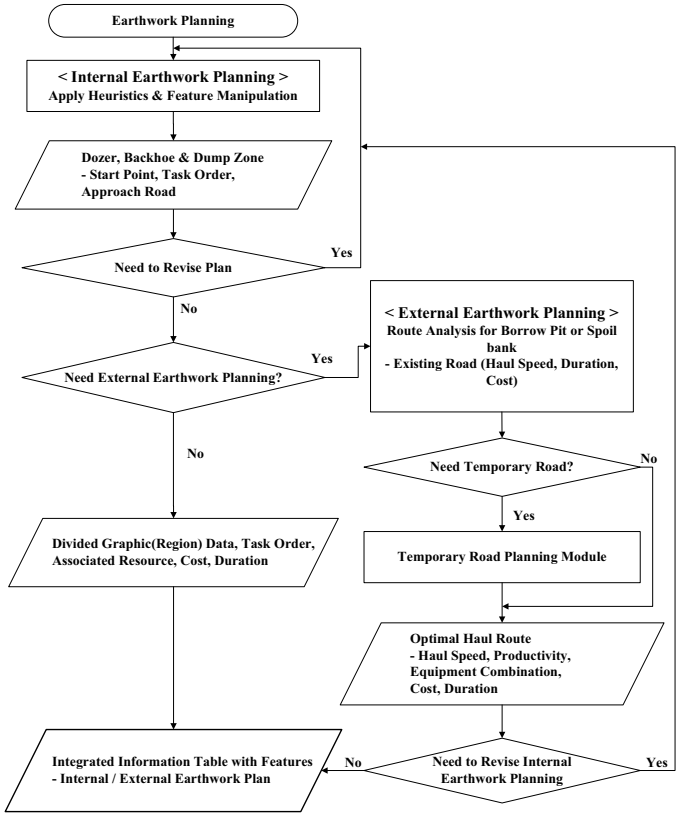


Figure 2. Planning Process

2.2 External Earthwork Planning

Carrying soil in/out is required in case there is deficit or redundant soil in the construction site. Actually, planners can save cost and time if they examine various alternative plans thoroughly because the routes from the site to the borrow pit or spoil bank is usually decided without detailed analysis. The overall productivity of the external earthwork depends on productivity of hauling equipment, which is calculated based on Equation 1. C_m which is the sum of load time, haul time, dump time, return time, and wait time is governing factor among the terms of the equation because while load time, dump time, and wait time are not likely to change, haul and return times are susceptible to haul distance. It means that haul and return times are the key factors that determine truck cycle time and productivity of the external earthwork.

$$Q = 60 \cdot q_t \cdot f \cdot E / C_m \quad (1)$$

where q_t is the truck capacity (in m3), f is the percent swell and shrinkage, and E is the truck efficiency.

The system provides a 3-dimensional analysis function for haul routes based on contour lines from digital map, which enables planners to examine various alternative routes so as to identify the best route. Also, planners can draw some lines on the interface directly for the better routes based on the module that the system provides if there are no satisfactory routes among existing roads.

It is also important that productivity of the external and internal earthwork should be systemized. The internal and external earthwork planning modules seek for the best alternative of their own. However, if necessary, the internal earthwork plan could be modified depending on the external earthwork productivity.

3. GIS-BASED OBJECT ORIENTED CLASS IMPLEMENTATION

A GIS is employed in the system for enabling construction planners not only to look around and investigate the topographical conditions of the site, but also to make the best use of GIS functions such as feature manipulation. There are some routine provisions for the interface. For example, the digital map of the site and design data modified to be suitable for a GIS data format in CAD/CAE or 3D-Max are converted to the system.

Various usable functions such as dividing and classifying 3D surface models and assigning task order to each divided objects based on heuristics are supported. Also, the system provides users with several classes which have some properties and methods for easier earthwork planning and feature manipulation. Figure 3 shows the object model diagram constructed and embedded to the system, and Figure 4 displays an example model. 'eCubic' is a rectangular parallelepiped volume (e.g. 3m x 8m x 8m for $1m^3$-excavator) of soil that can be normally processed by an excavator with its platform placed at one position. An 'eLayer' class may have more than one 'eLane' as asterisk sign of the 'eLane' class means multiplicity. Also, 'eLayer' class has properties that users can get or set the feature's characteristics such as 'Color', 'Elevation', 'Order', etc. and methods with which users can flash or divide itself into more than one 'eLanes.'

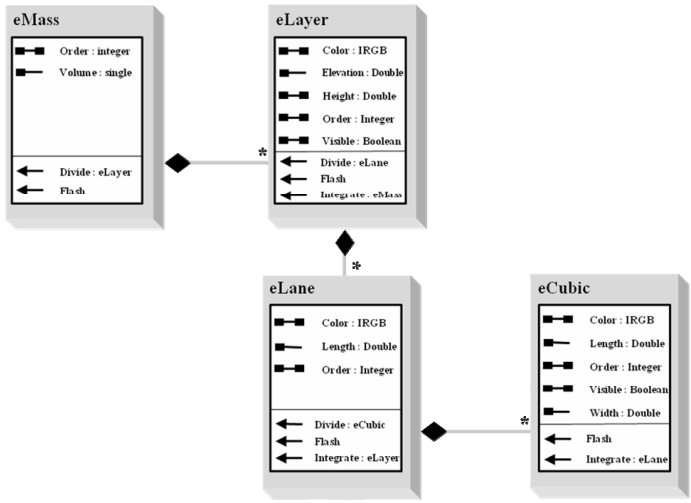


Figure 3. Object Model Diagram for Earthwork Planning

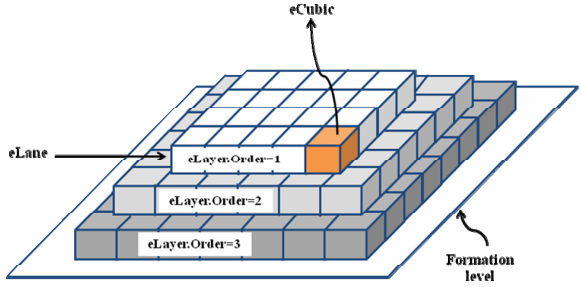


Figure 4. Divided Mass of Soil

4. APPLYING HEURISTICS TO PLANNING

Skillful operators' intuitive decision plays an important role for the quality of earthwork because the task is conducted in an unstructured environment that planners cannot expect all the factors at the planning stage. If skillful operators' experienced knowledge is reflected at the planning stage, the efficiency and the productivity of the task will increase. Investigation was conducted through questionnaire survey and expert interview to find out the knowledge that can be applied on a GIS environment for the earthwork planning purposes. Table 1 shows the heuristics applied to the system for task planning derived from skillful operators' knowledge. For example, skillful excavator operators say that 2 to 3m excavating depth is appropriate and efficient for excavation and preventing landslide of work area.

Table 1. Heuristics for Task Planning

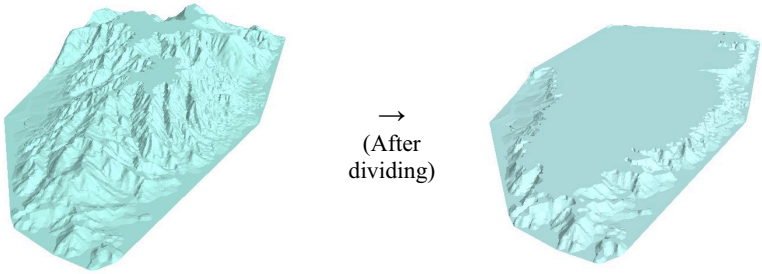
Skillful operators' knowledge	Applied heuristics to GIS
Generally, skillful operators start their task on the highest point of the site.	An *eLayer* with higher elevation has order priority than the other *eLayers* in an object *eMass*.
A skillful operator proceeds so as to make outflow or surface water drain naturally depending gravity.	Planners should avoid polylines or polygons representing expected or investigated water flow.
Generally, 2 to 3m excavating depth is appropriate and efficient for excavation and preventing landslide.	An *eLayer*'s height property is set to 2 – 3.
A skillful operator digs straightly and continuously until he/she cannot move backward.	Many *eCubics*' order properties have succeeding numbers in an object *eLane*.
⋮	⋮

Once features are objectified, those heuristics shown in Table 1 can be easily applied based on customized GIS functions because each object has its own properties and methods. Now planners can conduct detailed task planning such as courses of an excavator and dump trucks on every layer. At this time, the system help the planners examine various alternatives by providing heuristics mentioned above.

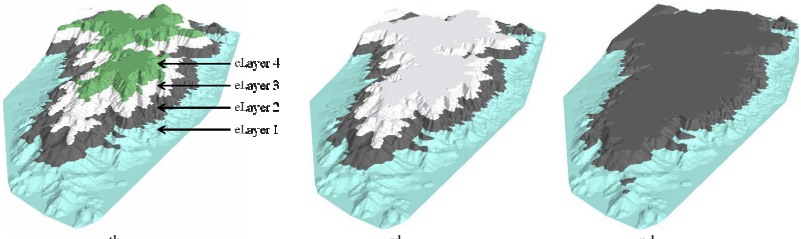
5. EXAMPLE ANALYSIS

5.1 Internal Earthwork Planning

Figure 5 shows 4 layers divided and stacked by 3m depth, which means that this earthwork can be done at four levels. Now that each layer is objectified to have its own properties and methods, planners can get or set the properties and control the objects by using the methods inherited from the classes pre-defined in the system. For example, planners can divide each layer into more than one 'eLanes' or 'eCubics' so as to assign detailed task order and direction.



(Initial topography) (1st layer)



(4th layer) (3rd layer) (2nd layer)

Figure 5. 4 Layers Divided by 3m Depth

5.2 External Earthwork Planning

For external earthwork planning, the system includes an existing module that developed in the previous research (Seo and Kang 2006). Figure 6 shows an example of 3D analysis of haul route conducted on external earthwork planning stage. The system identifies the line drawn by planners and provides the profile graph of the haul route and information about haul distance, speed, time, and return speed, time etc. In this example, planners can know that it will take about 29 minutes for a truck round trip between the construction site (point A) to the spoil bank (point B). Subsequently, the system calculates productivity with the results of the route analysis and some user inputs such as percent swell and shrinkage, wet density etc. as shown in Figure 7. Figure 8 shows cost and duration of the equipment combination required to finish the earthwork. Now planners can select the best equipment combination among various alternatives provided by the system. Based on this information, planners may draw another route line or revise internal earthwork planning so as to balance the productivities of internal and external earthworks.

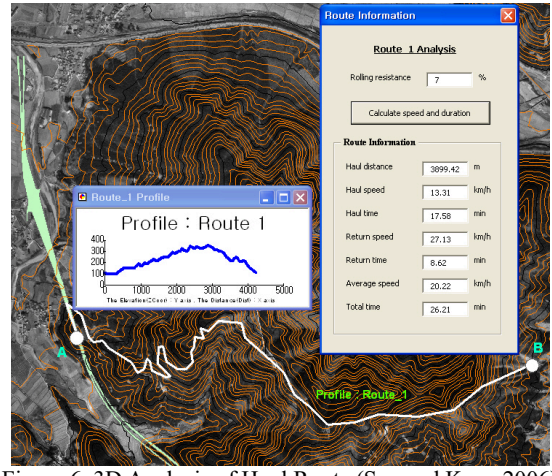


Figure 6. 3D Analysis of Haul Route (Seo and Kang 2006)

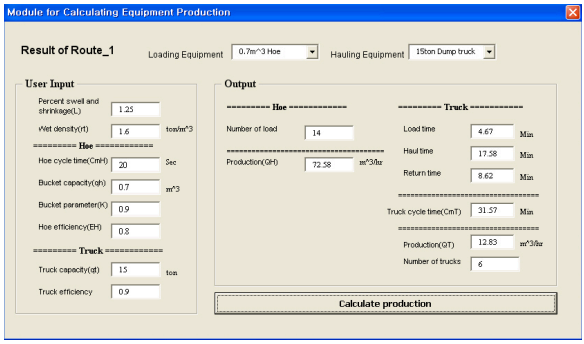
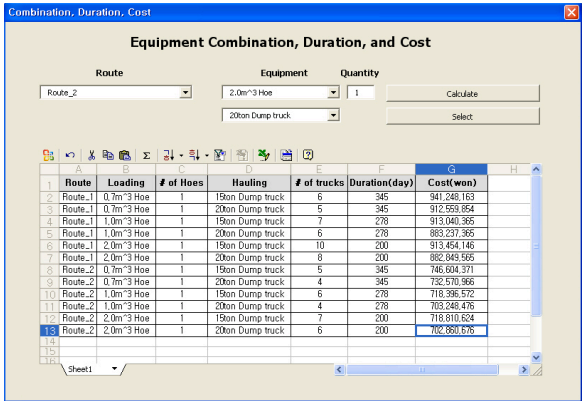


Figure 7. Productivity Calculation (Seo and Kang 2006)



Route	Loading	# of Hoes	Hauling	# of trucks	Duration(day)	Cost(won)
Route_1	0.7m^3 Hoe	1	15ton Dump truck	6	345	941,248,163
Route_1	0.7m^3 Hoe	1	20ton Dump truck	5	345	912,559,854
Route_1	1.0m^3 Hoe	1	15ton Dump truck	7	278	913,040,365
Route_1	1.0m^3 Hoe	1	20ton Dump truck	6	278	883,237,365
Route_1	2.0m^3 Hoe	1	15ton Dump truck	10	200	913,454,146
Route_1	2.0m^3 Hoe	1	20ton Dump truck	8	200	882,849,565
Route_2	0.7m^3 Hoe	1	15ton Dump truck	5	345	746,604,371
Route_2	0.7m^3 Hoe	1	20ton Dump truck	4	345	732,570,966
Route_2	1.0m^3 Hoe	1	15ton Dump truck	6	278	718,396,572
Route_2	1.0m^3 Hoe	1	20ton Dump truck	4	278	703,248,476
Route_2	2.0m^3 Hoe	1	15ton Dump truck	7	200	718,810,624
Route_2	2.0m^3 Hoe	1	20ton Dump truck	6	200	702,860,676

Figure 8. Equipment Selection (Seo and Kang 2006)

6. CONCLUSIONS

This paper demonstrates that 3-dimensional spatial manipulation and objectification of features on a GIS environment can be effectively used for earthwork planning. The proposed system provides the planners with functions and classes for internal earthwork planning with which the planners can divide and convert 3-dimensional surface models into blocked solid models so as to handle the objects easily for planning and procedure visualization. It is also possible to conduct external earthwork planning with the proposed system based on the capability of the system to perform 3D analysis of haul routes and equipment selection. With the proposed functions based on a GIS environment planners can conduct internal/external earthwork planning considering 3-dimensional topographic conditions of construction site and surroundings as well as the characteristics of equipment and other non-spatial information comprehensively.

SURVEYING METHODS FOR BILINGUAL CONSTRUCTION WORKERS

Jenna Brummett[1] and MaryEllen C. Nobe[1]

ABSTRACT

With a shrinking supply of workers entering the construction industry, it is vital to maintain the current workforce. As a growing source of labor, more information is needed about Spanish-speaking construction workers, including their perceptions of discrimination. The purpose of this study is to identify Spanish-speaking workers' perceptions of discrimination in the construction industry including: (a) how the language barrier has affected communication at work, (b) opportunities and obstacles for advancement, (c) compensation, and (d) overall treatment at work. Data for this mixed-method study was collected through the use of a customized survey instrument and group discussions with participants using a foreign-born interpreter. Survey data collection for Spanish-speaking individuals, however, is often difficult to gather due to cultural differences that often exist between the researcher and the participants. This paper will review the survey development process for a bilingual population and surveying techniques used with this special population.

Introduction

"Our industry is in the midst of a skilled workforce crisis" (Whyte et al., 2007, p. 1). During this time of need, the construction industry is looking to untapped labor sources and underrepresented populations, including foreign-born and native-born Hispanics. According to a 2002 construction think tank comprised of construction industry and academia representatives, solutions to the workforce crisis primarily involve nontraditional sources of labor, with one of the largest labor pools being comprised of Spanish-speaking minorities (Schleifer, 2002). While some research has focused on recruitment of new workers, other research from the Center for Construction Industry Studies (CCIS) and the Construction Industry Institute (CII) has focused on maintaining the current workforce (e.g. Brandenburg et al., 2003; Castañeda et al., 2003; Chini et al., 1999; Construction Industry Institute, 2005a, 2005b, 2005c). Current issues affecting workers include pay, benefits, opportunities, obstacles, workloads, commuting, safety, education, training, stress, health, productivity, quality of life and treatment. A particular population of concern, which needs to be better understood by construction employers, is the emergent Spanish-speaking workforce. Accessing this population, however, is very difficult. The intent

of this paper is to discuss surveying methods for bilingual construction workers in an effort to increase understanding and awareness about this population.

Effects of Perceived Discrimination in the Workplace

Due to age, education, geography, immigrant status, language difficulties, and discrimination, Hispanic workers have not always been afforded similar opportunities for advancement, fair treatment, or equal pay (Reimers, 1983). Furthermore, in a politically charged environment where anti-immigration sentiment is growing, native-born, Spanish-speaking workers may be feeling the effects of blind-discrimination against the language that they speak and the color of their skin. The 2006 Latino National Survey (Fraga, Garcia, Hero, Jones-Correa, Martinez-Ebers, and Segura, 2006), and the 2006 and 2007 National Survey of Latinos (Pew Hispanic Center, 2006a, 2007) incorporated questions about immigration, job security, language preferences, and perceived discrimination to help uncover changes in the treatment of native-born and foreign-born Hispanics in light of immigration reform. All three reports showed significant differences between the perceptions of native-born and foreign-born participants (Fraga et al., 2006; Pew Hispanic Center, 2006a, 2007).

While outsiders may not see the difference between native and foreign-born Spanish-speaking workers, the significant differences in their perceptions have potential for dramatic effects in the workplace. Treating unique populations the same with a bias either for or against a qualifying characteristic is a form of discrimination. Examples of actual workplace discrimination include not paying overtime, withholding benefits, higher risk work for minorities, turning down promotions, and hiring workers as independent contractors or subcontractors to avoid paying insurance, overtime and benefits. Actual discrimination can also mean hiring workers because of who they are, who they aren't, or not hiring them at all.

Even in the absence of actual workplace discrimination, the mere perception of discrimination has been shown to cause significant harm to employees and employers. Perceived discrimination has been linked to stress and health consequences which ultimately affects the quality of life of the worker (e.g. Finch, Kolody, and Vega, 2000; Finch, Hummer, and Vega, 2001; Sachez and Brock, 1996). Since perceived discrimination in the workplace has the potential to increase stress, affects health adversely, and may also affect productivity, it is important to better understand the experiences of the Spanish-speaking workforce. Perceived discrimination may also be related to both the short-term and long-term employment decisions of employees in the construction industry which directly affects the labor supply.

Stress. Contrada, Ashmore, Gary, Coups, Egeth, Sewell, Ewell, Goyal, and Chasse (2000) described the research trend away from studies about discriminatory behavior and toward the perception and experience of discrimination of minorities. The movement to studies of perceived discrimination was driven by research into the physical and psychological well being of minorities under stress (Contrada et al.,

2000). One of the key studies preceding this movement was completed by Mena, Padilla and Maldonado in 1987. Their study found differences in the responses of 1st, 2nd and 3rd generation immigrants with respect to stress. Additional findings included higher levels of stress related to perceptions of discrimination (Mena et al., 1987).

The Hispanic Stress Inventory (HSI), compiled by Cervantes, Padilla and Salgado de Snyder (1991), was created to advance assessment tools for psychosocial stress of Hispanics. Short statements were taken from interviews about stress with the initial 62 respondents. These statements were then assessed and categorized until the result was 133 items which would be randomly ordered into a survey instrument on a 5-point Likert scale regarding stress. The survey was then administered to 493 Hispanics, representing both native and foreign-born (Cervantes et al., 1991). One key caution that was highlighted in the HSI study was against assessment and evaluation of stressor events without additional questions focused on mediation of stress and coping techniques (Cervantes et al., 1991).

Health. While there are few studies of the relationship between discrimination and depression among racial and ethnic populations, there are even fewer on Hispanics" (Finch et al., 2000). Finch et al. (2000), conducted a study on perceived discrimination, depression and Mexican-origin adults in California. The study addressed the selection process of individuals using demographic information with specifics about nation of origin, ethnicity, and parental birthplace. Finch et al. (2000) found that higher levels of perceived discrimination increase depression for immigrants and transnationals and that the largest effects of perceived discrimination on depression are observed among native residents. This study reflects why the perception of discrimination of Hispanics is of concern, despite nation of origin or residency status.

Finch, Hummer, Kol and Vega (2001) conducted a study to assess the effects of discrimination and stress on the physical health of Mexican-origin adults. This study was the first to assess the effects of immigrant specific stressors (e.g. legal status issues and job market discrimination) on the health of participants (Finch et al., 2001). Perceived discrimination was captured in four general discrimination questions. However, the study found significant results of overall discrimination on self-reports of negative health outcomes (Finch et al., 2001).

A study by Krieger, Smith, Naishadham, Hartman, and Barbeau (2005) examined the validity and reliability of various self-report scales on discrimination for use in large-scale population research on health and racism. The study collected data from working black, Latino, and white adults, targeting a sample of 200 for each. The survey was administered on site using Audio-Computer Assisted Self-Interviewing (ACASI). This computer software allows users to see questions and answers on the screen, while hearing information read aloud through headphones. The ACASI system also allows the participant to complete the assessment in either English or Spanish. This method of data collection was used due to the sensitivity of perceived

discrimination inquiry and to increase the number of responses from low-literacy participants (Krieger et al., 2005).

Employment decisions. A 2000 study by the Construction Industry Institute (CII) focused on how to attract and maintain a skilled workforce. Reported findings were that, "craft workers believe their fellow workers leave the industry because of pay, lack of permanent employment, poor safety, poor treatment, and poor working conditions…Additional factors include wage rate perceptions and/or realities, desire for less mobility, increased licensing mandates and, most importantly, relatively low participation in formal training across the industry" (Whyte et al., 2007, p. 3). While this statement concerns all workers in construction, the results have serious implications for lower-level workers, in particular Hispanics who may receive even lower wages, less training, and perceive working conditions differently. The language barrier may also stand in the worker's way of communication and clear understanding of an employer's expectations for promotion opportunities.

A study by Sanchez and Brock (1993) examined how perceptions of discrimination of Hispanic employees affected work outcomes like organizational commitment, job satisfaction and work tension and how coping mechanisms could reduced the negative effects. The study cautions against generalization of results to other populations as the sample was, "slightly younger and better educated than the target population" (Sachez et al., 1993, p. 715). However, Sanchez and Brock's (1993) findings, "reveal the central role of perceived discrimination in the process of work stress through which ethnicity influences employee outcomes" (p. 715).

Survey Instrument Development

The survey instrument was compiled using questions from various instruments about perceived discrimination and minority populations, specifically Hispanics (e.g. Finch et al., 2000; Finch et al., 2001; Fraga et al., 2006; Krieger et al., 2005; Mena et al., 1987; Pew Hispanic Center, 2006a, 2007; Sanchez et al., 1996). Additional questions were created to target the career expectations of construction workers, particularly expected retirement and career options.

The survey instrument for this study took into special consideration the issues and recommendations from prior studies, including: addressing the nation of origin and language preferences of participants; using a 5 point Likert scale where possible; discussing coping techniques to remediate harmful stress effects on participants; and including questions about specific stressors and events. Testing participants using a bilingual computer aided survey software was pursued but was ultimately eliminated. The two major obstacles were the cost to administer the survey in a group format and computer literacy issues of some participants.

As Mena et al. (1987) pointed out, the issue of generational identity affects differences in perception and opinions. Therefore, specific questions focused on generational identity were included. Language preferences at work and at home were found to be connected to perceptions of discrimination in a study by Fraga et al.

(2006) and were also included. Due to the length of the survey instrument, questions about the overall discrimination in the community were excluded; this survey instead focused solely on perceived discrimination at work. As this is not a medical study, specific health questions were not included in the survey instrument.

Modeling some of the questions used by Sanchez and Brock (1993) regarding job satisfaction and work tension, questions were developed specifically for this study that pertain to how long employees expect to work in the construction industry, and what options they might pursue upon leaving, if not retirement. One question was created for participants to discuss their feelings should their children choose to work in construction. These final questions about employment decisions and family were determined to also yield results in a qualitative format, useful in an interview setting; therefore they were included in the quantitative survey instrument and flagged for potential follow up questions. The survey instrument was developed in both Spanish and English and pre-tested with a sample of Spanish-speaking construction workers. Translations, syntax, and formatting were adjusted before final data collection. The final quantitative survey instrument consisted of fifty-seven (57) questions on the following topics: twelve questions on speaking Spanish at work; five questions on being Hispanic in the United States; six questions about opportunities and work experiences; seventeen questions about being Hispanic at work and perceptions of discrimination; three questions on future plans in the construction industry; five questions about wages received; and nine demographic questions.

Access to Population

Two approaches to accessing this population were utilized. Initial access to participants was through employers. Two employers were agreeable to participating in this study. One company primarily employs workers as independent subcontractors, holding only two employees officially on payroll on an annual basis. This company setup has become more common as the construction market has fluctuated and documentation requirements have become the burden of employers. By holding workers out as independent contractors, the liability is shifted from the employer to the employees to provide proper documentation to the government of their right to work. In order to contact employees, it was necessary for the employer to call and inform workers personally of the study. Flyers were left at his office in sealed envelopes for pick up by potential participants. Due to the company setup, it was likely that many of the workers contacted would be more hesitant to participate, and have more trust issues to overcome with the researcher. While this setup was not ideal, independent contracting is a reality for this population, and therefore it was necessary and important to try and access this special sub-population of Spanish-speaking workers. The second company had a more traditional payroll system. Sealed flyers were mailed to Spanish-speaking workers after Human Resources addressed the envelopes.

This initial approach failed, without any way to verify how or why. Many possible reasons include the potentially intimidating testing location at the local University, the geographic proximity of the testing site to where the workers lived and worked,

time of day, day of the week, fear, and even lack of motivation. The second access approach attempted to eliminate many of these unknown issues simply by changing the location of the testing site, and taking the research process directly to the participants, in a more relaxed and familiar setting. The second approach to accessing this population was with the help of the local Catholic church. The church supports a large Spanish-speaking congregation, of which an estimated 70% are employed in construction, according to the church administrator. This approach yielded results.

Method

It was determined that a mixed method study in two phases would be best to develop and test the survey instrument for a larger population and further explore the experiences and opinions of the sample. The purpose of the survey instrument used in Phase I was to better understand the perceptions of discrimination of Spanish-speaking construction workers with respect to pay, opportunities for work and advancement, language barriers, and overall treatment at work. The purpose of second phase interviews was to better understand employment decisions, perceptions of the construction industry, and alternative employment options of Spanish-speaking construction workers through the use of qualitative group discussions. The group discussions also provided more detailed insight on how Spanish-speaking construction workers' perceptions of discrimination impact their employment decisions, along with an exploration of the effectiveness of the survey instrument itself.

The study began with a quantitative survey instrument administered in a group setting by a foreign-born interpreter. Questions appeared projected at the front of the room on a large screen, but were also read aloud by the interpreter in either Spanish or English. The participants were recruited because they work in construction and speak English as a second language, with a first language of Spanish. Participants volunteered for the study and participated anonymously. The sample consisted of up to five hundred (500) Spanish-speaking construction workers for Phase I and up to fifty (50) for Phase II.

The survey in Phase I takes approximately forty (40) minutes to complete. The survey was administered by the researcher and an interpreter in a group setting, at a local church on a Sunday, after church services, to protect the privacy of the participants. Participants were recruited using an announcement in the church bulletin written in Spanish, and an oral announcement by the researcher, which was translated at church services the week prior to data collection. While the survey was administered in a group setting, the discussion in the room was limited to questions of the researcher or translator only, to prevent bias and influence of data collected.

Follow up qualitative group discussions in Phase II were optional for all participants and anonymous. While initially up to five hundred (500) participants were qualified for Phase II, it was decided that only the first fifty (50) participants who volunteered specifically for Phase II would be used in small group discussions in order to limit the amount of in-depth qualitative analysis to a manageable but significant numbers.

Small groups were limited to no more than seven (7) participants at a time to facilitate more individual expression and less pack mentality. Each group interview took approximately fifteen (15) minutes to complete. Participants were informed of their option to be a part of Phase II upon completion of Phase I. Responses were recorded for translation using a digital recording device. The group discussions were lead by a foreign-born interpreter in a separate room, away from the survey collection process.

Items of Concerns

There are many underlying issues which need to be treated with care in the collection of personal perceptions of bilingual workers. The data collection and analysis process must protect the identity of the participants, while reporting their perceptions of discrimination. Researchers must be careful to protect the employee from any repercussions of sharing negative perceptions about their work experiences, therefore all information and results for this study shall be presented in aggregate form, with no specific questions focused on the participant's current employer.

For legal reasons, the specific question of immigration status must be avoided. However, it was necessary to determine how long a person and his family have been in the U.S., his nation of origin, educational background and experience, and his specific exposure to the English language; research has shown that these variables are related to perceived discrimination (e.g. Finch et al., 2000; Finch et al., 2001; Krieger et al., 2005; Mena et al., 1987; Sanchez et al., 1996). However, no personal identification or documents were requested for this study.

Some of the many issues to be aware of that affect cross-cultural communication are trust of outsiders, white identity, language and interpretation, obtaining mutual understanding, literacy levels, male and female interactions, and cultural expectations and family roles for specific individuals which may vary by gender. In order to eliminate as many of these concerns as possible, a foreign-born translator administered the survey and proctored the group discussion and all documents were translated into Spanish at a lower literacy level. For a better understanding of how certain issues may affect the methodology of a study involving bilingual participants, see the decision matrix in Figure 1.

Conclusions

While the United States has a long history of being a nation of immigrants, that history may be changing, along with general attitudes about opportunities afforded to individuals who come to the U.S., documentation status as a pre-requisite for opportunity, and English as a requirement for permanent residency. "Considering the fact that this country was built by immigrants, it is surprising that the construction industry has not turned more immediately and strongly toward this source of willing workers" (Schleifer, 2002, p. 101). While things are changing in the political arena, there is still a large population of workers caught in the middle of the debate about immigration rights and language in the United States, including native-born, Spanish-speaking employees. Whether they have legal documentation and permission to be in the United States, and whether they speak English or not, Spanish-speaking and

bilingual workers are an important part of the economic and social systems of the United States.

Item of Concern	*Yes*	*No*
language barrier between researcher and participants	Consider the use of a translator or interpreter to overcome the language barrier	No action required
little trust for outsiders	Consider access that creates or builds a relationship between the researcher and participants over time	No action required
low literacy level	Consider oral surveys, group discussions, personal interviews, focus groups rather than written data collection methods, and reduce any written communication to the lowest literacy level of participants.	Maintain an average literacy level for all written communications.
cross cultural study	Consider the use of a mediator or translator to deliver questions and information in apropriate formats across cultures	No action required
gender differences between researcher and participants	Consider whether a more approachable gender (similar to the participants) is required for the specific population	No action required
neutral site needed for testing	Consider where participants will feel most comfortable and whether additional incentives are needed to overcome any fear of attending	No action required
participants have strong religious beliefs or affiliations	Consider where participants will feel most comfortable and whether this connection can/should be used to access this population	No action required

Figure 1. Decision Matrix

While the debates rage on about immigration and language, the construction industry has been experiencing widespread labor shortages. In the middle of the labor shortage, one demographic stands out: the number of Hispanics in construction is growing. Hispanics represent a diverse population from a number of countries, including the United States. Hispanics do not have a native language common to all; English, Spanish, or both may be spoken by a person who identifies as Hispanic. So while the construction workforce is in crisis, it is important to identify any positive labor changes and support any evident growth in numbers or representation which could help the entire industry. Therefore, employers need to know more about the Hispanic workforce.

A particular item of concern with respect to Hispanic employees, is the effects of a potential language barrier. While not all Hispanics speak Spanish, or Spanish only,

the numbers of Spanish-speaking employees in construction is also climbing. Whether these workers expect to stay in the construction industry should concern many employers who desire to maintain their workforce in the future. Therefore the perceptions of these workers and how they have been treated by industry is critical.

The Spanish-speaking workforce, which includes both native and foreign-born workers, is caught directly in the line of fire of the debates on immigration and language. In order to protect workers, prevent misunderstandings, and maintain a workforce in a time of crisis, the issue of perceived discrimination is important. While actual discrimination is damaging and a very real issue, living and working with perceptions of discrimination can increase stress, cause adverse health conditions, and negatively affect the employment decisions of a worker (Finch et al., 2000; Finch et al., 2001; Sachez et al., 1996). Increased knowledge and awareness of perceived discrimination gives employers an opportunity to improve the working conditions of all employees. Improving research methods, including giving special consideration to survey development and access to participants is critical to increasing knowledge about this particular population.

Simply accessing a diverse, bilingual population which may be hesitant to participate in similar research opportunities, can be challenging. Research methodologies must confront and conquer many unique issues with special populations like that of Spanish-speaking construction workers. As part of this study, a decision matrix was helpful in developing an effective approach to the population, but not without an initial failed attempt to recruit participants. In the end, additional limitations were accepted with an enlarged sample using the Catholic church as part of the recruitment for this study, as the researcher ultimately cannot verify that participants actually work in construction full-time, part-time or at all. The importance of the data collection itself, and the information that was obtained as part of this study, overpowered the limitation on the results.

REFERENCES

Brandenburg, S., Haas, C. T. M., and Glover, R. W. (2003). The tier I construction work force management strategy. *Proc., 2003 Construction Research Congress*, ASCE, Reston, Va.

Castañeda, J. A., Tucker, R. L., and Glover, R. W. (2003). A revolutionary and structured approach to construction work force management: The tier II strategy. *Proc., 2003 Construction Research Congress*, ASCE, Reston, Va.

Cervantes, R.C., Padilla, A.M., & Salgado de Snyder, N. (1991). The Hispanic stress inventory: A culturally relevant approach to psychosocial assessment. *American Psychological Association (3)*3, 438-447.

Chini, A.R., Brown, B.H, & Drummond, E.G. (1999, April). Causes of the construction skilled labor shortage and proposed solutions. *ASC Proceedings of the 35th Annual Conference,* 187-196.

Construction Industry Institute. (2005a, April 15). Construction industry image. *CII WP Idea #30.*

Construction Industry Institute. (2005b, April 15). National strategic goals of the construction industry. *CII WP Idea #60.*

Construction Industry Institute. (2005c, April 15). Shared learning: A workforce renewal imperative. *CII WP Idea #26.*

Contrada, R.J., Ashmore, R.D., Gary, M.L., Coups, E., Egeth, J.D., Sewell, A., Ewell, K., Goyal, T.M., &Chasse, V. (2000, August). Ethnicity-related sources of stress and their effects on well-being. *American Psychological Society 9*(4), 136-139.

Finch, B.K., Hummer, R.A., Kol, B., & Vega, W.A. (2001). The role of discrimination and acculturative stress in the physical health of Mexican-origin adults. *Hispanic Journal of Behavioral Sciences, 23,* 399-429.

Finch, B.K., Kolody, B., & Vega, W.A. (2000, September). Perceived discrimination and depression among Mexican-origin adults in California. *Journal of Health and Social Behavior, 41*(3), 295-313.

Fraga, L.R., Garcia, J.A., Hero, R., Jones-Correa, M., Martinez-Ebers, V., & Segura, G.M. (2006). Latino National Survey: Executive Summary. Retrieved April 15, 2008, from http://depts.washington.edu/uwiser/LNS.shtml

Kavanaugh, P., & Retish, P. (1993). The Mexican American employee: A growing labor force. *Public Personnel Management, 22*(3), 421.

Krieger, N., Smith, K., Naishadham, D., Hartman, C., Barbeau, E.M. (2005). Experiences of discrimination: Validity and reliability of a self-report measure for population health research on racism and health. *Social Science and Medicine, 61*, 1576-1596.

Mena, F.J., Padilla, A.M., Maldonado, M. (1987, June). Acculturative stress and specific coping strategies among immigrant and later generations college students. *Hispanic Journal of Behavioral Sciences, 9*(2), 207-224.

Pew Hispanic Center (2006a). *2006 National survey of Latinos: The immigration debate.* Washington, DC: Author.

Pew Hispanic Center (2007). *2007 National survey of Latinos: As illegal immigration issue heats up, Hispanics feel a chill.* Washington, DC: Author.

Reimers, C.W. (1983, November). Labor market discrimination against Hispanic and Black men. *The Review of Economics and Statistics, 65*(4), 570-579.

Sanchez, J.I., & Brock, P. (1996, June). Outcomes of perceived discrimination among Hispanic employees: Is diversity management a luxury or a necessity? *The Academy of Management Journal, 39*(3), 704-719.

Schleifer, T.C. (2002, August). Degenerating image of the construction industry. *Practice Periodical on Structural Design and Construction*, 99-102.

Thomas-Breitfeld, S. (2003, August). The Latino workforce: Statistical brief. *National Council of La Raza Statistical Brief* (3), 1-16.

Whyte, D., & Greene, S. (2007). The skilled workforce crisis. *Owner's Perspective Magazine, Spring 2007,* 1-10.

OVERTIME AND PRODUCTIVITY IN ELECTRICAL CONSTRUCTION

Awad S. Hanna[1], Gilbert Haddad[2]

[1]Professor and Chair, Construction Engineering and Management Program, Department of Civil and Environmental Engineering, University of Wisconsin-Madison, 2320 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706, E-mail: hanna@engr.wisc.edu
[2]Project Assistant, Department of Civil and Environmental Engineering, University of Wisconsin-Madison, B1189 Mechanical Engineering Building, 1513 University Avenue, Madison, WI 53706, E-mail: ghaddad@wisc.edu

ABSTRACT

Electrical contractors are at high risk, mainly because of the high percentage of labor in electrical construction activities and the fact that a significant part of their work is last in line in a project, which leads to facing schedule compression. The main schedule compression techniques are overtime, overmanning, and second shift. This paper quantifies the impact of overtime on labor productivity for electrical contractors. Several studies have addressed overtime, but they tend to be old and the source of data is questionable. This paper contains both quantitative and qualitative analyses. The qualitative analysis is based on a survey sent to companies around the United States and Canada and analyzes contractors' responses regarding use of overtime on their projects. The quantitative analysis consists of collecting productivity data from different contractors and studying the effect of using overtime on labor productivity. Statistical models are developed and show the behavior of productivity when using overtime. The quantitative analysis further contains macro and micro approaches. The macro approach model projects where productivity for the whole project is tracked, and no specific overtime schedule is used. As for the micro approach, it shows the effect of using a fixed overtime schedule using the Measured Mile Method (MMM) which compares the productivity in unimpeded time to that in impacted time in order to determine how significantly the project's productivity was impacted. The models developed show that as the number of hours per week increases, the productivity decreases. This study will decrease disputes among owners and contractors regarding the price of additional work. Furthermore, the paper presents a scientific method for forward pricing overtime work and aiding in understanding the risks and rewards of implementing different types of overtime schedules. It also offers valuable insight with regards to safety, supervision, worker fatigue, absenteeism, and other factors related to overtime use.

INTRODUCTION

In recent years, the need for electrical constructors to complete a construction project in a shorter than customary time period is ever increasing. It is not uncommon for an electrical constructor to find that he/she must compress or accelerate a construction schedule to meet the basic objectives of the project. In the United States' system of competitive contract construction, it must be conceded that for any given project, a prudent and capable constructor will plan the work most economically within the scheduled period of time. Then, if the contract is either compressed (reduced from the normal or typical time frame) or accelerated (speed of progress increased from the normal or typical progress speed) so that the constructor is required to perform substantially the same work in a different length of time, the cost of the work will necessarily increase.

Previous research has indicated that in approximately 73% of all construction delays, project owners refuse to grant time extensions (Leonard et al. 1988). The lack of time extension and accelerated completion date forces the constructor to compress the construction schedule and complete the project in a less than customary time frame. There are many other potential causes of schedule variation that lead to the necessity of schedule compression or acceleration uniquely associated with each and every project. Some of these causes may be attributed to the following:

(1) Contract change orders; most (90%) of change orders are caused by increased scope, design changes, design errors, and design coordination (Hanna, 2001).

(2) Poor performance by previous work crews; this is particularly important as electrical contractors are typically a follow-up trade and a big part of their work is performed "last-in-line."

(3) Anticipated weather conditions; limit the available time for consideration.

(4) The owner requires that the proposed project be completed in a less than normal time frame.

(5) Seasonal construction considerations.

(6) Planned and unplanned utility work; this requires the outage to customers to be minimized.

(7) Minimize the shut-down time to plant operations during construction or maintenance work.

(8) Construction delay and delay recovery; lack of design detail or incomplete design prior to the start of construction may also result in construction delay.

RISK AND ELECTRICAL CONSTRUCTION

Electrical contractors generally allocate 33-50% of a project's total budget to labor costs (Hanna 2000). Of the typical project cost components (material, equipment, and labor), labor is considered the project element containing the most risk. The other cost components (material and equipment) are predominately determined by market price and consequently beyond the influence of the project management. As a result, the management of labor and its productivity becomes paramount in determining the success of a project. Additional risk carried by electrical contractors is the fact that a significant part of their work is last in line and typically carries delays created by other trades and increased scope.

THE USE OF OVERTIME IN ELECTRICAL CONSTRUCTION

This study shows that overtime is the most common but not the most preferred acceleration technique an electrical contractor can use to expedite a project, and it is problematic when forward pricing work and understanding associated labor inefficiencies. Forward pricing occurs when a contractor prices overtime work before it is performed. If an electrical contractor is delayed and an owner requests the contractor to forward price the remaining work with an accelerated overtime schedule, the contractor will likely have difficulty proving costs of anticipated labor inefficiencies because no overtime studies exist in this area. Current overtime studies are only able to capture labor inefficiencies after work is completed, and these studies combine impacts of overtime, overmanning, and shift-work. Therefore, a study is needed to understand and forward price labor inefficiency for overtime.

There have been several research efforts to study the effect of overtime on labor efficiency, namely those by the Bureau of Labor Statistics (1947), Business Roundtable (1980), and the National Electrical Contractors Association (1969). The accuracy of these overtime studies have been questioned by researchers and attacked in such industrial and academic publications as Cost Engineering, the Construction Industry Institute (CII), and the Journal of Construction Engineering and Management (JCEM) of the American Society of Civil Engineers. Moreover, the data sources for most of these studies are unknown and unable to be scientifically scrutinized. One of the major problems in applying the NECA 1969 study, for example, is that it produces results that surpass the Total Cost Method. The Total Cost Method is the contractor's actual hours used minus his estimated hours. The Total Cost Method is rarely used in the U.S. court system because it holds the claimants blameless and is barred by many superior courts, including California and Wisconsin. Other problems of overtime studies include limitations of generalizability to only a particular overtime schedule such as 5x10 or 6x10, reliability for a limited number of weeks overtime is used (16 weeks maximum for NECA 1969), lack of robustness when overtime is interrupted briefly by a non-overtime schedule, and research methodology.

TERMINOLOGY

Schedule compression commonly refers to the reduction of time available to complete a project. Common methods that are used when facing schedule compression are overtime, shift work, and overmanning. Overtime is often preferred because it can produce a higher rate of progress without the coordination problems of shift work and the additional craftsmen needed for overmanning. However, overtime introduces problems such as fatigue, low morale, higher cost per unit, higher accident rate, and a phenomenon described by the U.S. Army (1979) where workers tend to pace themselves to adjust to the longer work day or week. Contractors often implement overtime in response to an accelerated schedule, in emergency rebuilding or outage work situations, to exploit the benefits of good weather, to maximize equipment use, to avoid penalty clauses, to achieve bonus clauses, or to beat strike or rate increase deadlines (Smith 1987; BRT 1980).

Following are some background definitions for this study: ***Overtime*** is work performed beyond the reference schedule of 8 hours per day and 5 days

per week. Overtime can occur in a variety of schedules, such as 5 days of 10 hours worked per day (5x10). Other examples of common overtime schedules include 5x11, 6x10, and 7x10.

Productivity is the ratio between earned work hours and expended work hours (work hours used).

Measured Mile Method (MMM) compares the unit productivity levels during unimpeded time (during the reference schedule) to those during impacted time (when using overtime) in order to determine how significantly the project's productivity was impacted (Zink, 1986). The theory is that the difference between a contractor's actual inefficient productivity and an identified normal productivity is the amount of excess cost to the contractor as a direct result of labor inefficiencies and loss of productivity.

Earned Value Analysis (EVA) is a performance measurement that compares planned and actual results. Earned value can be determined by monitoring the actual production of field labor as compared to estimated production. Equation 1 can be used to determine the number of hours earned at both activity and project levels.

Equation 1: $$Earned\ hours = Percent\ complete * Estimated\ hours$$

Performance Factor (PF) can be determined by comparing the earned hours of an activity to the actual number of hours needed to complete the task. Equation 2 shows this relationship. PF is also known as Efficiency or Performance Index.

Equation 2: $$PF = \frac{Earned\ hours}{Actual\ hours}$$

When PF > 1, the activity is completed in less time than expected and is viewed as efficient. If PF < 1, the activity took more time than expected and is viewed as inefficient.

LITERATURE REVIEW

Numerous researchers have undertaken studies which report and document that overtime reduces labor productivity. All studies concur that productivity is reduced, but the magnitude of the decline varies from study to study. The more prominent and most widely used studies are by the Bureau of Labor Statistics, the Business Roundtable, NECA, and the Construction Industry Institute (CII).

Kossoris (1947), showed how productivity decreases as hours per day and days per week increase. Nothing is known about the source, nature, or quality of the data used by Kossoris (Horner and Talhouni 1995), and it is probable that the data was taken from the manufacturing sector rather than construction (Thomas 1992). The Business Roundtable (BRT 1980) reported data collected over a ten-year period from a Proctor and Gamble processing plant in Green Bay, Wisconsin. However, what is known about the nature of the data must be compiled from various documents since the BRT's report lacked a detailed description. Horner and Talhouni report that the data referred to a series of scheduled overtime jobs each lasting less than 13 weeks. Thomas (1992) reports that the Proctor and Gamble data was from a single project, consisting of shorter jobs with overtime, and the true type of construction performed is unknown. The Roundtable report itself did mention that the operations of the project were performed under excellent field

management in times of tranquil labor relations (Business Roundtable 1980). Smith (1987) reported a very similar interpretation, but he failed to provide a reference or source of data in his document. The National Electrical Contractors Association released an overtime and productivity study in 1969 that related productivity loss to weeks of overtime. The study gave different scenarios of work days per week and hours worked per day. A graphical representation of this study is presented in Figure 1. The data is around 40 years old, and the source and quality of the data is again uncertain.

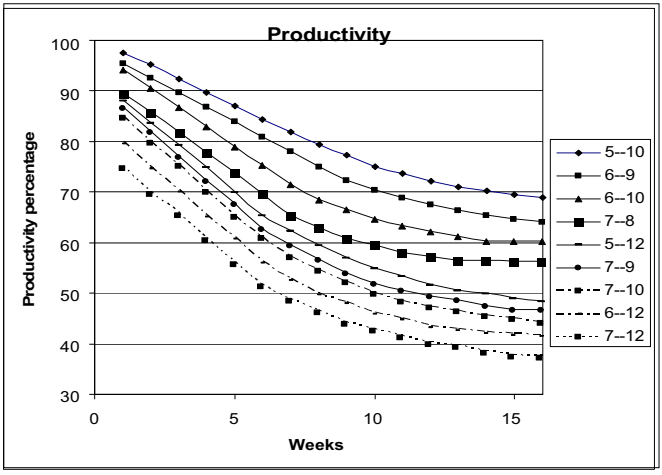


Figure 1- Productivity Loss (%) vs. Weeks of Overtime (NECA 1969: reproduced)

Furthermore, data taken from concrete work performed in amiable climate (Adrian 1987) are reported and a model very similar to the NECA model.

In 1988 the Construction Industry Institute published the results of data collected from 25 different crews working on 7 independent projects. The different crews worked under overtime schedules of 4x9's with 1x8, 5x10's with 1x8, 6x8's, 6x10's, and 7x10's (CII 1988).

Several authors, including Thomas and Larew, question the validity and accuracy of past overtime studies. Thomas concludes that the literature on scheduled overtime is dated, based on small sample sizes, and largely developed from questionable or unknown sources (Thomas 1992). In a paper examining the reliability of past overtime studies, Larew (1998) presented an argument that the overtime data published by the Bureau of Labor Statistics, NECA, the MCAA, the Business Roundtable, and the U.S. Army may actually come from one or two common sources with some manipulation of the data to make each study appear unique. Larew concludes that the published data cannot be relied upon to a reasonable degree of cost engineering certainty (Larew 1998). This paper quantifies the impact of overtime on labor productivity for electrical contractors through

quantitative and qualitative analyses. By analyzing well determined data sources, models are developed to study the effect of overtime on labor productivity.

QUALITATIVE ANALYSIS

In order to gain an understanding of how electrical contractors view the use of extended overtime and alternative methods of schedule compression, a survey was developed and mailed to NECA members. The survey gathered information about the contractors' perceptions of overtime use in the electrical construction industry, why extended overtime is used, alternatives to using extended overtime, and the types of overtime schedules commonly used. Of the initial 400mailed surveys mailing, 51 were returned by contractors.

Responses are from the United States and Canada. The United States was divided in 5 regions: Northwest, Southwest, Northcentral, Southeast, and Northeast. Table 1 shows the average opinion of the responses to nine questions regarding the use of overtime.

Table 1- Average Opinion of Overtime Responses (1- Strongly Disagree, 5- Strongly Agree)

	Regions						
Question	**NE**	**SW**	**NW**	**MW**	**SE**	**Canada**	**Aggregate**
1. Extended Overtime is used frequently in the construction industry.	2.917	3.500	3.429	2.800	3.333	2.750	3.121
2. Extended Overtime reduces labor productivity.	4.083	4.900	4.571	4.667	5.000	3.750	4.495
3. Extended Overtime increases accidents.	3.833	4.100	4.429	4.133	4.667	3.500	4.110
4. Extended Overtime increases absenteeism on projects.	4.000	4.300	4.571	4.067	4.667	2.750	4.059
5. Extended Overtime increases turnover on projects.	3.500	3.400	3.000	3.429	4.000	2.000	3.221
6. Extended Overtime is necessary to achieve project schedules.	3.167	2.500	2.857	2.500	3.000	3.500	2.921
7. Extended Overtime is necessary to attract skilled crafts to projects.	2.667	2.900	2.714	2.133	2.667	2.500	2.597
8. Owners and contractors are using more overtime than is required.	2.833	3.200	3.571	3.200	4.333	2.000	3.190
9. There are better alternatives that can be used instead of extended overtime.	4.000	3.800	3.857	4.000	4.000	3.500	3.860

The companies surveyed were asked to report the percentage of their projects that use extended overtime, or working more than 40 hours per week for more than four weeks. The responses indicate 18.9% of projects used extended overtime. The Northeast region had the highest use with 24.79% of its projects utilizing extended overtime. Next is the South West with 23.6%, followed by the Northwest with 19.29% and the Midwest with 14.13%, then the Southeast with 11.67%, and finally Canada with 11.25%.

Responses across all regions signify that contractors feel overtime reduces labor productivity. Contractors in the SE and NW were more likely to blame the reduction of productivity on an increase in accidents and absenteeism than other regions; however, the NE, SW, and MW also recognized that more accidents and absenteeism may lead to lower productivity. Responses also indicate that an increase in accidents and absenteeism during times of extended overtime likely contributes to decreased productivity. It can also be concluded that overtime is not commonly used to achieve project schedules or to attract labor. Moreover, most regions feel better alternatives to extended overtime exist.

In regards to reasons for overtime use, contractors in the MW were most likely to use overtime because of an aggressive schedule and to reduce plant outages. The SW used overtime for aggressive schedules which may be caused in part by growth in California and the Las Vegas area. The SE relied on overtime mainly to reduce plant outages, which could be driven by the oil refineries in the Gulf of Mexico. The NW relied on overtime to reduce plant outages and to compensate for scope changes. All of the regions reported that attracting labor or making up for labor-related delays was not a main motivator of overtime usage.

The use of a 2nd Shift was the most commonly utilized alternative to overtime. This was followed by the use of Rolling Crews/Shifts, which allows for constant labor on a project and decreases the number of craftsmen used at a given time. Overmanning was perceived as the least effective option, most likely due to increased costs associated with additional labor. Moreover, maintaining adequate access to tools, materials, and space is more difficult with additional labor on site.

Since overtime allows for the crew size to remain small and doesn't require additional tools or craftsmen, it is the most popular method of schedule acceleration.

On the results about overtime schedules, 5-10 was preferred by nearly half the respondents because it can be implemented by simply altering the labor break schedule, and it allows for labor and management alike to enjoy a full weekend.

QUANTITATIVE ANALYSIS

The macro and the micro approaches are used for analyzing overtime in projects. The macro approach is used when no fixed overtime schedule is used, or mixed work schedules are used throughout a week, and productivity data is not accumulated for individual electrical construction activities. On the other hand, the micro approach is used to analyze projects that use a fixed overtime schedule; such as 5x10, 6x10 throughout a certain number of weeks.

Macro Approach

In some projects where overtime is used, a fixed schedule might not exist, or the work hours per day may be different each day of the week. In such cases, the task of identifying a fixed overtime schedule becomes impossible. An alternative method is to plot the performance factor index against the total hours worked per week. The performance factor is derived from Formula 2 (Performance Factor = Earned Hours/Actual Hours). Figure 2 shows that productivity decreases as the number of hours of work per week increases.

A regression line ($y= -0.0207x + 1.8295$) is fitted to the data (accumulated from different projects between 2005 and 2008) with an R^2 squared value of 65.72%, and the line shows a productivity of 1 for about 40 hours per week. This confirms the belief that productivity

is the best for a forty hour per week schedule. Moreover, the upper and lower limits on figure 2 are the 95% confidence interval for the proposed model.
The advantage of this method is its representation of both the direct and indirect effects on productivity, since actual labor hours are calculated after the completion of a project. Additionally, projects often use mixed overtime schedules (e.g., 5x10s and 6x10s) or fail to utilize a set overtime schedule throughout the project duration. Moreover, the crews working overtime on a project often change, and periods of extended overtime work may be interrupted by periods of straight time work. These circumstances, coupled with a lack of detailed record keeping by contractors, force the need for a macro approach to determine the impact on productivity instead of using an earned value approach for a specific overtime schedule.

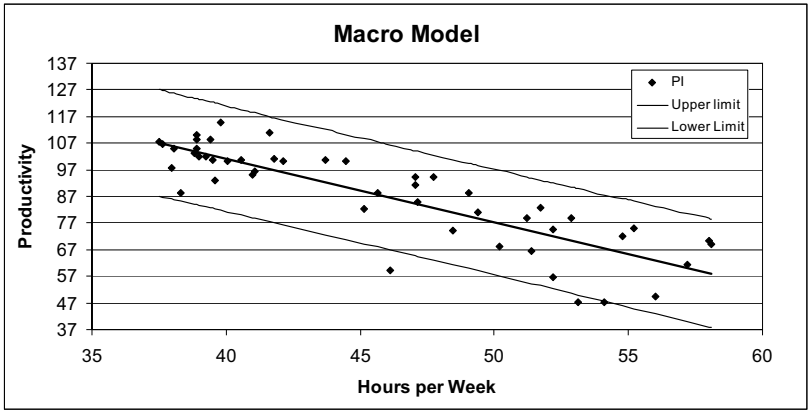


Figure 2- Performance Factor versus hours per week

Micro Approach

When consistent earned value data is maintained over the duration of a project and a single overtime schedule is used, it is possible to develop more detailed and accurate productivity loss models which correlate to specific types of overtime schedules. Ideally, the project would include a period without overtime in order to develop the Measured Mile Method (MMM) to gage productivity. To develop these models, earned value is expressed in the form of a Performance Factor and can be correlated to the week of extended overtime or to percent complete. Productivity is expressed as the ratio of earned hours to actual hours worked. The Measure Mile Method is developed by calculating the difference in productivity for the same activity when subjected to a fixed overtime schedule and the regular 5x8 schedule. The NECA model is reproduced from the NECA 1969 study.

In a 36 story condominium project in Florida, overtime was used because delays were introduced. The increase in manpower and working hours was attributed to one of the contractors accelerating the work activities. Furthermore, the project was poorly

managed. The project started with a 5x8 schedule but then used a 6x10 overtime schedule. Figure 3 shows the MMM, and the NECA model. The MMM model is applied to study the change of productivity when moving from the reference schedule to overtime.
The MMM and NECA models produce very similarly decreasing trends, though the MMM over-predicts (higher productivity) the NECA model by about 12% at week 1, and the difference increases till week 8 where the MMM over-predicts by 17.4%. The difference starts to decrease at week 9, till the two models match between weeks 14 and 15. And then the NECA model over-predicts the MMM at week 15 and on.

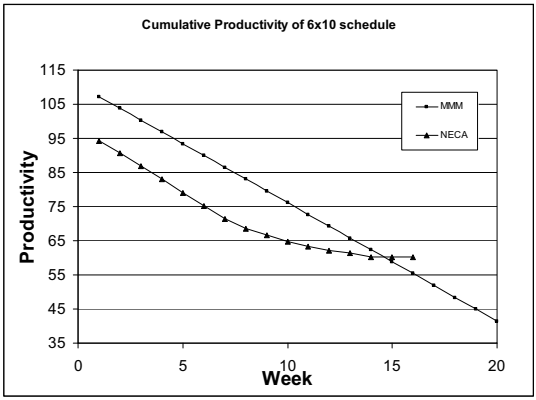


Figure 3- 6-10 model with NECA and Measure Mile Method

Similar models are developed for common overtime schedules (5x10, 7x10, 7x12), and they provide a reference for the actual drop in productivity when using overtime. This will help in understanding the impact of accelerating the schedule and forward pricing overtime on a project. Furthermore, the models also help in capturing overtime labor inefficiencies.

CONCLUSIONS

This paper first explained the problem of overtime in electrical construction and reviewed relevant existing research in the field. It also explained the different ways a manager can make up for delays in a particular project. Contractors in the US and Canada were surveyed, and their responses indicated their opinion on the use of overtime.
A macro approach was developed where no fixed overtime schedule was applied. The decreasing trend of the best fit line comparing Performance Index and the number of hours worked per week confirms that an increase in overtime is associated with a decrease in labor productivity. Additionally, the MMM was utilized to develop a micro approach to determine the effect of overtime schedules on productivity. A model was developed and was compared to the NECA models, and the results reflected alignment in different parts.

By providing models based on reliable data, this study will assist the industry in understanding the impact of accelerating the schedule and forward pricing overtime on a project. This research will decrease disputes among owners and contractors regarding the price of additional work by providing a supported method for capturing overtime labor inefficiencies. This research further offers a scientific method for contractors to forward price overtime work and aids them in understanding the risks and rewards of implementing different types of overtime schedules. It will also provide valuable insight with regards to safety, supervision, worker fatigue, absenteeism, and other factors resulting from overtime use. For owners, this study identifies realistic expectations of how schedule compression will affect the price of electrical work and when, or by how much, a project should be accelerated.

REFERENCES

Adrian, James J. (1987). "Construction Productivity Improvement." Elsevier Science Publishing Company, New York, N. Y.

Business Roundtable. (1980) "Scheduled Overtime Effect on Construction Projects." New York, New York.

Construction Industry Institute. (1988). "The Effects of Scheduled Overtime and Shift Schedule on Construction Craft Productivity." University of Texas at Austin.

Hanna, Awad S. (2000). "Quantifying the Cumulative Impact of Change Orders for Electrical and Mechanical Contractors." Construction Industry Institute Report.

Horner, R. M. W. and Talhouni, B. T. (1995). "Effects of Accelerated Working, Delays, and Disruptions on Labor Productivity." The Chartered Institute of Building, England.

Kossoris, M. (1947). "Hours of Work and Output." Bureau of Labor Statistics. Bulletin No. 917. U.S. Department of Labor.

Larew, Richard E. (1998). "Are Any Construction Overtime "Studies" Reliable?" Cost Engineering, Vol. 40, No. 9.

Long, Richard J. (1988). "Proof of Damages in Construction Claims." American Association of Cost Engineers Transactions.

National Electrical Contractors Association. (1969) "Overtime and Productivity in Electrical Construction." Washington D.C.

Smith, Andrew G. (1987). "Increasing Onsite Production." American Association of Cost Engineers Transactions.

Thomas, H. R. (1992). "Effects of Scheduled Overtime on Labor Productivity." Journal of Construction Engineering and Management, Vol. 118, No. 1, March.

Waldron, James A. (1968). "Applied Principles of Project Planning and Control." Haddonfield, New Jersey.

Schwartzkopf, William (2004). "Calculating Lost Labor Productivity in Construction Claims", second edition.

UNABSORBED OVERHEAD: EICHLEAY AND OTHER METHODS

Amarjit Singh[1] F.ASCE and Thomas Taam[2]

Abstract
The technique for calculation of home office overhead damages, a claim category on construction projects, has been widely debated. The Eichleay Formula is a well known technique for such claims that evolved over the past 48 years. This paper provides concepts of compensable home office overhead damage due to a project delay, the evolution and required prerequisites for using the Eichleay formula, and alternate formulas and techniques used. A "Direct Method" is proposed, which is simpler to apply. In the final analysis, obtaining a 100% accurate estimate of home office expenses is impractical, if not infeasible.

Introduction
Home office overhead expense damages incurred due to project delay are called 'unabsorbed overhead'. The most commonly applied method for calculating home office overhead claims for damages due to delay is the "Eichleay Formula". This paper focuses on several areas relating to the Eichleay Formula and its evolution, and provides an explanation of the elements of the formula and alternate formulae for calculating unabsorbed overhead. The paper will present criticism surrounding the use of the Eichleay Formula. Various techniques for calculating unabsorbed home office overhead will be presented, and the results will be compared and analyzed. All known techniques have been pulled together in this study.

Items in Home Office Overhead
Home office overhead normally consists of costs such as rent, utilities, furnishings, office equipment, executive staff salaries, support and clerical staff salaries, project related staff (engineers, estimators, schedulers), mortgage costs, outside legal and accounting expenses, depreciation, auto travel, professional trade licenses and fees, employee recruitment, relocation, training and education, photocopying, entertainment, contributions, donations, postage, cost of preparing bids, review of submittals, taxes, advertising, insurance premiums, interest costs, and data processing/computer costs. The contractor needs to pay or recover these costs by allocating these costs to the projects it performs (Taam and Singh, 2003). The unabsorbed home office overhead that will be discussed here consists of the home office overhead for which the contractor is not paid for work that is really compensable.

[1] Dept of Civil Engrg., Univ of Hawaii, Honolulu, HI 96822; PH (808) 956-3933; FAX (808)-956-5014; email: asingh@hawaii.edu

[2] U.S. Army Corps of Engineers, Fort Shafter, HI 96819; email: ttaam@yahoo.com

Evolution of the Eichleay Formula

History of the Formula

Before 1940, unless expressly permitted by the contract, the contractor could not recover consequential damages for government delay (*McCord v. United States)* [1]**.** The bias towards owners is found to increase as one checks case law further back in history. The U.S. government's position in earlier centuries was simply that it had paid for the right to change the contract. In 1945, however, in the case of *Fred R. Comb Co. v. United States* [2]*,* the Court of Claims found the government liable to the contractor for home office damages caused by delay. The court also found that the government, having breached its contract, had no right to state that a contractor will go uncompensated. This laid the foundation for the emergence of the Eichleay formula, which set up criteria and formulae for calculating compensation due to the contractor.

The Eichleay Formula originated from a decision by the Armed Services Board of Contract Appeals in 1960, *Eichleay Corporation v. United States* [3]**.** In its appeal before the Board, the Eichleay Corporation proposed a formula for calculating the damages. The Board accepted this formula as a reasonable method for calculating the damages (Trauner, 1990).

The Eichleay Formula

The Eichleay formula is a three-step process as per the following formulae:

(Actual Billings for Delayed Contract x Total Actual Billings for Period (All Contractor Contracts)) ÷ Total Home Office Overhead for Period = Overhead Allocable to Delayed Contract (OACD) -(1)

OACD ÷ Days of Performance = Daily Contract Overhead for Delayed Contract -(2)

Daily Contract Overhead for Delayed Contract x Number of Days Delay = Overhead Claim Amount for Delayed Contract -(3)

A step-by-step example of the Eichleay Formula, using the data in the example shown later, yields a value of $6,667.

The Eichleay Formula first determines the allocation of home office overhead for a particular project. Next, it takes a portion of the allocation and applies it to the total days of performance, which results in a daily home office overhead cost. Finally, the Eichleay Formula calculates compensation due to a contractor for an owner-caused delay by multiplying the daily overhead rate with the days delayed. The formula is an attempt to provide a realistic basis for allocating home office overhead costs.

Acceptance of the Eichleay Formula

Since its inception, the Eichleay Formula has gained considerable acceptance, but courts and boards have generated numerous opinions concerning its application, going alternately back and forth on it. For example, in *Excavation-Construction, Inc. v. United States* [4]**,** the board recognized the use of the Eichleay Formula to determine the cost not only of a suspension of work, but also of a delay caused by extra work. In *Wickham Contracting Co. v. Fischer* [5]*,* the 3rd Federal Circuit held that the Eichleay formula was the exclusive means available for calculating unabsorbed overhead, overruling the earlier decision by the GSBCA (General Services Board of

Contract Appeals). In *Capital Electric Co. v. United States* [6], 1984, the 2nd Federal Circuit reaffirmed the applicability of Eichleay. However, disputes continued as to whether the Eichleay formula was the only correct method and whether other formulas led to a more accurate calculation of unabsorbed overhead (Peckar and Abramson, 1999).

Arguments against the Eichleay Formula

The most common argument against the use of the Eichleay Formula is that the contractor is already compensated for home office overhead in his markup of direct costs on changes, and therefore, requires no further compensation. The problem with this argument is that a contractor receives the markup regardless of whether or not the change causes a delay.

The Eichleay formula is often challenged and criticized in two principal areas by auditors, private and government attorneys, and judges. These two areas are (1) the overall concept of unabsorbed overhead, as covered in the Eichleay formula; and (2) the accuracy of the formula. In *Wickham Contracting Co. v. U. S. Dept of Defense* [7], the GSBCA claimed that Eichleay was entirely theoretical, and that *the Eichleay formula, which is a simple proration, cannot give a correct result because it has no mechanism for allocating wasted overhead where there are two or more delay sources* (Kaufmann and Holman, 1995).

Cibinic (1991) also took issue with the Eichleay formula by stating:

> *The Eichleay formula does not take into consideration the first and most important factor --- how much fixed overhead would have been allocated to the contract. In addition, it calls for a determination of the total overhead incurred during the contract period. This too, is defective; since fixed overhead (the subject of unabsorbed overhead) is incurred for accounting periods (usually the contractor's fiscal year), not contract periods (which would equate with the contractor's fiscal year in only the most rare and unusual coincidence).*

Denial and Reinstatement of the Eichleay Formula

As a result, courts minimized the formula in the late 1970's and early 1980's. A judge for the GSBCA predicted its complete demise. Non-government contract forums were the first to reject the use of the Eichleay formula; courts in New York [8] and Texas[9] both refused to apply it in construction delay cases. The low point for Eichleay was the GSBCA decision in *Capital Electric Co.*[10], where Judge Lieblich stated:

> *[We can be confident] ... that the government will never again go along with any payment to a contractor for "extended overhead" nor will it ever again agree to the application of the Eichleay formula to any overhead calculation in a construction case. Whether distinguished or overruled, those prior decisions will be dead letters hereafter.*

Within one year, however, the U.S. Court of Appeals for the 2nd Federal Circuit reversed the *Capital Electric* decision and reinstated the contractor's right to utilize Eichleay.

Compensability Criteria for the Eichleay Formula

Since the inception of Eichleay in 1960, courts have required prerequisite criteria to determine whether a particular situation would qualify for application of the Eichleay Formula. The first criteria is the uncertainty of the delay or standby period, and the second criteria is the "practicality" and "possibility" for the contractor to take on additional work, which would "absorb" the home office expenses during the period of delay. "Standby" is defined as an order by a contracting office to not perform any further work on a contract until requested to do so by the contracting officer.

The first criteria was upheld in *Community Heating & Plumbing Co., Inc. v. Kelso*[11]**.** Again, in *C.B.C. Enterprises, Inc. v. United States* [12]**,** the contractor appealed the Navy's denial of an extended overhead claim. The courts found that there was no suspension, delay, or disruption of work and that the period of performance was known. Recovery is permitted only when a "cloud of uncertainty" exists regarding the period of performance.

In *Interstate General Government Contractors v. West* [13]**,** the contractor claimed unabsorbed overhead costs because of government-caused delay subsequent to a standby. In this case, the project was completed 13 days early, but the standby was prolonged. The Federal Circuit implemented a three-part test that needed to be met whenever a contractor completes a contract early:

1. The contractor must prove that it intended to complete the contract early.
2. the contractor must prove that it had the capability to do so, and
3. It must prove that it actually would have completed early, but for the government's action.

The test is to assure prevention of a contractor receiving double payment on its overhead claim.[14] However the universal rationality of this test does not seem to have been established. The test is much like the victim of an injury in torts having to prove he had no intention to injure himself, a requirement that is not entertained in modern tort law.

In *Wickham Contracting Co. vs. Fischer*, the Federal Circuit court affirmed that the Eichleay Formula was the exclusive formula to use to calculate home office overhead damages when the Eichleay prerequisites were met. The prerequisites for use of the Eichleay formula are standby with uncertainty, and the impractical ability to take on additional work during the delay period to absorb the home office overhead. Since Wickham, the question in most government delay damage cases has been more a question of entitlement instead of a contractor having to prove damages in order for use of Eichleay.

In *West v. All-State Boiler* [15], the court found that the government could not meet its burden by showing either: "(1) that it was not impractical for the contractor to obtain other work to which it could reallocate its indirect costs; or (2) that the contractor's inability to obtain other work was not caused by the government's suspension…" This decision further clarified the second prerequisite of a contractor not having to prove that it was impossible to take on new work, but only that it was impractical to do so (Peckar and Abramson, 1999).

In *Melka Marine, Inc. v. United States* [16]**,** the Court further clarified that when the government identifies with certainty the date on which its delay will end, the standby test is not met. Standby requires an uncertain delay period where the government can

require the contractor to resume work. Naturally, many of these prerequisites are harsh and unwarranted, making recovery quite an onerous task for the contractor.

Alternate Techniques and Formulas

Other Formulae and Techniques

Critics of the Eichleay formula have suggested the use of various formulae and methods for use in calculating unabsorbed overhead damages, depending on the situation. Alternate techniques include ten methods, including one designed by the authors. These are the Comparative Absorption Rate Method (CARM), Burden Fluctuation Method, Carteret Method, Allegheny Method, Canadian Method, Modified Eichleay Method, Calculation based on Actual Records, Total Direct Cost Allocation Method (DCAM), Specific Base Allocation Method (SBAM), and Direct Method. Not all the methods can be discussed here for want of space, but the most important and representative ones will be described. The interesting factor about these alternate techniques is that they do not come with strings attached, such as the prerequisite criteria of Eichleay. Such is the nature of case law on this topic.

The following example will be applied to above methods to calculate unabsorbed home office overhead (McDonald and Baldwin, 1989). A summary of the results for comparison purposes is provided later.

Example Situation

The example applied to the formulas and methods to follow, is described: A project could have been performed by the contractor for a price of $400,000 over a four-month duration assuming no change orders were issued, and no suspensions of work or other delays were encountered. The contractor, in this example, has a fixed home office overhead rate of $40,000 per month, has $100,000 of monthly billings on this contract, has $400,000 per month from other contracts, and thus regularly does $500,000 worth of total business per month including the contract in question.

Under the contractor's "potential performance," contract billings are made through months 1 and 4 (both inclusive). Total billings stay at $500,000 for all months and reflect what would have happened but for any changes or delays by the owner on this project.

In the "actual performance", there is a one-month suspension in the third month: the contractor has to forego contract billings for that month, but still must carry a home office overhead. Thus, while total billings are $500,000 for all months, they fall by $100,000 in month 3.

Burden Fluctuation Method

This method determines unabsorbed overhead by finding the increase in the absorption rate and allocating that increase to the non-contract work, which was forced to bear more than its fair share of overhead expenses. The burden fluctuation method has been used by courts and boards to calculate manufacturers' unabsorbed overhead claims.

Total Billings - Contract Billings = Other Contract Billings -(4)

Actual Overhead Rate - Potential Overhead Rate = Burden Fluctuation -(5)

Burden Fluctuation x Other Contract Billings = Unabsorbed Overhead Claim -(6)

Under the Burden Fluctuation Method, the contractor could claim a 0.33 percent increase in his overhead rate for the example considered, resulting in a claimed amount of $6,600.

Modified Eichleay Method

The Eichleay Formula tends to understate the overhead rate because it considers and includes the delay period in the formula calculation for the disputed contract. The Modified Eichleay Method changes this by deleting the days of delay from the number of days in the contract performance period (Equation 8). The result will be a higher Daily Overhead Rate. The Modified Eichleay Formula is provided below. A simple calculation yields unabsorbed overhead = $8,333.

Actual Billings for Delayed Contract ÷ Tot. Actual Billings for Period (All Contractor Contracts) x Total Home Office Overhead for Period = OADC -(7)

OADC ÷ Days of Performance (less delay period) = Daily Contract Overhead for Delayed Contract -(8)

Daily Contract Overhead for Delayed Contract x Number of Days Delay = Overhead Claim Amount for Delayed Contract -(9)

The Canadian Method

This method is used extensively in Canada (Trauner, 1990). The Canadian Method uses the contractor's actual markup for overhead in its calculation. This markup is based on bid documents or audit records. An audit of the contractor's records will determine a percentage based on history. The result for the example is $8,000.

Percentage Markup (from bid docs or audit) x Original Contract Sum ÷ Original Number of Days in the Contract = Daily Overhead Rate -(10)

Daily Overhead x Number of Days of Compensable Delay = Compensation for Home Office Overhead -(11)

The Allegheny Method [17]

This formula focuses on the difference in overhead rates between the actual period of performance and the originally expected period of performance. The excess overhead rate is multiplied by the contract base costs to determine the unabsorbed overhead amount. This method yields only a rough order of magnitude estimate of the damage, since the two periods will be intermixed and the excess overhead is calculated on the costs of the contract amount (Cibinic, 1991). For the example, unabsorbed overhead = 0.33% * $2,400,000 = $7,920.

Incurred O/H Rate During Actual Period - Incurred Overhead Rate for Projected Performance Period = Excess Rate of Overhead -(12)

Excess rate of O/H x Base Costs of all Contracts = Unabsorbed Overhead -(13)

Total Direct Cost Allocation Method

The Total Direct Cost Allocation Method allocates the direct costs incurred to calculate the overhead rather than what has been billed (Hewitt, 1986). The calculation for the method is as follows. For the example, unabsorbed overhead = $10,000 * 1 = $10,000.

Overhead Applicable to the Disputed Contract, OHDC = Disputed Contract Direct Costs x Total Company O/H ÷ All Other Contract Direct Costs -(14)

Daily O/H Rate = OHDC ÷ Days of Contract Performance (less delay days) -(15)

Overhead Cost Claimed, COH = DOR x Days of Delay -(16)

The total direct cost approach suffers from a number of weaknesses. It does not consider the differences in the cost components from a contractor's various projects. The methodology assigns the same overhead rate calculation to every project. Normally, rates are determined based on the type of work involved in the contract. Overhead rates would vary based on the level of effort required.

Specific Base Allocation Method (SBAM)

SBAM is a substantially accurate allocation approach, but is also considered the most complicated and expensive to use (Hewitt, 1986). SBAM allocates overhead costs based on the specific characteristics of a job and each overhead cost element. SBAM would only be a practical approach if the methodology for collecting data was already in place or when the claim amount can justify the analysis expense. The method involves creating indirect cost pool accounts and a basis for allocating the accounts to each contract. This involves developing, comparing, and establishing cost relationships for all elements. The costs for overhead items are allocated to each job based on the established percentages of the overall item cost. Of the various established techniques, SBAM comes closest to counting the dollars in detail the exact way they are allocated. This is, of course, time consuming and tedious. For the example, unabsorbed overhead = $8,000.

Allocation Basis (AB) = Allocation Item Cost on Disputed Jobs
÷ Allocation Item Cost on All Jobs -(17)
Allocated Overhead of Pool Account (AH) = Pool Account Cost x AB -(18)
Average Daily Overhead (ADOH) = AH ÷ Total Contract Days -(19)
Claimed Overhead Costs= ADOH x Days of Delay -(20)

Calculation Based on Actual Records

In the calculation of damages based on actual records, the contractor needs to provide detailed accurate records of his home office overhead expenses that will support his claim. In providing the records, the contractor will need to determine the percentage of effort expended for this project performance period or during the delay period. This percentage can be applied to the fixed home office costs, which will result in an allocation for the particular project (Trauner, 1990). This procedure requires detailed accounting procedures, from a record-keeping standpoint, which can be quite onerous. However, the effort may produce substantial benefits to the contractor, which might otherwise not be realized (Ernstrom and Essler, 1982). This method is very accurate if used precisely, and requires no formulas, which is a welcome benefit.

The Direct Method

The Direct Method is a method proposed by the authors, since it espouses a one-step calculation.

Planned Overhead Rate x Planned Earnings during the delay period
= Unabsorbed Overhead -(21)

For the example, unabsorbed overhead = 8.00% * $100,000 = $8,000. The calculation of unabsorbed overhead should really not be more complex than this, and this reflects exactly what the contractor would have earned on the home office overhead had there been no delay or standby. The expected (i.e. planned) production during period of delay can be known from client-approved contractor schedules, the information for which should be readily available. On complex, high-volume projects, especially those of the Department of Defense, earned value reports are mandatory, so the expected earnings should be available and easily acquired.

For this particular example, the result of the Direct Method agrees with the Canadian, Comparative Absorption Rate, the Carteret, and Specific Base Allocation Methods. The important factor in the "Direct Method" is that the planned earnings are based on the latest updated schedule. There needn't be any interference from Total Billings in the calculation of unabsorbed overhead for a specific project, and the Direct Method has taken this into account. The Direct Method is much less convoluted than the other methods presented. It consequently appears evident that attorneys and judges, in their ignorance of construction engineering and management, have made a simple process as complicated as possible.

Summary of Unabsorbed Overhead Calculations

The results for unabsorbed home office overhead damage calculations for each alternative are provided below:

Burden Fluctuation Method	$6,600
Eichleay Method	$6,667
Allegheny Method	$7,920
Canadian Method, CARM, Carteret, SBAM and Direct Methods	$8,000
Modified Eichleay Method	$8,333
Direct Cost Allocation Method	$10,000

Discussion

The median result of all methods is $8,000. The mode is the same, as well. The Eichleay Formula calculation, at $6,667, is approximately 20% lower than the median. It appears that various claimants have used different, but rational approaches to calculate the value of unabsorbed home office overhead, each which have been upheld by courts and boards.

Results for the various alternatives and methods vary, predicated by the particular situation, conditions, and assumptions used in each particular method. All the alternative methods have been used at some time or the other to calculate *compensable damages for unabsorbed home office overhead due to delay*. Each alternative and technique is based on assumptions, have their own formulas, their individual issues and weaknesses, and they all result in estimates or approximations of the damage.

Summary and Conclusions

The history and evolution of the Eichleay formula for unabsorbed overhead expenses, first developed in 1960, were presented and discussed. The calculation of unabsorbed overhead still continues to dog owners and contractors alike. Multiple issues and criticism has risen on the use and application of Eichleay. Case law and court decisions that shaped the prerequisite criteria for use of the Eichleay were studied, and alternate methods and formulae for the calculation of damages for unabsorbed home office overhead due to delay were presented. The calculation of the results were summarized and discussed.

The alternate methods have similarities and differences. Even critics of the Eichleay formula acknowledge the difficulty in the determination and calculation of delay overhead damage costs. However, many of these alternate methods utilize questionable assumptions, end up approximating the damages, and often result in some of the same problems alleged against the Eichleay formula.

An exact method or calculation is probably quite impossible to develop, unless actual overhead expenses are accepted, in which case dividing the extra expenses from contractual expenses can be a knotty problem. Therefore, the goal, given the circumstances, is to determine a fair allocation for compensating a contractor for the delay. Consequently, the Direct Method is proposed as an alternate method for the calculation of unabsorbed overhead. The Direct Method is a simple, straightforward, and realistic method for calculating unabsorbed overhead damages and is simpler to use and apply, using, as it is, only a one-step process. Subsequent to all the convoluted techniques studied, it appears reasonable to recommend the straightforward Direct Method, better even than the widely adopted Eichleay.

References

Cibinic, John (1991). "The Eichleay Formula: Does it Spell Relief?" The Nash & Cibinic Report ¶ 62, Nov.

Ernstrom, William J. and Essler, Karl S. (1982). "Beyond the Eichleay Formula: Resurrecting Home Office Overhead Claims." The Construction Lawyer, Winter, v3, n1, pl (5).

Hewitt, R. (1986). "Winning Contract Disputes: Strategic Planning for Major Litigation." Arthur Young, Sacramento, CA.

Kauffman, Micheal W. and Holman, Craig A. (1995). "The Eichleay Formula: A Resilient Means for Recovering Unabsorbed Overhead." Public Contract Law Journal, 24(2), 319, Winter

McDonald, Phillip R. and Baldwin, George C. (1989). "Builder's and Contractor's Handbook of Construction Claims." Prentice Hall, Englewood Cliffs, NJ.

Peckar & Abramson, P.C., Attorneys at Law (1999). "Reassessing Eichleay." Peckar & Abramson Newsletter, X(2), Fall.

Taam, T. and Singh, A. (2003). "Unabsorbed Overhead and the Eichleay Formula." J. of Professional Issues in Engineering Education and Practice, 129(4), Oct.

Trauner Theodore Jr. (1990). "Construction Delays: Documenting Causes, Winning Claims, Recovering Costs." R. S. Means Co., Kingston, Mass.

Watson, Jeffrey W. Major (1995). Military Law Review, Winter (147), pp. 262-288.

List of Cases

[1] McCord v. United States, 9 Ct. Cl. 155, 169 (1873)
[2] Fred R. Comb Co. v. United States, 103 Ct. Cl. 174 (1945)
[3] Eichleay Corporation v. United States, ASBCA 5183, 60-2 BCA 2688
[4] Excavation-Construction, Inc. v. United States, ENG BCA 3851 (1984)
[5] Wickham Contracting Co. v. Fischer, 12 F.3d 1574, 1580 (Fed. Cir. 1994)
[6] Capital Elec. Co. v. United States, 729 F.2d 743, 748 (Fed. Cir. 1984)
[7] Wickham Contracting, Inc., GSBCA No. 8675, 92-3 BCA ¶ 25,040, at 124,815, aff'd 12 F.3d 1574 (Fed. Cir. 1994)
[8] Berley Industries, Inc. v. City of New York, 45 N.Y.2d 683, 385 N.E. 2d 281 (1978).
[9] Guy James Construction Co. v. The Trinity Industries, Inc., 644 F.2d 255 (5th Cir. 1981)
[10] Capital Electric Co. v. United States, GSBCA Nos. 5316, 17, 83,3 BCA ¶ 16.548
[11] Community Heating & Plumbing Co., Inc., 987 F.2d 1575 (Fed. Cir. 1993)
[12] C.B.C. Enterprises, Inc. v. United States, 978 F.2d 669 (Fed. Cir. 1992)
[13] Interstate General Government Contractors v. West, 12 F.3d 1053 (Fed. Cir. 1993)
[14] Watson, Jeffrey W. Major, Military Law Review, Winter (147), PP. 262-288, 1995.
[15] West v. All-State Boiler, 146 F.3d 1368 (Fed. Cir. 1998)
[16] Melka Marine, Inc. v. United States, 187 F.3d 1370 (Fed. Cir. 1999)
[17] Allegheny Sportswear Co., ASBCA No. 4163, 58-1 BCA ¶ 1684.

APPROACHES FOR STRUCTURING CONCESSION LENGTHS AND TOLL RATES FOR TRANSPORTATION INFRASTRUCTURE PPPS

Martha E. Gross, P.E., S.M.ASCE[1] and Michael J. Garvin, P.E., M.ASCE[2]

Abstract

Many US transportation public-private partnerships (PPPs) are based on the concession model, under which the structure of user fees and the agreement duration is central to ensuring a fair balance of risk and reward between the public and private participants. Yet previous studies of toll-rate structuring and concession-length determination have treated these two variables largely independently. Toll charges, for instance, are typically established as either supply-based, linked to the cost of constructing, maintaining, and/or operating the facility; or demand-based, adjusted to influence driver behavior in certain ways such as through variable time-of-day congestion charges. Concession lengths are designed separately to enable tax-depreciation advantages for the private sector and/or to mitigate traffic-demand risk. Considering these two variables together, though, provides new opportunities to improve the risk-and-reward profile for both partners. A review and comparative analysis of dual-variable approaches, illustrated by projects in which these strategies have been used, offers additional tools to consider in structuring future PPP procurements.

Introduction

The growing challenge for public agencies to fund construction and maintenance of transportation facilities has led to increased interest in public-private partnerships (PPPs) for highway project delivery. Most US transportation PPPs are based on the concession model, under which a private developer or operator collects tolls from road users for a specified length of time, sometimes in conjunction with an up-front cash payment to the public owner, in exchange for developing or improving and

[1] Graduate Research Assistant, Myers-Lawson School of Construction, Virginia Tech, 200 Patton Hall, Blacksburg, VA 24061; martha.gross@vt.edu

[2] Associate Professor, Myers-Lawson School of Construction, Virginia Tech, 310A Bishop-Favrao Hall, Blacksburg, VA 24061; garvin@vt.edu

operating the facility. The structure of these user fees and lease terms is central to ensuring a fair balance of risk and reward between the public and private participants.

With cost and time as crucial variables of PPP contracts, these two elements have been investigated at length. Yet most prior studies have considered these factors in isolation from each other; further, the separate valuable contributions of engineers and economists to this field have not been comprehensively integrated. Hence, as an initial contribution toward harmonizing the engineering and economic perspectives, a review of current single-variable approaches to determining PPP cost and time structures is presented. Their theoretical underpinnings and strengths and weaknesses are examined, while specific examples of practical application are highlighted.

Building from this base, procurement models which simultaneously consider cost and time variables—user fees and concession periods—are introduced. A review of several transportation projects in which these dual-variable approaches have been employed illustrates significant advantages which can be realized from considering these elements together, and it offers opportunities for improving the PPP risk-and-reward profile for both public and private partners.

Single-Variable Approaches

As primary elements of PPP contracts, toll rates and concession lengths receive substantial attention in the procurement process. Examining the influences on these variables' development, with a focus on applications to the US transportation market, offers additional insights into the strengths and weaknesses of different approaches.

Toll Rates

Toll rate structures can generally be classified as supply-based or demand-based. In the former category are average-cost pricing models, which set user fees at a level just adequate to cover a facility's ongoing operations and maintenance costs (as well as capital expenditures, if not already recovered). These rates are typically lower than those under marginal-social-cost and revenue-maximizing pricing models, which fall into the demand-based category. In setting user fees, these two latter approaches take into account the elasticity of user demand, often in relation to roadway congestion levels. The following review examines fundamental economic principles underlying all three toll-rate structures, along with their strengths and weaknesses in practical application, in the context of concessions for which tolls are the private sector's sole source of operational revenue.

Though focusing on the complex impacts of direct tolling, this study recognizes other pricing structures (such as shadow tolls and availability payments) offer additional flexibility in structuring concession contracts. Likewise, an evaluation of specific revenue mechanisms for PPP risk sharing (such as price caps, rate-of-return limits, and income guarantees) is beyond the scope of this paper, but these have been addressed elsewhere (e.g., Charoenpornpattana and Minato 2007; Mayer 2007).

Average Cost Pricing

"...in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation," wrote economist and later Nobel laureate William Vickrey in 1963. The debate surrounding average cost pricing—the seemingly logical establishment of toll rates at levels exactly covering road provision, operation, and maintenance costs—shows Vickrey's observation still has merit today.

From a theoretical standpoint, economists Sharp et al. (1986) agreed tolls for uncongested roadways should generally be set equal to the facility's operating costs but not include construction expenses, since these higher rates would create economic distortions and artificially decrease demand for the roadway. The economist Ragazzi (2005) pointed out operations-plus-capital-cost tolls would effectively require drivers to subsidize both users of free roads and general taxpayers. He further noted linking user fees to actual road costs (whether with or without construction expenses) would contribute to an irrational patchwork of toll levels throughout a country, as illustrated by the case of 24 highway concessionaires in Italy charging between 4.6 and 14 euro cents per kilometer. For a publicly-administered highway system, engineers Oh et al. (2007) countered this concern by calculating and proposing an average per-mile cost-recovery fee which could be imposed statewide.

From a practical standpoint, the public sector does have the option of implementing average cost pricing schemes which largely address the concerns above for uncongested existing facilities. But even though PPPs' project-finance structure has the advantage of quantifying operations and maintenance costs perhaps much more accurately than does the public sector, average cost pricing is entirely infeasible for private-sector concessionaires, since it does not permit the profit opportunity which supports their investment in such projects.

Marginal Social Cost Pricing

Marginal social cost pricing, a demand-based fee structure, recognizes tolls' ability to influence traffic congestion and thus addresses a shortcoming of the average cost pricing model, whose economic justification applies only to uncongested facilities. The relationship between tolls and traffic demand had received little attention until the 1960's; until then, the standard solution for congestion had been constantly to increase capacity, primarily by building additional roads (Thomson 1998). But the Smeed Report (UK Ministry of Transport 1964), a seminal publication in transportation economics, proposed more efficient use of existing roadway capacity by charging drivers for the impacts (or "marginal social costs"), particularly congestion, which they imposed on their surrounding environment.

Because precise measurement of these costs, given the temporal and spatial variations in congestion throughout a transport network, was prohibitively difficult, economists developed numerous "second-best solutions" for road pricing. These studies sought to optimize social benefits under various constraints on time-of-day variations, spatial tolling limits, or vehicle-category differentiation (de Palma et al. 2005). Other economists (Chu and Tsai 2004; Newbery 1989) investigated the feasibility of combining the average-cost and marginal-cost pricing approaches by considering operations and maintenance costs as a type of environmental impact

caused by driving. They proposed developing an optimal toll level by adding an average-cost operations component to the previously-derived marginal social cost.

Although the Smeed Report authors recognized the systems of their day could not assess continuously-variable user charges, recent advances in tolling technology now enable continuous monitoring of congestion levels and regulation of toll rates to influence driver demand and promote free flow of traffic. This real-time adjustment of congestion-based tolls approximates the constantly-changing marginal social cost of roadway usage. The I-495 HOT Lanes concession in northern Virginia presents one example of this variable-toll strategy: users with inelastic demand can choose to pay a toll and drive on uncongested lanes, while drivers with more elastic demand travel on the heavier-traffic lanes for free. Yet the theory underlying this strategy awaits confirmation by northern Virginia drivers once the facility opens.

Revenue-Maximizing Pricing

Although revenue-maximizing pricing is also a demand-based tolling structure, it differs from marginal social cost pricing by decoupling the link between tolls and congestion (or environmental impact) levels. Rather, it estimates the levels of traffic demand for a specific transportation network segment under various toll rates, then sets pricing for that roadway at the level resulting in the highest overall toll revenue for the operator. These models predict the extent to which tolls will divert travelers to less direct but less costly routes, based on the value of drivers' time and vehicle operating costs, as well as the characteristics of these alternate routes (HRPDC 2005).

Except in the uncommon case when demand is perfectly elastic, economists Ubbels and Verhoef (2008) noted the revenue-maximizing toll necessarily exceeds the welfare-maximizing, or marginal social cost, charge. The result, economically speaking, is an underutilized road with unused capacity. But in practice, revenue-maximizing tolls are rarely used: the public sector typically limits not only the initial user fee which a PPP concessionaire can impose, but also the rate at which these charges can be increased over time. A typical use for revenue-maximizing toll calculations is to determine the bounds of a candidate PPP project's financial feasibility.

Though public-policy considerations effectively restrict the use of this pricing approach, the choice of toll structure is nevertheless a significant factor in concession length determination: higher revenue conceptually allows the private sector to accept a shorter lease term to recoup its investment. This tradeoff highlights one of the complex linkages between the cost and time variables of PPP agreements, a theme which will be examined in further detail below.

Concession Length

Another single-variable consideration in PPP structuring is the determination of appropriate concession length. Following a discussion of factors influencing lease terms in general, issues specific to brownfield (operating lease) and greenfield (project-financed) PPP contracts are explored by reviewing research findings in each area and examining alternate concession-length structures either proposed or

implemented. This section concludes with a discussion of public concerns related to long-term concessions.

General Influences on Fixed Concession Length

PPP procurements in the US, both greenfield and brownfield, typically specify fixed concession periods in their contract agreements. Many of these durations are significantly longer than the 30- to 40-year terms common abroad: US examples include the 75-year Chicago Skyway lease, 80-year I-495 HOT Lanes concession, and 99-year lease for both the Indiana Toll Road and Virginia's refinanced Pocahontas Parkway.

Although further influences specific to brownfield and greenfield contract length are addressed below, all longer-term US concessions—typically 50 years or more—enjoy significant tax advantages (US House of Representatives 2007), which represent a federal subsidy of PPP projects. One estimate values these accelerated depreciation benefits at 1 to 1.5% of the cost of a $1 billion infrastructure concession (Goldman Sachs 2005).

Another general influence favoring longer concession terms is the expectation that the private sector will provide higher quality construction and rehabilitation—and thus greater public value for money—if the concessionaire remains responsible for the subsequent maintenance and upgrade costs of these facilities (Mayer 2007).

Brownfield Concessions

Demsetz (1968) was among the first to explore the unique economic aspects of competition for furnishing public-utility services, a market very similar to brownfield PPP procurements. Although such competition is *for* the field in its entirety, rather than *in* the field, he concluded the single winning firm nevertheless cannot employ monopoly pricing levels after a properly structured competition. With increasing numbers of contestants, he noted, the winning bid price approaches the cost of providing the service; and this natural competition reduces the need for external regulation. Transportation economist Ponti (2005) explored the effect of such "Demsetz competition" on roadway concession length. For operating leases which are periodically re-bid, he cautioned long-term concessions can pose risks of information asymmetry and "capture" by the current operator. D'Alpaos et al. (2006) further noted the private sector's increased flexibility in investment timing decisions enabled by longer lease terms can, but does not necessarily, increase a concession's up-front value.

Other considerations influencing brownfield PPP lengths in the US include the public sector's interest in the higher up-front concession payments resulting from longer terms. Since these operating leases carry only modest traffic demand risk, at least in the short term, they are also favored by investment and pension funds seeking stable long-range returns. Such investors, who provide capital for concessionaires' up-front payments, also favor longer contract durations over which to collect these returns.

Greenfield Concessions

Greenfield PPP contracts incorporate not only the operational considerations of brownfield concessions, but also the added complexities of construction risk and particularly traffic-demand risk for an unproven facility. These risks have been investigated in the engineering literature to develop optimal concession lengths using approaches such as fuzzy simulation models (Ng et al. 2007) and Monte Carlo simulation (Zhang and AbouRizk 2006).

In practice, the value to a concessionaire of a longer facility lease lies not primarily in the increased value of gross toll receipts over time, since the present value of the terminal years' revenue is negligible. Rather, private developers favor longer greenfield concession terms in part because the additional time provides a buffer to smooth out the historically-common problems with traffic demand. In fact, 30-year concession terms are often specified in the UK with the intent of allowing 20 years for debt repayment and 10 years as a demand-risk buffer (Mayer 2007).

Numerous other options for containing greenfield risks have been employed. Ye and Tiong (2003) present several examples of two-period concessions, which specify separate contract lengths for a project's construction and operations phases. If the construction work is completed early, the concessionaire is typically permitted to retain any operational revenues collected before the formal start of the operations phase; these funds can be shared with the contractor as an early-completion incentive. Though this model does not address demand risk, it provides a useful structure for containing construction delays. One could argue the single-period model also has this inherent incentive, and experience to date suggests delay is not frequently a problem.

Although PPP procurements typically consider concession length as a fixed element, Mexican concessions in the late 1980's and early 1990's experimented with treating it as a single-variable proposal evaluation factor: concessions were awarded to developers offering to build and operate roads for the shortest lease terms. With the resulting highway tolls reaching $35, most traffic diverted to parallel roads, despite their congestion; and the government eventually committed over $8 billion to bail out these developers and their lenders (Engel et al. 2002). Such experiences underscore the potential drawbacks inherent in focusing on a single-variable solution.

Long-Term Concession Issues

The recent US practice of assigning lengthy concession terms up to 99 years has awakened considerable concern that the public sector may be losing control of these assets for extended periods. Buxbaum and Ortiz (2007) present several public-policy issues stemming from such long concession terms. Particularly in the US, where much of the public sector has limited experience with the complex financial and legal elements of PPP contracts, they note state agencies may not yet be sufficiently qualified to identify the decisions which are in the public's best interest. In such a case, longer concession terms could magnify the impact of any missteps in the procurement process. One often-mentioned area of concern is the fiscal implication of undervaluing an infrastructure concession, potentially allowing the private sector to collect decades of super-profit toll revenues with no distributions to the public sector. Yet Mayer (2007) notes rigorous limits on concessionaires' upside benefit can

reduce their incentives for efficiency—a quality touted as a prime advantage of PPP delivery—and thus emphasizes revenue-sharing clauses for long-term concessions must be carefully structured.

This crucial issue further underscores the indivisible linkage between the cost and time elements of PPP agreements. The following section develops an alternative approach to the traditional procurement strategy of treating these variables separately.

Dual-Variable Approaches

A challenge of simultaneously considering toll rate structures and concession length determination lies in the complex trade-offs between the public and private sectors' preferences for each variable. The nearly-continuous set of possible cost-and-time combinations, though, offers each sector additional options to converge on a tailored contract solution providing both partners the best mutually-available balance of risk and return. Numerous dual-variable approaches have already been established, and several examples from literature and practice are examined and compared below.

Variable-Length Concessions

A significant category of PPP contracts linking cost and time considerations is the variable-length (or dynamic) concession, whose term concludes when certain financial targets are met. Since the private sector bears little traffic-demand risk under such arrangements, concessionaires need no longer include substantial contingencies in their pricing or timing to cover this risk, as is customary under traditional single-variable procurements. Variable-length PPPs' financial targets are based on elements such as debt coverage, rate of return, or present value of revenues collected.

An example of a contract term based on project debt repayment is the Queen Elizabeth II toll bridge across the river Thames, whose contract was awarded in 1993 for a "concession period of 20 years or such earlier date as the Contractor accumulates sufficient revenue to exceed the total debt outstanding" (Walsh 2003). In this case, high demand for the project enabled toll revenues to reach that level within ten years, though the developer's recourse in the case of abnormally low traffic demand was apparently minimal.

Another variation is PPPs whose length depends on the concessionaire's reaching an agreed-upon internal rate of return (IRR), as implemented in multiple Spanish and French concessions. A significant disadvantage of basing concession duration on debt repayment or IRR attainment, though, is the complexity of auditing these items and establishing targets such as the initial IRR, due to asymmetrical information (Mayer 2007).

A third type of contract links concession length to an agreed-upon level of toll revenues. These least present value of revenue (LPVR) procurements were first used in Chile, where the concession term for the Santiago-Valparaíso-Viña del Mar toll road was limited to 300 months or the point at which toll revenues reached the concessionaire's pre-specified level, whichever occurred sooner. The project was

awarded in 1998 to the bidder accepting the least present value of revenue, given a fixed toll structure and discount rate (Matsukawa and Habeck 2007).

The variable-length LPVR structure has strengths and weaknesses. Among the benefits of its flexibility is a significant reduction in traffic-demand risk for both public and private entities (Engel et al. 2002). De Rus and Romero (2004) observe LPVR pricing still retains some exposure to traffic variation, due to fixed operating costs which are not proportional to traffic demand, and they recommend the slightly modified least present value of net revenue (LPVNR) model to address this concern.

LPVR has the advantage of reducing the pressure for contract renegotiation (Nombela and de Rus 2004). During Chile's 1998-2002 recession, many concessionaires sought to renegotiate fixed-term highway PPPs. In contrast, the LPVR contract for the Santiago highway automatically adjusted its term to accommodate this financial crisis without renegotiation (Vassallo and Soliño 2006).

A potential drawback of LPVR contracts is that they offer little incentive for concessionaires to minimize demand-reducing highway deficiencies by careful maintenance (e.g., through expeditious pothole repair or snow removal). This issue can be addressed, though, with contractually-stipulated maintenance standards and inspections (Engel et al. 2001). Guasch (2004) noted further practical disadvantages of the LPVR structure may include complications in arranging financing due to the uncertain concession lengths, as well as the necessity for public and private parties to agree on an appropriate discount rate for the LPVR calculation.

But Mayer (2007) observed this contract structure is much simpler to audit than the debt-based or IRR concessions. A further public-policy consideration is the relative ease with which the public sector can change toll rates if circumstances require, since the target revenue total is not affected: the concession length automatically adjusts to the new toll levels (Nombela and de Rus 2004).

Rate and Term as Simultaneous Bid Variables

Although the variable-length concession model typically involves the public sector selecting a preferred value for toll rates and allowing the concession term to float, another option is to have the concessionaire propose values for both items as bid variables.

One example is the 2004 concession for the EastLink highway and tunnels in Melbourne, Australia. The procuring agency asked concessionaires to propose both toll rates and concession term length as bid variables, and the agency then applied a public sector comparator methodology to determine the resultant value-for-money for each bidder's package. Based on this analysis, the contract was awarded to a concessionaire offering a low toll rate—in fact, the lowest per-kilometer rate in Australia—in combination with a relatively lengthy 39-year concession term.

Summary

These dual-variable approaches offer a sampling of options for granting both public and private partners additional flexibility in structuring PPP concessions. Combinations of cost and time parameters can be tailored to address both sectors'

needs: for instance, if certain toll levels are of particular value to the public sector (perhaps marginal social cost pricing for congestion control, or constant-rate tolls for regional uniformity), these goals can be accommodated by negotiating adjustments in the time variable accordingly.

Conclusion

The synthesis of literature and practice associated with two PPP variables—toll rates and concession length—indicates they have typically been treated independently. To illustrate the benefits of joint consideration of cost and time elements, this study has described current single-variable PPP structures, reviewed their respective strengths and weaknesses, and examined applications of dual-variable solutions in practice. This investigation, which is an initial step toward integrating toll and concession-period considerations, offers additional options for shaping future PPP procurements to improve the risk-and-reward profile for both public and private partners.

References

Buxbaum, J. N., and Ortiz, I. N. (2007). "Protecting the public interest: the role of long-term concession agreements for providing transportation infrastructure." USC Keston Institute, Research Paper 07-02.

Charoenpornpattana, S., and Minato, T. (2007). "Innovative revenue-sharing scheme for public-private partnerships in infrastructure projects." *Proc., Construction Management and Economics 25th Anniversary Conf.*, Reading, UK.

Chu, C.-P., and Tsai, J.-F. (2004). "Road-pricing models with maintenance cost." *Transportation*, 31(4), 457-477.

d'Alpaos, C., Dosi, C., and Moretto, M. (2006). "Concession length and investment timing flexibility." *Water Resources Research*, 42(2), 1-4.

de Palma, A., Kilani, M., and Lindsey, R. (2005). "Comparison of second-best and third-best tolling schemes on a road network." *Transp. Res. Rec.*, 1932, 89-96.

de Rus, G., and Romero, M. (2004). "Private financing of roads and optimal pricing: is it possible to get both?" *Annals Regional Sci.*, 38(3), 485-497.

Demsetz, H. (1968). "Why regulate utilities?" *J. Law Econom.*, 11(1), 55-65.

Engel, E., Fischer, R., and Galetovic, A. (2001). "Least-present-value-of-revenue auctions and highway franchising." *J. Political Econom.*, 109(5), 993-1020.

Engel, E., Fischer, R., and Galetovic, A. (2002). "A new approach to private roads." *Regulation*, 25(3), 18-22.

Goldman Sachs. (2005). *Presentation, US/Mexico Border Finance Conf.*, <http://uac.sct.gob.mx/fileadmin/espanol/seminariocct/resultados/sesion_5/S5A_JH.pdf> (August 1, 2008).

Guasch, J. L. (2004). *Granting and renegotiating infrastructure concessions: doing it right*, World Bank, Washington, DC.

Hampton Roads Planning District Commission (HRPDC). (2005). "Travel demand forecasting: state of practice review." *Toll feasibility study*, <http://www.

hrpdc.org/Documents/Transportation/final%20toll%20study%20report.pdf> (August 1, 2008).
Matsukawa, T., and Habeck, O. (2007). *Review of risk mitigation instruments for infrastructure financing and recent trends and developments*, World Bank, Washington, DC.
Mayer, J. (2007). "Private returns, public concerns: addressing private-sector returns in public-private highway toll concessions." *Transp. Res. Rec.*, 1996, 9-15.
Newbery, D. M. (1989). "Cost recovery from optimally designed roads." *Economica*, 56(222), 165-185.
Ng, S. T., Xie, J., Skitmore, M., and Cheung, Y. K. (2007). "A fuzzy simulation model for evaluating the concession items of public-private partnership schemes." *Automation in Constr.*, 17(1), 22-29.
Nombela, G., and de Rus, G. (2004). "Flexible-term contracts for road franchising." *Transp. Res. Part A*, 38(3), 163-179.
Oh, J. E., Labi, S., and Sinha, K. C. (2007). "Implementation and evaluation of self-financing highway pricing schemes: a case study." *Transp. Res. Rec.*, 1996, 25-33.
Ponti, M. (2005). "The regulatory issues of transport infrastructures, and of toll highways in particular." *Res. Transp. Econom.*, 15, 1-4.
Ragazzi, G. (2005). "Tolls and project financing: a critical view." *Res. Transp. Econom.*, 15, 41-53.
Sharp, C., Button, K., and Deadman, D. (1986). "The economics of tolled road crossings." *J. Transp. Econom. Policy*, 20(2), 255-274.
Thomson, J. M. (1998). "Reflections on the economics of traffic congestion." *J. Transp. Econom. Policy*, 32(1), 93-110.
Ubbels, B., and Verhoef, E. T. (2008). "Auctioning concessions for private roads." *Transp. Res. Part A*, 42(1), 155-172.
UK Ministry of Transport. (1964). *Road pricing: the economic and technical possibilities*, HM Stationery Office, London.
US House of Representatives. (2007). "Public-private partnerships: financing and protecting the public interest." Hearing, 13 Feb 2007. 110th Cong., 1st sess. Government Printing Office, Washington, DC.
Vassallo, J. M., and Soliño, A. S. (2006). "Minimum income guarantee in transportation infrastructure concessions in Chile." *Transp. Res. Rec.*, 1960, 15-22.
Vickrey, W. S. (1963). "Pricing in urban and suburban transport." *Am. Econ. Review*, 53(2), 452-465.
Walsh, A. (2003). "A legal perspective on risk management in public-private partnership." *Public-private partnerships: managing risks and opportunities*, A. Akintoye, M. Beck, and C. Hardcastle, eds., Blackwell Science, Oxford, UK, 153-181.
Ye, S., and Tiong, R. L. K. (2003). "The effect of concession period design on completion risk management of BOT projects." *Constr. Manage. Econom.*, 21(5), 471-482.
Zhang, X., and AbouRizk, S. M. (2006). "Determining a reasonable concession period for private-sector provision of public works and services." *Can. J. Civ. Eng.*, 33(5), 622-631.

ANALYZING THE INSTITUTIONAL FRAMEWORK FOR URBAN PUBLIC PRIVATE PARTNERSHIPS IN INDIAN STATES

Ganesh A. Devkar,[1] Ashwin Mahalingam[2] and Satyanarayana N. Kalidindi[3]

[1]PhD Research Scholar, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, 600036, India. PH (91) 9840567798; Fax (91) 44-22574252; e-mail: ganesh_devkar@iitm.ac.in

[2]Assistant Professor, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, 600036, India. PH (91) 44-22574318; Fax (91) 44-22574252; e-mail: mash@iitm.ac.in

[3]Professor, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, 600036, India. PH (91) 44-22574268; Fax (91) 44-22574252; e-mail: satyakn@iitm.ac.in

Abstract

The quality of urban engineering services such as water supply and sanitation have gradually deteriorated across India in contrast to the increasing contribution of these areas to the country's GDP. The service delivery departments of the urban local bodies (ULBs) are responsible for providing municipal services to urban residents. These departments have over the years developed and nurtured engineering competencies for the implementation of municipal projects. Now, given the deficit in urban infrastructure services, public private partnerships (PPP) are emerging as a promising model for improving municipal service delivery. From a ULBs perspective, the implementation of PPP projects differs substantially from conventional projects since executing PPP projects requires competencies in multiple disciplines such as finance, contract law, taxation policy & regulations. The lack of capacity in ULBs to execute these complex PPP projects has subsequently emerged as a key bottleneck to the timely delivery of urban infrastructure services. The state governments in India have created institutional frameworks for facilitating PPPs in the delivery of municipal services. The state of Tamil Nadu in India has formed a nodal institution – the Tamil Nadu Urban Development Fund (TNUDF) for facilitation of PPPs in the delivery of municipal services in Tamil Nadu. This paper analyzes several case studies of PPP projects in the urban engineering sector facilitated by TNUDF to determine the contribution made by TNUDF in effective implementation of PPP projects. Improvements in the existing institutional framework have been suggested based on lessons from the case studies and experiences of existing institutional models in other countries. Generic insights are also drawn that will help other urban

governments plan and execute PPP projects better. This research contributes to knowledge at the intersection of engineering, management and policy, all of which are essential pieces in the quest to deliver basic engineering services to citizens anywhere in the world. A research agenda for the future to optimize institutional arrangements is also indicated.

Introduction

The process of urbanization has attracted the attention of all nations over the years. It has attained a new significance in 2008; as half of the human population will be residing in urban areas (UNPFA 2007). Urbanization in India has brought forth both challenges and opportunities. Urban areas contribute to 65% of India's GDP and this factor is growing Various cities have projected themselves as attractive investment destinations to potential investors with attractive industrial policies, stable political environment and supporting infrastructure. The resultant employment opportunities offered by urban areas make these cities an attractive proposition for migrants leading to urban sprawl. 50% of Indian citizens are expected to reside in cities by 2025. The southern state of Tamil Nadu, which will be the focus of this paper, has also witnessed a substantial amount of investment in the industrial and services sector resulting in large urban growth across cities and towns within the state. Tamil Nadu is one of the most urbanized states of India with 43.86 percent of the population of 62 million living in urban areas.

Urban infrastructure is the backbone of cities and affects the competitiveness of organizations, livelihood of urban citizens and quality of urban life. There has been a backlog in the creation of urban infrastructure to keep pace with urban growth and the resulting deterioration of municipal services such as water supply and sanitation has now grabbed the attention of the state governments and urban local bodies (ULBs). ULBs are statutorily responsible for provision of basic urban service such as water supply, sanitation, roads. In the state of Tamil Nadu, three types of ULBs have been created to help provide efficient delivery of municipal services in urban areas. These are the Municipal Corporations for large urban areas, Municipalities for smaller urban areas and Panchyats for transition or semi-urban areas. There are 8 municipal corporations, 150 municipalities and 561 panchyats in the state (Government of Tamil Nadu 2006). As was the case in many states in India, ULBs in Tamil Nadu played relatively minor roles in infrastructure development, with the Government of Tamil Nadu and other state-ledl agencies making a majority of the decisions. This and other barriers such as (1) the presence of a multiplicity of government agencies with overlapping responsibilities in the urban infrastructure sector, (2) a lack of accountability towards the citizens with citizens not being given adequate representation in the municipal governance framework and (3) a lack of capacity for municipal management, have slowed down the development of infrastructure in the state. Recent policy reforms such as the 74th constitutional amendment, that promote autonomy and decentralization have led to a transfer of powers and functions from state governments to urban local bodies and thus in the near future ULBs will have to play an important role in the provision of urban services.

Currently most ULBs across the country have neither the financial resources nor skills for effective delivery of municipal services in urban areas. For instance, ULBs have given undue importance in the past to the creation of new urban infrastructure assets rather than to the efficient utilization of existing assets. This has resulted in the absence of operation, maintenance and asset management skills in these organizations. The scenario is not different in Tamil Nadu where municipal services provided in urban areas have failed to meet vital safety and quality parameters. Attention has therefore turned to the private sector to help in the delivery of infrastructure by bringing in capital, resources and efficiency in delivery of urban services. Public Private Partnerships (PPPs) are strongly believed to be win-win arrangements that can help ULBs create the necessary infrastructure for urban rejuvenation. In order to engage with the private sector under PPP arrangements, ULBs will need to identify, analyze and structure infrastructure projects that can be developed and operated by private firms. However the problem remains that ULBs lack the capacity to do so on their own and this is proving to be a key bottleneck to the entry of the private sector in the provision of infrastructure services in the urban sector. In response, many states have established innovative institutional frameworks for supplementing capacities at the municipal level for the implementation of PPP projects.

Institutional Frameworks for PPPs In India and Other Countries

Countries such as Australia, Canada, Philippines, South Africa, Italy, Ireland and Netherlands had established cross sectoral institutional agencies - also called as PPP coordination units - for supplementing capacities in governmental line agencies. These line agencies may be at the federal, state or municipal level. Except for the PPP unit in Australia which primarily acts as a resource center and disseminates guidelines, all other PPP units also perform project development and advisory functions. In addition, PPP units in the Netherlands and Philippines provide contract oversight and project management expertise whereas PPP units in the U.K and British Columbia in Canada perform these functions upon request. PPP units in South Africa and U.K are also endowed with powers to approve projects. Creating PPP coordination units as an institutional model to supplement capacities has gained the attention of the central and state governments in India. Gujarat, Andhra Pradesh and Punjab have established PPP units that have the power to approve projects, provide project-specific advisory services and can disseminate guidance material and funding for PPP preparation. Karnataka, West Bengal and Rajasthan have established PPP units with most of these functions except for project approval capabilities (Dutz et al. 2006).

Tamil Nadu Urban Development Fund

The Government of Tamil Nadu established the Tamil Nadu Urban Development Fund (TNUDF) in 1996, to provide assistance for the development of urban infrastructure in the state of Tamil Nadu. TNUDF was formed by merging the existing Municipal Urban Development Fund (MUDF), with contributions from the

Government of Tamil Nadu and financial institutions such as ICICI Bank Limited, Housing Development Finance Corporation Limited and Infrastructure Leasing and Financial Services Limited. TNUDF is the first public-private partnership venture in India that provides long term debt for municipal services on a non guarantee mode. Tamil Nadu Urban Infrastructure Financial Service Limited (TNUIFSL) is the fund manager of TNUDF. The strategic mandate of TNUDF is to facilitate private sector participation in urban infrastructure, enable ULBs to access debt finance from markets and fund urban sustainable and viable infrastructure projects. The financial resources available to TNUDF are unit capital, IBRD line of credit and market borrowings. Since its inception TNUDF has facilitated the implementation of municipal PPP projects in sectors such as sewerage, solid waste management, roads, bridge and bus stands (Tamil Nadu Urban Development Fund 2007).

Results of Case Study Analysis

The main objectives of this paper are (1) to determine the contribution made by TNUDF in the effective implementation of PPP projects, (2) to suggest improvements in the existing institutional framework in Tamil Nadu for facilitation of PPP in delivery of urban services.

The methodology adopted for this research study is (1) literature review on PPP in delivery of municipal services and existing institutional models for facilitation of PPP in India and other countries, (2) case studies of PPP projects in the urban engineering sector facilitated by TNUDF, and (3) analysis of case studies in order to identify common themes emerging from the cases as well as to facilitate comparison between the cases and the literature.

The collection of data for this research was carried out primarily through interviews with key participants in each of these projects, with supplementary evidence provided through project documentation. TNUDF was involved in all these projects. These projects were implemented in Tamil Nadu and therefore formed a natural comparative multiple case study research design. The selected projects shared several similar characteristics such as the socio-economic and political environment under which they were undertaken, governmental processes that had to be followed and so on, thereby providing natural controls for the study. At the same time, these projects also differed in a number of parameters, thus providing differing outcomes and the scope for theoretical sampling, analytical generalization and theory building (Strauss and Corbin 1998) (Eisenhardt 1989).

The details of case studies are as follows:

1) *Alandur solid waste management project* – Alandur town is located at a distance of 14 Km to the south of Chennai and lying within the Chennai Metropolitan Area. Alandur is among the growing residential suburban areas of Chennai. As of 2005, the town had a population of around 169, 845 and generates around 75MT of solid waste per day. Alandur municipality decided to engage a private service provider to manage

the solid waste management activities of the municipality. The scope of work was primary collection, segregation, secondary collection, processing and disposal of municipality SWM at Alandur municipality. TNUDF provided assistance to Alandur Municipality in the designing of bidding process, preparation of bid documents, conducting the pre bid meetings, evaluation of bids, conducting negotiations with private operator and singing of the agreement.

2) *Alandur underground sewerage project*- The absence of the sewerage system in Alandur town was affecting the health and well being of residents of town. Chairman of Alandur municipality decided to solve this situation by envisaging an underground sewerage scheme for Alandur town. The scope of the work involves the construction of underground sewerage system and financing, construction, construction and operation of a sewerage treatment plant. The financing for construction of underground sewerage network consists of combination of mobilization of finance from users, loan and grant. The sewage treatment plant was developed on BOT model. The capacity of sewerage treatment plant is 24 MLD. TNUDF provided assistance to Alandur municipality in project conceptualization, project development including engineering studies, designing of bidding process, development of bidding documents, project marketing, conducting negotiation with private contractor and signing of agreement.

3) *Karur toll bridge project* - Karur is one of the emerging urban areas of Tamil Nadu. The town is spread oven an area of 5.96 sq. kms and as of 2001 the town had population of 76338. It is situated on the banks of the river "Amaravathi" and is about 400 Kms from Chennai. Amaravathi river flows along the southern border of Karur is a major natural barrier for the traffic. The existing bridge across the river was in dilapidated condition preventing heavy vehicles from using the bridge causing heavy congestion and delays in the journey. Karur municipality decided to construct a bridge under BOT model, the scope of work comprised of design, finance, construct and operate the new bridge. TNUDF assisted Karur municipality in project conceptualization, project development including traffic appraisal, willingness to pay survey and development of specifications, structuring the bidding process, development of bidding documents, conducting the bidding documents, evaluation of bids and signing of the agreements.

Contribution

1. Providing a holistic view to infrastructure development and building project supply

ULBs tend to follow a piecemeal approach to identify municipal service needs. The identification process is heavily biased towards the fund availability within the ULBs and often results in fragmented infrastructure development. In the Alandur underground sewerage project TNUDF took the municipal service requirement of entire town into consideration while designing the project. The sewerage from the urban areas was often discharged untreated or partially treated into the streams and

rivers. TNUDF ensured that the project complied with environmental standards by designing the sewage treatment plant such that it had the capacity to treat entire amount of sewage generated in Alandur.

As part of the Tamil Nadu Urban Development Project – II, TNUDF has developed City Corporate cum Business Plans for ULBs. These plans are developed consulting a wide range of stakeholders and represent a vision for the future development of the ULB. The plans critically analyzed the future requirements and unmet demand for municipal services. This has resulted in the creation of a pipe line of municipal projects which can potentially be implemented through PPPs.

2. Reducing transactions costs and augmenting coordination among stakeholders

The urban sector has several stakeholders such as residents, users, governmental organizations, social institutions, environmentalists, political representatives, private investors and so on, who have diverse interests in a project. The effective implementation of the project largely depends upon integrating the inputs given by these stakeholders at various phases of the project. TNUDF being a PPP in itself was able to successfully merge a process driven governmental mindset with an outcome driven private sector culture and incorporate best practices in inclusive stakeholder decision making in project development.

To oversee the Alandur UGS project, TNUDF formed a steering committee with representation from the Tamil Nadu Water Supply and Sewerage Board, Chennai Metro Water, Commissionerate of Municipal Administration, municipal officials and Experts from TNUDF. TNUDF then created channels of communication among stakeholders to understand each others positions and compulsions. It is mandatory for ULBs to obtain administrative and technical approvals from the state government implementing a municipal project. The inclusion of state government officials' right from the inception of the the Alandur UGS project reduced the bureaucratic hurdles in the implementation of project.

TNUDF ensured the continued participation of stakeholders in all PPP processes by giving recognition to them in the contracts and municipal procedures. The residents welfare associations were given the access to records of municipal accounts and made part of project monitoring team at Alandur. This created trust and transparency in the process.. During the drafting of contract documents for the Alandur solid waste management project, TNUDF imposed an obligation on the service provider to obtain a compliance certificate from the resident's welfare association in each municipal area to ensure quality of service.

3. Creating an enabling environment for PPP service delivery

Using PPPs in the delivery of municipal services was a new concept for the Government of Tamil Nadu. Fiscal difficulties and a lack of capacity for ramping up the development of urban infrastructure pushed the state government to invite the

private sector to provide municipal services. The commitment of Alandur Municipality and TNUDF to develop the Alandur UGS project on a PPP mode culminated in the issuance of a Government Order on the privatization of municipal services in 1998 by Government of Tamil Nadu, paving the way for private sector participation for delivery of municipal services in Tamil Nadu. Similarly the Tamil Nadu State toll act was amended in 1997 allowing ULBs and entrepreneurs to levy and collect toll. As a result of this, the municipality of Karur was able to implement a bridge project on a BOT model.

4. Supplementing competencies for implementing municipal PPP projects

A lack of skills and competencies that are required to implement PPP projects has been a key hurdle that understaffed and resource-constrained ULBs have had to face. ULBs have traditionally developed in house technical skills based on the nature of services to be provided such as water supply, sanitation, solid waste management and so on. Implementing PPP projects demands specialized skills in the area of project financing, accounting, public policy, contract law, regulation and so on. These skills are difficult to develop in the ULBs due to unattractive remuneration packages, lack of pipeline of PPP projects etc. TNUDF was able to bridge this competency gap in Tamil Nadu. For instance, the municipality of Alandur did not have the competencies to assess the feasibility of delivering sewerage infrastructure under the PPP model. When attempts to meet the financing needs of the project from traditional sources failed, the municipality approached TNUDF for debt financing. It was clear from the balance sheet that the borrowing capacity of the municipality was quite low. TNUDF investigated the possibility of implementation of a sewage treatment plant via the BOT model. This PPP orientation reduced the need for public finance. Eventually the sewage treatment plant was implemented on a BOT model while the sewerage network was financed with a combination of loans, mobilization of funds from Alandur residents and grant funding. Without TNUDFs knowledge of PPPs and their capacity to structure such a project – a set of skills that the municipality did not possess - the Alandur residents would have deprived of quality sewerage services. In the case of the Karur bridge project, the existing bridge over the Amaravathi river was in a dilapidated condition. Karur municipality lacked internal funds to construct the bridge. However Karur was a rapidly growing town and TNUDF suspected the potential for economic growth to lead to increased traffic across the river. Traffic and willingness to pay surveys instigated by TNUDF confirmed the revenue potential of the new bridge which allowed the conceptualization of project on BOT mode. The local government had been unable to analyze these options on their own.

These instances show that TNUDF facilitates the identification, conceptualization, project development and bid process management of PPP projects. The need for a wide range of skills coupled with diversity of municipal services from water supply to parks, makes the task of supplementing skills cumbersome. TNUDF has dealt with these challenges by a creating skill bases within the TNUDF. It has in house skills for financial structuring and the technical expertise specific to each municipal sector such as water supply, sanitation and transportation. These in house skills enable TNUDF to

outsource the actual functions involved in project development and bid process management to external advisors and provide efficient oversight capabilities to these operations. TNUDF provided handholding support in the preparation of designs and cost estimates, as well as the bid process management of Alandur UGS project, Alandur SWM project and Karur project. In many instances ULBs approach TNUDF purely for project funding without recognizing the project shaping expertise that TNUDF can offer.

5. Bridging the Public-Private cultural divide

TNUDF has fewer layers of management as compared to traditional public sector organizations, which in turn enables faster decision making and a reduction in the ambiguity of roles & responsibilities of personnel. Most TNUDF staff have some prior experience of working with or in the private sector which helps them understand expectations in a PPP project. TNUDF is headed by a senior government officer from the elite Indian Administrative Services. As a result. decisions made by TNUDF command respect in the corridors of state government.

The private sector views TNUDF as a corporate organization rather than as a traditional bureaucratic government organization. With successful project delivery in Alandur and Karur, TNUDFs reputation has been enhanced and private developers in Tamil Nadu now show more willingness to partner with the public sector. TNUDF carries out interface management between the ULBs / state government, stakeholders and the private sector for effective implementation of municipal PPPs. The confidence of both the private sector and the government agencies in TNUDF stems from high quality project preparation studies, adoption of World Bank guidelines for procurement of consultants and private partners, timely payment to consultants and high quality service delivery. TNUDF's project advisory actions have therefore been able to inspire confidence in PPPs as a mode of project delivery and has thereby been able to bridge the public-private ideological divide.

Improvement in the Existing Institutional Framework

The existing institutional environment and the role of TNUDF can be further improved by following interventions:

1. Building capacity within government machinery

TNUDF plays a critical role in making ULBs appreciate the value brought in by the private sector in the delivery of municipal services. However the fundamental issue of the absence of basic know-how in ULBs on PPPs should not be left unattended. State governments should address this issue by training municipal officials as well as municipal councilors. This will go long a way towards creating ownership of PPP projects in ULBs and in an effective utilization of TNUDF's knowledge base.

2. Political commitment to PPPs

The Government of Tamil Nadu has achieved significant success in some of its initial municipal PPP projects but has failed to scale up its PPP programme. The absence of a regulatory body, cross sectoral PPP laws or policies, dispute resolution mechanisms and approval mechanisms are roadblocks towards realizing the full potential of PPP for bridging the gap in municipal infrastructure in Tamil Nadu. These reforms can be brought in practice only with continuous political commitment to PPP. In 2005, the Government of Tamil Nadu appointed a consortium of Indian and international consultants for development of a PPP policy framework. Due to lack of commitment towards PPP in the political circles this draft policy framework could not see light of the day. Currently the Government of Tamil Nadu is undertaking PPPs without a policy framework in place. There are problems with this approach. Karur bridge project – although successfully developed - has been caught between the crossfire of political parties in Tamil Nadu. The concession for the Karur bridge was cancelled on 2005 on the pretext of a failure by the private partner to remedy defects caused by floods. Judicial inquiry has been initiated against not only private partner, ruling political parties during implementation of project but also government officials questioning the rationale behind involving the private sector in a public project.

ULBs need not avail project development support solely from nodal agencies such as TNUDF. The Tamil Nadu Industrial Development Corporation (TIDCO) – a state government organization has also provided handholding support to ULBs specifically for PPPs in municipal solid waste management. In the Tamil Nadu Urban Development Project – III, which is an ongoing project financed by World Bank, a project preparation facility will be established within Commissionerate of Municipal Administration to provide consultancy services to ULBs to prepare and implement infrastructure projects (World Bank 2005). In the previous projects the project preparation assistance was provided by TNUDF and it is considered as key strength of TNUDF's institutional structure. This fluid situation results in wastage of public resources, confusion among ULBs and hindrance to development repository of knowledge about municipal PPPs in TNUDF.

3. Increasing scope of TNUDF

In India, various states such as Gujarat, Andhra Pradesh, Punjab and Karnataka have established cross sectoral PPP units for supplementing capacities at the state and municipal level. TNUDF is unique in a sense; it is limited to the municipal level. TNUDF does not have a mandate to develop standardization and dissemination of guidance material. Most PPP units in India and other countries also play an information dissemination role and develop guidance material. In Tamil Nadu ULBs do not following standard procedures & contract documents for implementation of PPP project which makes the financing and implementation of municipal PPP projects a complex endeavor. Such standardization, led by a nodal agency will go in long way in reducing of bidding time, clarifying the roles & responsibilities of various agencies, and enabling and faster governmental approvals.

Currently TNUDFs role ends when the project is awarded and thereafter the critical phase of contract management is handled by ULB. The seeds sown in project identification, development and procurement phases of PPP project will bear fruits only if ULBs work in true sense of partnership with the private sector during delivery phase of the project. The implementation of municipal services under PPP arrangement has multiple facets such as contract law, regulation, negotiation, relationship management etc. Technical assistance in contract management can also be made available to ULBs through agencies such as TNUDF.

4. Valuing the advisory services of TNUDF

TNUDF is providing handholding support in various phases of project such as identification, project development and bid process management. TNUDF is paid for this handholding support in proportion to the disbursement of grant fund. Grant fund is created under the TNUDP for providing financial assistance in preparation of engineering studies, bid process management. Even though TNUDF carried out most of the work by outsourcing it to external advisors; it brings in value to the project by managing these advisors in a way to meet the strategic objectives and government policy intent behind the proposed PPP project. The advisory fees charged by TNUDF should be on project specific rather than tied with disbursement from grant fund. It will make the ULBs / state government to understand TNUDF's value proposition.

Conclusions

The analysis of case studies in this paper has comprehensively established the fact that the Tamil Nadu Urban Development Fund has played a pivotal role as a nodal agency in development of urban infrastructure in the state of Tamil Nadu. The contributions of TNUDF such as providing a holistic view to infrastructure development, creating pipeline of projects, reducing the transaction costs, augmenting co ordination among stakeholders, creating enabling environment for PPP service delivery, supplementing competencies at municipal level and bridging the public private cultural divide resulted in effective implementation of PPP projects. The current institutional framework was developed keeping in mind the policy framework prevailing in the past. The potential of TNUDF for solving urban infrastructure bottleneck is left untapped due to bit and pieces approach followed by Government of Tamil Nadu in implementation of PPP programmes. The role of TNUDF in meeting huge urban infrastructure needs hinges on improvements in existing institutional framework by building capacity within the government machinery, political commitment to PPPs, increasing the scope and valuing the advisory services of TNUDF. The lessons learned from existing institutional frameworks in other countries for facilitation of PPP in delivery of infrastructure services provides rich source of information. But the mixed results from these institutional frameworks make it imperative for the research community to contribute in development of institutional framework considering state's need, socio economic environment, administrative culture and political requirements.

EFFECTS OF THE REGULATORY ENVIRONMENT ON CONSTRUCTION PROJECT DELIVERY METHOD SELECTION

Valerie R. Riecke Smith[1], Daniel Castro-Lacouture[2], and Rita Oberle[3]

[1] Contracting Officer, General Services Administration, Public Buildings Service, 401 West Peachtree Street, NW, Atlanta, GA 30308; PH (404) 224-2279; email: valerie.riecke@gsa.gov
[2] Assistant Professor, Building Construction Program, Georgia Institute of Technology, 280 Ferst Drive, Atlanta, GA 30332; PH (404) 385-6964; FAX (404) 894-1641; email: dcastro@gatech.edu
[3]Associate Professor, Building Construction Program, Georgia Institute of Technology, 280 Ferst Drive, Atlanta, GA 30332; PH (404) 894-4875; FAX (404) 894-1641; email: rita.oberle@coa.gatech.edu

Abstract

The selection of an appropriate procurement system contributes significantly to the outcome of a design and construction project. Previous research has attempted the development of a systematic approach to project delivery method selection. However, such attempts did not properly address public agencies and legislative impediments are almost entirely neglected as suggested variables in such models. This paper addresses these limitations by presenting a quantitative analysis to test whether state legal limitations do influence the selection for federal projects. Project characteristics from the U.S. General Services Administration Capital Construction Project database are presented. The database is analyzed using cross-tabulation to ascertain potential correlations among the variables, and specifically their relation to project delivery method choice. Contributions from this research are reflected in providing a methodology for a decision maker who is choosing among project delivery methods and is assessing the project characteristics and specifically the legislative impediments associated with a construction project.

Introduction

The selection of an appropriate procurement system contributes significantly to the outcome of a design and construction project (Chan et al. 2002; Love 2002; Chan et al. 2004). And while no one system is superior in all circumstances, there is probably a best choice for any specific project (Dell'Isola et al. 1998). Many owners base their project delivery method choice upon biased experience of in-house experts and/or advice from external consultants (Masterman and Duff 1994). Other owners

use project delivery methods based on over-simplified practices that "take into account the characteristics of each job rather than adopt a method developed from detailed consideration of both the projects themselves and their effects on the ongoing business of the organization" (Griffith and Headley 1997).

Researchers and practitioners are constantly seeking to determine which construction project delivery method best suits a project. This project delivery method selection process is part of the programming phase of a project, and typically is overshadowed by the need to determine sufficient program definition during the same phase. This problem is exacerbated in alternative project delivery methods in that the public owner does not have the design reviews that are common in traditional construction delivery methods. Public owners who are without experience in alternative project delivery methods or who are unsure about the appropriate application will opt for the traditional method of project delivery, design-bid-build, and face the risks associated with its low-bid process. Skitmore and Marsden (1988), argue for the development and application of a more systematic approach to project delivery method selection. Since then, there is substantial research that suggests and even attempts to develop a systematic approach to project delivery method selection. However, existing literature rarely addresses public agencies and legislative impediments are almost entirely neglected. Over the past several decades, there has been growing dissention toward the design-bid-build project delivery method. Critics claim that choosing a builder based on the lowest price under the design-bid-build method supports unscrupulous behavior. This growing dissention has led to court cases to challenge the Brooks Act, which evolved to the passage of the National Defense Authorization Act of 1996, re-named the Clinger-Cohen Act. This Act allows all federal agencies to award one contract to an entity or team of entities to design and build the construction project. However, many federal agencies and state governments have yet to embrace design-build as a viable procurement system. Five years after the Clinger-Cohen Act was passed, almost half of all states did not allow design-build. And 10 years after its enactment, there are still five states that forbid design-build, and of those that allowed it, many are highly restrictive in its use. This paper addresses legal legislative limitations inherent in the public construction industry by presenting an analysis that can be integrated into existing models and taken into consideration when choosing a project delivery method. The analysis uses a series of multivariate flowcharts, or models, that reflect how project delivery methods influence project characteristics, such as project duration and project cost. These flowcharts guide public owners in determining the advantages and disadvantages of alternative project delivery methods, such as design-build and construction manager at-risk. The analysis aids public owners and the construction industry by identifying, testing and analyzing the impact of legislative impediments in the project delivery method selection process.

Research Hypothesis and Data

The data used to test the research hypothesis, whether benefits exist to public owners when using alternative project delivery methods and whether benefits exist to public owners when legislative impediments are lifted, and alternative project delivery methods are allowed to be used, is provided from the Project Information

Portal (PIP) from the General Services Administration (GSA). The PIP is a nationwide system for tracking the GSA's Public Buildings Services (PBS) over-prospectus construction program, where users can obtain project information, from its design renderings, construction photos, or completed project views.

The database includes project characteristics or variables to assist Congress and GSA executives to track the progress of such projects. These variables are: (1) Region; (2) Project Type; (3) Program Area; (4) Project Delivery Method; (5) Political Party; (6) Gross Area; (7) Usable Space; (8) Congress Authorization; (9) Conference Appropriation; (10) Central Office Allowance; (11) Estimated Total Project Cost; (12) Estimated Total Project Cost Site; (13) Estimated Total Project Cost Design; (14) Estimated Total Project Cost Construction; (15) Congress Authorization Year; (16) Planning Phase Duration; (17) Design Phase Duration; and (18) Construction Phase Duration. Several of these variables were grouped to analyze the data in more detail: (19) Congress Authorization Year to Construction Finish Duration; (20) Planning Start to Construction Finish Duration; and (21) Design Start to Construction Finish Duration. To test the hypothesis, whether benefits exist when alternative project delivery methods are used and whether legislative limitations allowing the use of alternative project delivery methods impede any such benefits to be realized, the researcher adds two new variables to the database: (22) Federal Legislation and (23) State Legislation.

This database is selected for this research and the variables contained within it are used because GSA's Project Information Portal (PIP) is the most comprehensive database that could be found. This database also is required through congressional mandate and so the variables within it are required through such mandate. The goal is to take a quantitative approach to determining whether benefits exist to a public owner when alternative project delivery methods, specifically design-build, are used for a construction project, and whether legislative limitations allowing the use of such alternative methods impede such benefits to be realized. To test the hypothesis, whether benefits exist when alternative project delivery methods are used and whether legislative limitations allowing the use of alternative project delivery methods impede any such benefits to be realized, Federal Legislation was added as a new variable to the database. Federal Legislation represents if the 1996 Clinger-Cohen Act is passed into law when Congress authorized funding for the project. The 1996 Clinger-Cohen Act allows qualifications-based selection of builders using the design-build and construction manager as-constructor forms of project delivery. This new variable provides information to explore the benefits of using alternative project delivery methods. Fifty-six projects in the database are approved by Congress before the Clinger-Cohen Act is enacted; these projects were approved by Congress before 1996. Three hundred and twenty-five projects in the database are approved after the Clinger-Cohen Act is enacted, or from fiscal year 1996 to 2008. And 115 projects in the database do not provide such information and those projects have missing data. These results in the database are depicted in Table 1.

Table 1. Descriptive Statistics of Federal Legislation

Clinger-Cohen Act of 1996	Number of Projects (Frequency)	Percent
Enacted before 1996	56	11.3
Enacted after 1996, and including 1996	325	65.5
Missing	115	23.2
Total	496	100.0

Following the lead of the federal government, state legislation has been enacted to enable the two-phase selection process for builders through the use of design-build as an alternative method of project delivery, even though many states have adopted the Miller Act for use at the state level (referred to as Little Miller Acts). This legislation is owner-driven by government agencies, not by industry associations. Public owners are looking for alternatives to low-bid, multiple contracts and are attracted by the cost- and time-savings that design-build can offer.

Quantitative Analysis

Cross-tabulations test the association among variables. This technique analyzes the relationships between independent and dependent variables, or between defined problems and factors contributing to those problems. This investigates cause-and-effect relationships, looking at the extent to which one variable (i.e., the cause) influences another variable (i.e., the effect) (Leedy and Ormrod 2005). A variable that is studied in research as a possible cause of something else is the independent variable. A variable that is potentially influenced by the independent variable is the dependent variable, because it depends on the independent variable. In this paper, the dependent variable is the project delivery method and the independent variables are the project characteristics, and specifically the variables to test the hypothesis, the legislative impediments. Cross-tabulations are performed using the dependent and independent variables to test the relationship of the associations.

As presented before, there are 24 independent variables and one dependent variable (i.e., project delivery method) in the database, and all independent variables are analyzed using cross-tabulations in this section. While cross-tabulations provide the relationship among two variables, it does not address the strength of the association. While it is possible to examine the strength of the relationship by modeling two or more independent variables, the scope of this paper to is to extrapolate information from the project variables and explore their relationship with project delivery method selection.

The Estimated Total Project Cost (ETPC) for the dataset reveals that projects using the design-bid-build delivery method, on average, are funded most heavily, with an average of $32,740,537 for all projects, as depicted in Figure 1. The ETPC represents the total cost for designing and constructing the project. Projects using construction manager as-constructor (also referred to in the construction industry as construction manager at-risk) delivery method rank second in funding, with an average of $30,867,296. Design-build projects rank third with an average of

$8,424,746 in costs, and design-build-bridging projects rank last with an average of $7,947,623 in costs.

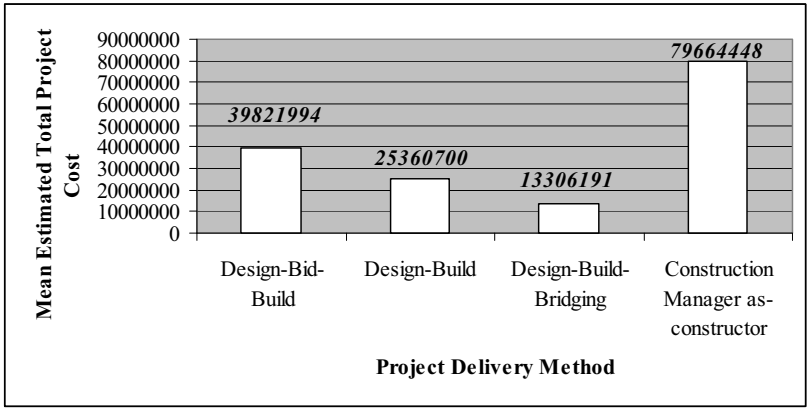


Figure 1. Cross-Tabulation of Project Delivery Method and Estimated Total Project Cost (Dollars).

The duration of time, on average, from when a design begins and when construction ends is telling. Similar to other cross-tabulations of time, projects using the construction manager as-constructor, on average, have the longest durations, with 2,661 days, as depicted in Figure 2. Cross-tabulations also suggest that projects using design-build-bridging have significantly lower durations, with an average of 1,099 days for design and construction phases. Projects using design-bid-build rank second in longest durations with an average of 2,246 days, and projects using design-build for project delivery average 1,850 days for design and construction activities.

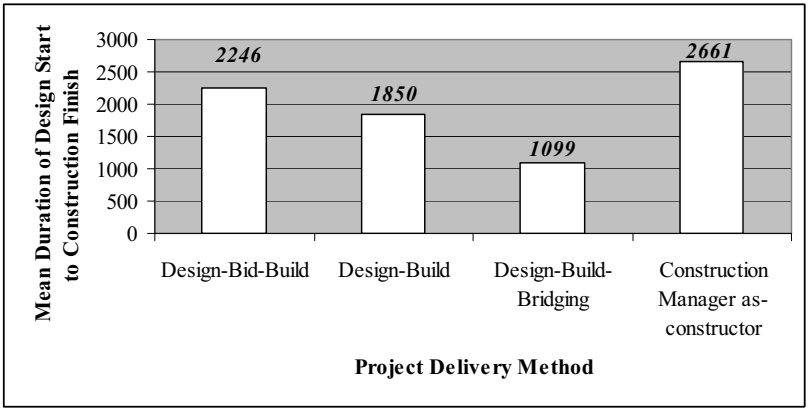


Figure 2. Cross-Tabulation of Mean Duration of Design Start to Construction Finish and Project Delivery Method (Number of Projects).

Federal Legislation

It was tested whether benefits exist when alternative project delivery methods are used and whether legislative limitations allowing the use of alternative project delivery methods impede any such benefits to be realized. Cross tabulation of the project delivery method and whether the 1996 Clinger-Cohen Act was passed when Congress authorized funding for the project is analyzed, as presented in Table 2. This analysis reveals that design-bid-build is the project delivery method chosen more often project after the Clinger-Cohen Act is enacted. GSA public owners have lessened legislative restrictions on using an alternative delivery method and still choose design-bid-build. There are significant numbers of projects that choose design-build, design-build-bridging and construction manager as-constructor once those legislative barriers are lifted. Only four projects choose design-build before 1996, and 73 choose design-build after 1996. There seems to be a trend using cross tabulation for the analysis.

Table 2. Cross-Tabulation of Project Delivery Method and Federal Legislation (Number of Projects)

	Federal Legislation			Total
	No	Yes	Missing	
Design-Bid-Build	44	173	35	252
Design-Build	4	73	23	100
Design-Build-Bridging	1	16	52	69
Construction Manager as Constructor	7	63	5	75
Total	56	325	115	496

State Legislation

Similar to Federal Legislation, cross-tabulation is explored to determine if there is trend in project delivery method selection and if design-build is authorized in the state when Congress authorized funding for the project. This tests whether benefits are realized when an alternative delivery method is chosen for a federal project when there are lessened legislative barriers at the state level. The results are presented in Table 3. The analysis reveals that more federal projects choose an alternative delivery method if state legislation (i.e., in the state the project is located) allows the use of design-build. This is true in all delivery methods, except for design-build-bridging. The use of design-build for federal projects doubled in states that allow design-build. The use of design-bid-build stays almost stable and yet there is only a slight increase when there are lessened state legislative barriers. Using cross tabulation indicates a trend in the use of design-build with lessened state legislative barriers.

Table 3. Cross-Tabulation of Project Delivery Method and State Legislation (Number of Projects)

	State Legislation			Total
	No	Yes	Missing	
Design-Bid-Build	81	86	85	252
Design-Build	22	49	29	100
Design-Build-Bridging	8	4	57	69
Construction Manager as Constructor	25	28	22	75
Total	136	167	193	496

Conclusions

Choosing an appropriate procurement method for construction projects continues to be one of the most-important topics for construction research. Yet, methodologies for investigating such topics are greatly underdeveloped. Cross-tabulation analysis provides a way to assess the impact of legislative impediments on project delivery method selection. This research moves toward a clearer focus of the vast and confusing domain of project delivery method studies. By offering additional insight into the benefits of alternative project delivery methods and the impact of legislative impediments on the outcome of a project, this research helps the public owner organize and manage the procurement of a construction project.

The cross-tabulation analysis reveals that there is an increase in the use of alternative delivery methods, especially design-build, once federal and state legislative barriers are lifted. Before Clinger-Cohen was passed in 1996, only 4 projects choose design-build; after this law is passed, 73 projects choose design-build. Design-build is selected twice as much after state legislative barriers are lifted. Cross-tabulations suggest a relationship among legislative impediments and project delivery method selection. However, while cross-tabulation as an analysis technique describes the relationship among two variables, it does not measure the strength of the relationship and does not describe whether a statistically significant relationship exists among the variables. This methodology proves to be a valuable approach in analyzing the effect of legislative impediments on the outcome of a construction project, and is recommended for future research in the construction industry.

References

Chan, A.P.C., Chan, A.P.L., and Scott, D. (2004). "Factors affecting the success of a construction project," *Journal of Constr. Eng. and Mgmt*, 130(1), 153-155.

Chan, A.P.C., Lam, E.W.M., and Scott, D. (2002). "Framework of success criteria for design/build projects," *Journal of Mgmt in Engineering*, 18(3), 120-128.

Dell'Isola, M.D., Licameli, J. P., and Arnold, C. (1998). "How to form a decision matrix for selecting a project delivery system," *Design-Build Strategies*, 4, 2.

Griffith, A., and Headley, J.D. (1997). "Using a weighted score model as an aid to selecting procurement methods for small building works," *Construction Management and Economics*, 15, 341-348.

Leedy, P.D. and Ormrod, J.E. (2005). Practical Research: Planning and Design. New Jersey: Pearson/Merrill Prentice Hall.

Love, P.E.D. (2002). "Influence of project type and procurement method on rework costs in building construction projects," *Journal of Constr. Eng. and Mgmt*, 128(1), 18-29.

Masterman, J., and Duff, A. (1994). The selection of building procurement systems by client organizations. *Proceedings of the 10th Annual ARCOM Conference,* Skitmore, R.M. and Betts, M. (eds), Loughborough University of Technology, Association of Researchers in Construction Management, 650-659.

Skitmore, M., and Mardsen, D. (1988). "Which procurement system? towards a universal procurement selection technique," *Construction Management and Economics*, 6, 71-89.

DEVELOPMENT OF A FUZZY EXPERT SYSTEM FOR SURETY UNDERWRITING

Krista Marsh[1] and Aminah Robinson Fayek[2]

ABSTRACT

In the construction industry, owners are constantly seeking practices to reduce the risk of contractor default. One method is the requirement of contractors to obtain surety bonds to bid on and complete construction projects. Similar to contractor prequalification, there are countless factors, both quantitative and qualitative, that the surety underwriter must consider and analyze. Many of these factors are uncertain and difficult to quantify, as every contractor and every construction project is different. The purpose of this paper is to describe the development of a model to assist surety underwriters in the decision-making process of providing contractors with bonding. It incorporates two types of artificial intelligence, fuzzy logic and neural networks, to create a neuro-fuzzy expert system. By combining fuzzy logic with neural networks, the individual limitations of each can be overcome. The resulting neuro-fuzzy expert system is able to model the complex relationship between input and output variables while remaining transparent in its logic. This model is not designed to replace the experience and expert judgment of surety underwriters and brokers, but rather to verify their decisions and validate their thought processes.

INTRODUCTION

Owners are constantly seeking practices to reduce the risk of contractor default due to the dynamic and unpredictable work environment. One method is the requirement of contractors to obtain surety bonds to bid on and complete construction projects. Similar to contractor prequalification, some factors that the underwriter must consider are extremely subjective.

[1] Research Assistant, Hole School of Construction Engineering, Department of Civil and Environmental Engineering, 1-080 Markin/CNRL Natural Resources Engineering Facility, University of Alberta, Edmonton, Alberta, Canada T6G 2W2, Phone 780/492-9131, FAX 780/492-0249, kdmarsh@ualberta.ca

[2] NSERC Associate Industrial Research Chair, Professor, Hole School of Construction Engineering, Department of Civil and Environmental Engineering, 3-013 Markin/CNRL Natural Resources Engineering Facility, University of Alberta, Edmonton, Alberta, Canada T6G 2W2, Phone 780/492-1205, FAX 780/492-0249, aminah.robinson@ualberta.ca

Surety bonding is used in the construction industry to mitigate the risk of contractor default. It is a three party agreement in which the surety ensures the owner that the contractor will complete the project according to the contract specifications. Surety companies bond contractors with the expectation that the contractor will not default. They evaluate contractors in detail with respect to the following five areas: capital (financial stability), character, capacity, project risk, and contractual risk. The latter two areas are considered after the contractor has established a relationship with the surety company and has requested bonding. Currently, the evaluation process is based on expert knowledge and rules of thumb, which are the foundation of human decision-making.

Many of these factors are uncertain and difficult to quantify, as every contractor and every construction project is different. Uncertainty also lies in the relationship between the factors, the measurement of each criterion, and the experience and opinion of the underwriter. The decision to bond a contractor is a very complex and subjective process that requires expert knowledge and judgment. The decision-making model described in this paper focuses on the initial evaluation of contractors and subsequent annual reviews, and therefore does not include factors pertaining to project or contract risk.

This model incorporates two types of artificial intelligence, fuzzy logic and neural networks, to create a neuro-fuzzy expert system. Fuzzy logic is able to deal with the uncertainties due to subjective judgment and expert opinion, linguistic expression, and ranges of acceptable values. Neural networks are capable of working with large data sets and learning the non-linear relationship between input and output variables. The neuro-fuzzy expert system was developed in consultation with several acknowledged senior underwriters and brokers. Their surety expertise was used in several steps of the model's development, including selection of criteria and their weights, generation of membership functions, construction of the fuzzy rule base, and the gathering of actual case data for neural network training and model validation.

LITERATURE REVIEW

An extensive literature review was conducted on surety underwriting and contractor prequalification, the latter of which is very similar to the evaluation done by surety underwriters. The fundamental evaluation criteria and the objective of determining the contractor's competence are similar in each process. Russell (1990a) indicates that the only differences between the two are: (1) prequalification generally places more emphasis on subjective factors, and underwriting generally places more emphasis on financial stability; (2) the owner has on-site personnel to monitor and react quickly to contractor failure, unlike an underwriter; and, (3) the underwriter is not restricted from viewing any information, specifically financial records, as is the owner. The pioneering work of Russell and Skibniewski in contractor prequalification criteria and decision-making models has created the basis for most research in this area. In 1988, Russell and Skibniewski presented a list of criteria used to evaluate contractors, which became the basis of several studies that subsequently added importance weights to the criteria (Russell 1992, Holt et al. 1994a, Ng and Skitmore 1999). Many early models incorporated multi-criteria

decision support systems that use weighted criteria to calculate an aggregate ranking score for potential contractors (Russell, 1990b, Russell and Skibniewski 1990a, 1990b, Russell et al 1990, Ng and Skitmore 1993). In attempts to deal with qualitative criteria, other models integrated utility theory (Diekmann 1983, Holt et al. 1994b, Hatush and Skitmore 1998). Cluster analysis was used by Holt (1996) to group contractors with similar attributes. Other techniques, including case-based reasoning (Ng et al. 1998) and data envelopment analysis (McCabe et al. 2005), have also been investigated. Several models have utilized fuzzy set theory, an artificial intelligence technique, to account for subjective criteria (Nguyen 1985, Elton et al. 1993, Sonmez et al. 2002, Singh and Tiong 2005, Li et al. 2007). Other artificial intelligence techniques have also been incorporated into contractor prequalification. Artificial neural networks (Hanna et al. 1997, Park et al. 1998) as well as fuzzy neural networks (Lam et al 2001) were used to determine the non-linear relationship between input and output variables. Although these models were efficient, the inner logic of the models is hidden, as is always the case with neural networks.

Only five studies were discovered specifically on the surety underwriting process. A quantitative model by Kangari et al. (1992) uses financial ratios to assess the contractor's financial stability. The model utilizes multiple linear regression to find the contractor's performance index. Kangari and Bakheet (2001) then created five evaluation forms to incorporate evaluation criteria other than financial ratios into the evaluation process. The criteria were assessed using linguistic terms. A model using discrete choice modeling was created to calculate the probability of contractor failure (Russell and Jaselski 1992); however, it only incorporated four evaluation criteria: amount of owner evaluation, cost monitoring, owner perception of contractor senior management support to project manager, and contractor's early involvement on a project. Discrete choice modeling is a regression technique used to determine the probability of a discrete outcome, in this case contractor failure. It was also used in a study conducted by Severson et al. (1994), which uses financial data alone to predict the probability of a surety claim. The final study found provided a comparison of the effectiveness of two artificial intelligence techniques, neural networks and genetic algorithms, in predicting contractor default (Al-Sobiei et al. 2005). Genetic algorithms were found to be more accurate; however, they were only accurate 88% of the time.

CONTRACTOR EVALUATION CRITERIA

The determination of contractor evaluation criteria was a very important step in creating the proposed neuro-fuzzy expert system. Experts in the surety industry were contacted through interviews, meetings, and questionnaires to ensure that factors applicable to industry practices were used. After interviewing several surety brokers, an initial list was created that documented every factor found in the literature and discovered during interviews that pertained to contractor evaluation. It also included questions and statements that an evaluator would use to determine the competency of the contractor for each factor. The list was circulated to other underwriters and brokers, each of whom added their comments and factors to the list. A questionnaire was developed based on this list that was sent to 4 underwriters and 4 brokers, each of whom rated the importance of each criterion. The 48 factors used as input into the

model were based on the results from the questionnaires and the input of these experts.

Each input variable was given 3 linguistic descriptors, as well as a fourth membership function that represented the linguistic term Not Applicable or Not Available (N/A). The N/A option allows the user to disregard input factors that do not apply to the contractor or for which they do not have information. Table 1 lists a sample of the model's input variables, their linguistic descriptors, and a scale used to quantify them (i.e. x-axis variable). The table also lists red flag indicators. If these significant threshold values are entered by the user, the model interface notifies the user so that he/she is aware of it. Many times the evaluator will assess the variable further and inquire about the circumstances relating to it.

Table 1 – Sample Input Variables used in the model

Input Variable	Linguistic Descriptors	X-Axis Variable	Red Flags
Quality of Financial Statement	Notice to Reader, Review, Audit	Categorical Values	If NTR
Current Ratio	Low, Average, High	Real Numbers	>=1.3
Gross Profit Margin Trend	Poor, Average, Good	Real Numbers	< -10%
Credit Score	Unacceptable, Acceptable, Good	Rating Scale of 1-7	< 3
Previous Claims and Past Judgments	Yes, No	Categorical Values	If Yes
Opinion of Previous Clients	Poor, Average, Good	Rating Scale of 1-7	< 3
Contract Overruns: Cost	Few, Some, Many	Real Numbers	> 30
Key Employee Experience	Poor, Average, Good	Real Numbers	< 5
Personal Feelings of Underwriter	Poor, Average, Good	Rating Scale of 1-7	< 3
Subcontractor Prequalification Process	Unacceptable, Acceptable, Good	Rating Scale of 1-7	< 3

Some input variables are categorical values (e.g., Yes/No). Other variables are rated on a scale of 1-7, where each value on this scale is given a linguistic descriptor or an explanation to reduce the subjectivity of the underwriter's judgment when rating the contractor for that particular variable. Other variables are based on objective values (e.g., real numbers).

Intermediate variables were created to reduce the number of rules needed for the expert system. The total number of rules required for a complete rule base is y^z, where y equals the total number of membership functions for each input variable, and z equals the total number of input variables. The largest rule base with 4 input variables contains $4^4 = 256$ rules. A total of 21 intermediate variables were used to create 21 sub-inference systems, each with their own rule base. Each sub-inference system has at most four input variables and one output variable. These output variables, with the exception of the overall output, make up the intermediate variables which are used as input into higher level sub-inference systems. The collection of sub-inference systems make up the entire neuro-fuzzy expert system.

Outputs were created at 14 of the intermediate variables, to allow the user to see the output at various sub-inference systems. One final output, contractor qualification rating, is created as the overall output for the entire expert system. The overall output was described using 5 linguistic terms: not qualified, somewhat qualified, qualified, very qualified, and extremely qualified. All output variables are defuzzified to a crisp value on a scale of 1-7. Table 2 lists a sample of output variables and their linguistic descriptors.

Table 2 - Intermediate and Output Variables

Output Variable	Linguistic Descriptors	X-Axis Variable	Red Flags
Capital	Poor, Average, Good	Rating Scale of 1-7	< 3
Liquidity	Poor, Average, Good	Rating Scale of 1-7	< 3
Financial Trends	Poor, Average, Good	Rating Scale of 1-7	< 3
Character	Poor, Average, Good	Rating Scale of 1-7	< 3
Reputation	Poor, Average, Good	Rating Scale of 1-7	< 3
Experience	Poor, Average, Good	Rating Scale of 1-7	< 3
Capacity	Poor, Average, Good	Rating Scale of 1-7	< 3
Current Work Load	Poor, Average, Good	Rating Scale of 1-7	< 3
Resources	Poor, Average, Good	Rating Scale of 1-7	< 3
OVERALL RATING	Not Qualified, Somewhat Qualified, Qualified, Very Qualified, Extremely Qualified	Rating Scale of 1-7	< 3

NEURO-FUZZY EXPERT SYSTEM

Background

Neuro-fuzzy expert systems combine expert systems with fuzzy set theory and artificial neural networks. An expert system is a computer-based system that imitates the human reasoning process in decision-making. Fuzzy set theory provides a method of representing qualitative and subjective data and allows variables to be described using natural language. In a fuzzy set, an element is associated with a degree of belonging to that set, ranging from 0 (no belonging) to 1 (full belonging). Artificial Neural Networks (ANN) have the ability to model non-linear, complex relationships between input and output variables using actual case data and can be used to train both the membership functions and the rules in a fuzzy expert system. The integration of ANNs and fuzzy expert systems creates a model that can benefit from the strengths of each technique. ANNs provide structure and learning abilities to the fuzzy expert system, and fuzzy expert systems provide transparent reasoning through the use of rules that employ fuzzy variables.

Fuzzy expert systems are generally composed of a knowledge base and an inference engine. The knowledge base consists of a set of fuzzy rules, which consist of a condition (IF part) and conclusion (THEN part). The condition and conclusion can each include more than one variable linked together by linguistic conjunctions (and, or). The inference engine of a fuzzy expert system consists of five steps: fuzzification of input variables, application of fuzzy operators, implication, aggregation, and defuzzification of output variables.

In a neuro-fuzzy expert system, ANNs can be used to weight the rules and train the membership functions. In the model described in this paper, ANNs were used to add weights to rules in order to give some rules higher relative importance in determining the output.

Membership Functions

One of the most difficult steps in creating a fuzzy expert system is in generating the membership functions (Medasani et. al. 1998, Pedrycz and Gomide 1998). Membership functions were created for the model described in this paper using the

horizontal method (Pedrycz and Gomide 1998), combined with heuristic methods developed by the authors.

A second questionnaire was sent to 30 recognized senior underwriters and brokers, in order to determine the range of values that belong to each predetermined linguistic descriptor for each input variable. A total of 14 questionnaires were completed and used to generate initial membership functions using the horizontal method. Participants were asked multiple choice questions in the form: "What would you consider is a LOW (linguistic descriptor) Gross Profit Margin (input variable)? Please circle as many answers as applicable." They were given 7-15 multiple choice answers applicable to each input variable. The horizontal method calculates membership values using the number of responses for that x-axis value divided by the total number of responses (Pedrycz and Gomide 1998). Figure 1 illustrates the initial membership functions for gross profit margin.

Heuristic methods were then used to visually curve fit the initial membership functions to triangular and trapezoidal functions. The final membership functions for gross profit margin are shown in Figure 2.

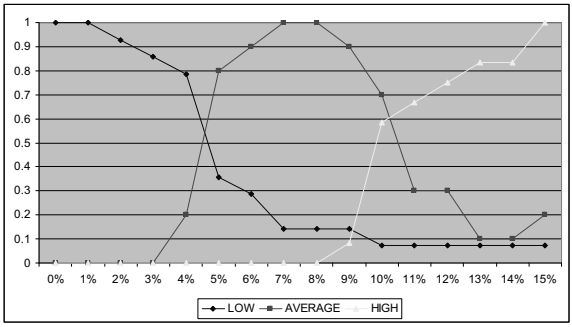


Figure 1 Initial Gross Profit Margin Membership Functions

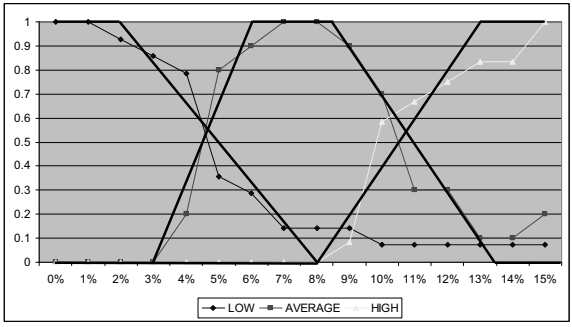


Figure 2 Final Gross Profit Margin Membership Functions

Neuro-fuzzy Expert System Structure

The interface of an expert system provides for interaction between the user and the system itself. It generally stores user input values and indicates the system output. Microsoft Excel is used as the interface for the neuro-fuzzy expert system. It prompts the user to enter all 48 input variables by asking appropriate questions and providing the predetermined rating scales. For categorical input variables and rating input variables, drop down menus are provided to ensure the user selects predetermined values.

Figure 3 illustrates the overall neuro-fuzzy expert system structure created using fuzzyTECH® version 5.5 Professional Edition (Inform GmbH 2005). Intermediate variables are characterized by a rule block that lists the sub-inference system input and output variables. Output variables extend from these intermediate rule blocks. Figure 4 shows a sample rule base for a sub-inference system with the output "overall qualification". The logic of rules was generated using information collected from the first expert questionnaire.

CONCLUSIONS AND FUTURE WORK

A neuro-fuzzy expert system was described to help surety underwriters and brokers to evaluate contractors for the purpose of bonding. Senior surety professionals provided direct input in the development of this model and determination of the contractor evaluation criteria. There have been numerous models created for the purpose of prequalifying contractors, but very little research has been done on the surety underwriting process. The model described in this paper incorporates two types of artificial intelligence, fuzzy logic and neural networks, to capitalize on the advantages of each. The model is currently being tested and validated for accuracy.

Further research will be conducted on the sensitivity of the model and its parameters to variations in the fuzzy logic operators. Future research will seek to increase the number of neural network training cases to broaden the model's capabilities and applicability.

ACKNOWLEDGMENTS

The authors would like to acknowledge Mr. Andre Giasson, Mr. Jason Smith, and Mr. Brian Davidson of Aon Reed Stenhouse, and Mr. Bob Landy, and Ms. Betty Shellnutt of AXA Pacific for their time and expertise in providing input while conducting this research. This research was funded by an NSERC Discovery Grant RGPIN, held by Aminah Robinson Fayek

REFERENCES

Al-Sobiei, O.S., Arditi, D., Polat, G. (2005). "Managing Owner's Risk of Contractor Default." *J. Constr. Engrg. and Mgmt.,* Vol. 131, (9), 973-978.

Diekmann, J.E., (1981) "Cost-plus contractor selection." *Journal of the Technical Councils*, ASCE, Vol. 107, 13-25.

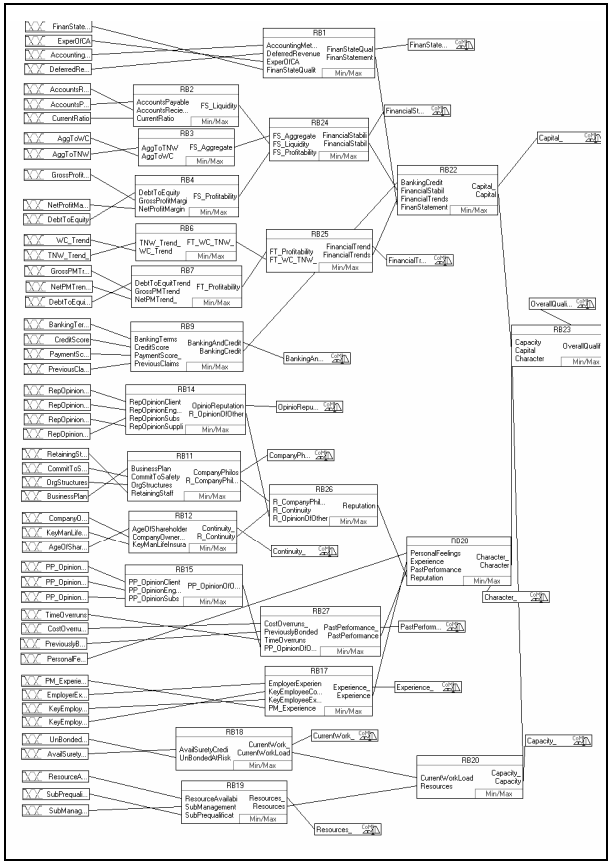


Figure 3 – Neuro-fuzzy Expert System Structure

Spreadsheet Rule Editor - RB23

#	IF Capacity	Capital	Character	THEN DoS	OverallQualifica
20	POOR	NA	GOOD	1.00	Qualified
21	POOR	POOR	NA	1.00	NotQualified
22	POOR	POOR	POOR	1.00	NotQualified
23	POOR	POOR	AVERAGE	1.00	SWqualified
24	POOR	POOR	GOOD	1.00	SWqualified
25	POOR	AVERAGE	POOR	1.00	SWqualified
26	POOR	AVERAGE	AVERAGE	1.00	SWqualified
27	POOR	AVERAGE	GOOD	1.00	Qualified
28	POOR	GOOD	NA	1.00	Qualified
29	POOR	GOOD	POOR	1.00	SWqualified
30	POOR	GOOD	AVERAGE	1.00	Qualified
31	POOR	GOOD	GOOD	1.00	VeryQualified
32	AVERAGE	NA	NA	1.00	Qualified
33	AVERAGE	NA	POOR	1.00	SWqualified

Figure 4 – Sample Expert System Rule Base

Elton, D.J., Juang, C.H., Russell, J.S., (1993). "Contractor Prequalification Using Fuzzy Sets." *Civil Engineering Systems*, Vol. 11. 1-17.

Fayek, A.R., Marsh, K. (2006). "A decision-making model for surety underwriters in the construction industry based on fuzzy expert systems." *Joint International Conference on Computing and Decision Making in Civil and Building Engineering,* June 14-16, Montreal, Canada.

Hanna, A.S., Russell, J.S., Taha, M.A., Park, S.C. (1997) "Application of neural networks to owner-contractor prequalification." *Artificial Neural Networks for Civil Engineers: Fundamentals and Applications*, 124-136.

Hatush Z., Skitmore M., (1998) "Contractor selection using multi-criteria utility theory: An Additive Model." *Building and Environment*, Vol. 33, (2), 105-115.

Holt, G.D., Olomolaiye, P.O., Harris, F.C. (1994a). "Factors Influencing UK Construction Clients' Choice of Contractor." *Building and Environment*, Vol. 29, 241-248.

Holt, G.D., Olomolaiye, P.O., Harris, F.C. (1994b). "Evaluating Prequalification Criteria In Contractor Selection." *Building and Environment*, Vol. 29 (4), 437-448.

Holt, G.D., (1996). "Applying Cluster Analysis to Construction Contractor Classification." *Building and Environment*, Vol. 31, (6), 557-568.

Inform GmbH. (2005) *fuzzyTECH® 5.5 User's Manual*. Inform Gmbh/Inform Software Corporation, Aachen, Germany.

Kangari, R., Farid, F., Elgharib, H. M., (1992). "Financial Performance Analysis for Construction Industry." *J. Constr. Engrg. And Mgmt.,* ASCE, 118 (2), 349-361.

Kangari, R., Bakheet, M., (2001). "Construction Surety Bonding." *J. Constr. Engrg. And Mgmt.,* ASCE, 127 (3) 232-238.

Lam, K.C., Hu, T., Ng, S.T, Skitmore, M. Cheung, S.O., (2001) "A fuzzy neural network approach for contractor prequalification." *Construction Management and Economics*. Vol. 19 (2), 175-188.

Li, Y., Nie, X. Chen, S., (2007) "Fuzzy approach to prequalifying construction contractors." *Journal of Construction Engineering and Management*, Vol. 133, (1), 40-49

McCabe, B. Tran, V., Ramani, J. (2005) "Construction prequalification using data envelopment analysis" *Canadian Journal of Civil Engineering*, Vol. 32, (1), 183-193.

Medasani, S., Kim, J., Krishnapuram, R., (1998). "An Overview of Membership Function Generation Techniques for Pattern Recognition." *International Journal of Approximate Reasoning*, Vol. 19, 391-417.

Ng, S.T., Smith, N.J., Skitmore, R.M., (1998). "A Case-based Reasoning Model for Contractor Prequalification." *International Journal of construction Information Technology,* Univ. of Salford Press, Edinburgh, Scotland, 61-66.

Ng, S.T., Skitmore, R.M., (1999). "Client and Consultant Perspectives of Prequalification Criteria." *Building and Environment*, Vol. 34, (5), 607-621

Ng, S.T., Skitmore, R.M., (1993). "CP-DSS: Decision Support System for Contractor Prequalification." *Civil Engineering and Environmental Systems* Vol. 12, (2), 133-159.

Nguyen, V.U. (1985). "Tender Evaluation by Fuzzy Sets." *Journal of Construction Engineering and Management*, Vol. 111, (3), 231-243

Park, S.C., Russell, J.S., Taha, M.A., (1998). "A distributed problem-solving approach for owner-contractor prequalification." *Annals of Operations Research*, n 78, 111.

Pedrycz, W., Gomide, F., (1998). *An Introduction to Fuzzy Sets: Analysis and Design*, A Bradford Book, the MIT Press, Cambridge, Massachusetts, London, England.

Russell, J.S., (1990a). "Surety Bonding and Owner-Contractor Prequalification: Comparison." *Journal of Professional Issues in Engineering*, Vol. 116, (4), 360-374.

Russell, J.S., (1990b). "Model for Owner Prequalification of Contractors." *Journal of Management in Engineering*, Vol. 6, (1), 59-75.

Russell, J.S., Benson, C.H, Fox, P.J. (1990). "A Stochastic Decision Model for Contractor Prequalification." *Microcomputers in Civil Engineering*, Vol. 5, (4), 285-297.

Russell, J.S., Hancher, D., Skibniewski, M.J., (1992) "Contractor Prequalification Data for construction Owners." *Const. Mgmt. Econ*., 10 (2), 117-135.

Russell, J. S., Jaselski, E. J., (1992). "Predicting Construction Contractor Failure Prior to Contract Award." *J. Constr. Engrg. And Mgmt.,* ASCE, 118 (4), 791-811.

Russell, J.S., Skibniewski, M.J., (1988). "Decision Criteria in Contractor Prequalification." *J. of Mgmt. in Engrg.,* ASCE, 4, 148-164.

Russell, J.S., Skibniewski, M.J. (1990a). "Qualifier-1: Contractor Prequalification Model." *Journal of Computing in Civil Engineering*, Vol 4, (1), 77-90.

Russell, J.S., Skibniewski, M.J. (1990b). "Qualifier-2: Knowledge-Based System for Contractor Prequalification." *Journal of Construction Engineering and Management,* Vol. 116, (1), 157-171.

Severson, G.D., Russell, J.S., and Jaselski, E.J. (1994). "Predicting Contract Surety Bond Claims Using Contractor Financial Data." ASCE, *Journal of Construction Engineering and Management*, Vol 120, (2), 405-420.

Singh, D. Tiong, R.L.K., (2005). "A fuzzy decision framework for contractor selection." *Journal of Construction Engineering and Management*, v 131, n 1, 62-70.

Sonmez, M., Holt, G.D., Yang, J.B. (2002). "Applying evidential reasoning to prequalifying construction contractors." *Journal of Management in Engineering*, Vol. 18, (3), 111-119.

ANALYSIS OF DESIGN-BUILD PROCUREMENT ACTIVITIES DURATIONS FOR HIGHWAY PROJECTS

Giovanni C. Migliaccio, Ph.D., M.ASCE[1] and Pramen P. Shrestha, Ph.D., P.E., M.ASCE[2]

ABSTRACT

The design-build (DB) method is being used at increasing rates for delivering highway projects in the United States. Benefits of adopting DB rather than the traditional design-bid-build (DBB) method have been identified by several studies that measured performance of projects delivered with DB as opposed to DBB. The majority of these studies support the widely-held belief that an owner can achieve a schedule advantage by adopting DB for delivering its projects. While these studies analyzed the duration of DB projects after a contract has been awarded, there is a lack of information on DB procurement activities' durations.

This paper reports preliminary findings from a study that is collecting and analyzing data on procurement schedule durations and project characteristics to identify factors affecting duration of DB procurement and effect of duration on project success. Based on data of nineteen DB highway projects, the authors provide descriptive statistics on duration of DB procurement activities. Findings show that project size measured by contract dollar amount affects the duration of DB procurement activities. The analysis of nineteen project data shows that procurement durations had no correlation with project cost for projects costing less than $250 million. However, when the projects costing more than $250 million were included in the analysis, a linear correlation between these two variables existed. Future research for determining relationships between project characteristics and procurement duration as well as between procurement duration and project success is also described.

KEY WORDS

Project delivery, Design-Build, Procurement duration

[1] Assistant Professor, Department of Civil Engineering, The University of New Mexico, Albuquerque, NM 87131; PH (505) 277-1948; FAX (505) 277-1988; email gcm@unm.edu

[2] Assistant Professor, University of Nevada, Las Vegas, Construction Management Program College of Engineering, 4505 S. Maryland Parkway, Las Vegas, NV 89154; PH (702)895-3841; FAX (702)895-4966; email pramen.shrestha@unlv.edu

INTRODUCTION

In the United States, owners are frequently adopting the design-build (DB) method for delivering construction projects rather than the traditional design-bid-build (DBB) method. Benefits of adopting DB have been identified by several studies that measured performance of projects delivered with DB as opposed to DBB (Ibbs, Kwak, Ng, & Odabasi, 2003; Konchar & Sanvido, 1998; Shrestha, Migliaccio, O'Connor, & Gibson Jr, 2007a, 2007b; USDOT-FHWA, 2007b). The majority of these studies support the prevalent belief that an owner can achieve a schedule advantage by adopting DB for delivering its projects. However, recent studies have suggested that the owner's personnel have to spend a considerable amount of time experimenting and developing procedures under the new delivery approach (USDOT-FHWA, 2007a; Migliaccio, Gibson, & O'Connor, 2008). For some projects, the duration of the procurement phase was as long as 35% of the total delivery time suggesting that the complexity of DB procurement may offset part of the expected schedule advantage (Migliaccio, 2007). While concerns involving duration of DB procurement have been raised, there is a lack of information on this topic.

Though several approaches to the procurement of design-build services are available to owners, processes that are based on the two-phase selection procedure are becoming the standard approach to DB procurement. Among others, the highway sector has been affected by the same tendency. In December 2002, the Federal Highway Administration (FHWA) released the "Design-Build Contracting Final Rule" (FHWA, 2002). This rule strongly encourages the use of two-phase selection procedures for DB procurement. As a result, the two-phase selection procedure represents the most common practice of procuring design-build services on highway projects. This institutionalization of DB procurement makes the task of collecting and comparing data on procurement duration easier and more consistent.

This paper reports preliminary findings from a study that is collecting and analyzing data on procurement schedule durations and project characteristics to identify factors affecting duration of DB procurement and effect of procurement duration on project success. The final goal of this study is to provide the industry with an empirical model that can be used for developing a DB procurement schedule. Relying on data of nineteen DB highway projects, the authors provide descriptive statistics on duration of DB procurement activities. In addition, DB procurement documents were analyzed to capture variations in the procurement approach that may affect the duration of the procurement phase. Future research for determining relationships between project characteristics and procurement duration is also described. Recommendations for practitioners on duration of DB procurement activities for highway projects will also be provided.

PROCUREMENT PHASES

A procurement process model developed in a previous study (O'Connor, Gibson Jr, & Migliaccio, 2004) was adopted in a simplified format to guide the break down of the procurement into phases. The adopted model was developed upon information on the procurement of two highway construction contracts by the Texas Department of Transportation. The model represents the two-phase best-value selection process.

A graphical representation of the process is shown in Figure 1. This process includes three phases. First, the Request for Qualifications (RFQ) phase includes three subphases: (a) preparation and issuance of RFQ package by owner (subphase RFQ1), (b) preparation of qualification submittals by private entities (subphase RFQ2), and (c) evaluation of submittal by owner (subphase RFQ3). Second, the Request for Proposals (RFP) phase may begin before the RFQ is completed and includes three subphases: (a) preparation and issuance of RFP package by owner (subphase RFP1), (b) preparation of proposals by private entities (subphase RFP2), and (c) evaluation of submittal by owner (subphase RFP3). Finally, the Contract Finalization (CF) phase is the time between the selection of a proposal and the execution of the contract. The duration of each of these phases/subphases is easily identified by milestones.

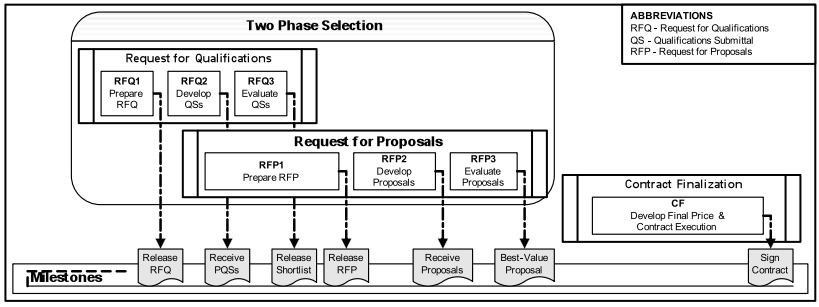


Figure 1 — Procurement Process with Milestones (adapted from O'Connor et al., 2004).

RESEARCH METHODOLOGY

The authors are conducting a study to identify factors affecting duration of DB procurement and effect of procurement duration on project success. Anedoctal evidence suggests that: (a) duration of certain DB activities may affect project success, and (b) DB procurement activities are currently scheduled based on consultant advice or organization experience with DB. Obviously, either one of these intuitions suggest that a more rational approach to scheduling DB procurement activities could strongly benefit success of DB projects. As a result, the final goal of this study is to provide the industry with an empirical model that can be used for developing a DB procurement schedule. To develop this model, researchers are: (a) collecting data on durations of DB procurement activities, (b) collecting data on project success, and (c) identifying factors that may affect duration of DB procurement.

Data on durations of DB procurement activities are being collected through archival sources. When adopting DB, public owners usually issue several documents that instruct private parties on the requirements and schedule of procurement. Documents that usually include information on procurement schedule are: (a) the request for letters of interest, (b) the request for qualifications, and (c) the Instruction to Proposers section of the RFP package. The authors are requesting to U.S. Department of Transportation a list of contracts for DB services that has been

awarded between 1997 and 2006. Based on preliminary information on the type of project (e.g., road, bridge, corridor), the authors are requesting a copy of the previously cited documents. Data on project success will be collected in a following phase through questionnaires and/or interviews with DOT representatives. Similarly, data on project characteristics are being collected through analyses of the contractual documents and interviews/questionnaires.

This paper reports preliminary findings based on analysis of archival sources for determining duration of DB procurement activities and their relationship with project complexity. These findings rely on the assumption that contract price can be considered a reliable measure of project complexity. Given the similarity of the projects (i.e., all road projects), this assumption may be considered correct. Using this approach, the authors had collected data for nineteen highway projects. The size of project ranges from $9 million to $1.3 billion dollars. The construction start date of these highway projects ranged from 1997 to 2006. The list of highway projects selected for this analysis is illustrated in Table 1.

Table 1: List of Selected DB Highway Projects

S. No.	Name of Project	Location (State)	Construction Start Year	Contract Price ($M)
1	Whittier Tunnel Road	Arkansas	1998	57
2	State Route 22	California	2004	390
3	T-REX	Colorado	2001	1,168
4	COSMIX	Colorado	2005	150
5	TH10/32	Minnesota	2004	9
6	Interstate 494	Minnesota	2004	136
7	Highway 53 Oronoco	Minnesota	2006	46
8	TH 212	Minnesota	2005	238
9	ROC 52	Minnesota	2003	23
10	US70 Hondo Valley	New Mexico	2002	129
11	NM 928	New Mexico	2002	19
12	Evans Creek	Oregon	1999	9
13	US 20	Oregon	2005	130
14	Interstate 5	Oregon	2006	242
15	State Highway 130	Texas	2003	1,300
16	State Highway 45 SE	Texas	2003	154
17	Interstate 15	Utah	1997	1,325
18	I-5 Everett HOV	Washington	2005	185
19	I-405 Kirkland	Washington	2005	47

FINDINGS

SUMMARY STATISTICS OF PROCUREMENT DURATION METRICS

Descriptive Statistics of Request for Qualification Duration

Table 2 shows descriptive statistics of RFQ duration in months. The data shows that the RFQ 1 took more time to complete than RFQ 2 and 3. The data trend shows that as the RFQ process moved forward, it took less time to complete RFQ 2 and RFQ 3. The average durations to complete the RFQ 1, RFQ 2, RFQ 3 were 2.6, 1.9, and 1.0 months respectively. The mean and median are very closed to each other. The

mean total RFQ duration was about 5.3 months. The difference between minimum and maximum values shows that there is a large disparity in total RFQ duration in DB highway projects.

Table 2: Descriptive Statistics of Request for Qualifications Duration in Months

Types of Statistics	RFQ -1	RFQ-2	RFQ-3	Total RFQ
Mean	2.6	1.9	1.0	5.3
Median	2.0	1.7	0.6	4.6
Maximum	4.7	6.0	2.0	10.0
Minimum	1.0	0.9	0.2	2.0
Standard Deviation	1.02	1.18	0.78	2.02
No. of Samples	11	16	15	11

Descriptive Statistics of Request for Proposal Duration

Table 3 shows descriptive statistics of RFP durations in months. The data analysis shows that RFP 1 took more time to complete than RFP 2 and 3. The trend is similar to that of RFQ. The mean and median are closed to each other. The maximum and minimum values show a wide range in RFP duration. The standard deviation also shows that the data were widely dispersed. The mean RFP 1, 2, and 3 were found to be 7.4, 3.3, and 1.8 months respectively. The mean total RFP Duration was 12.2 months. The maximum and minimum duration to complete the total RFP process were 23.0 and 5.4 months respectively.

Table 3: Descriptive Statistics of Request for Proposals Duration in Months

Types of Statistics	RFP -1	RFP-2	RFP-3	Total RFP
Mean	7.4	3.3	1.8	12.2
Median	7.0	3.2	1.3	11.7
Maximum	15.0	6.0	8.0	23.0
Minimum	2.7	1.1	0.7	5.4
Standard Deviation	3.70	1.63	1.9	4.92
No. of Samples	13	14	13	13

Descriptive Statistics of Contract Finalization Duration

Table 4 illustrates descriptive statistics of contract finalization duration in months. This duration is the time taken by owner to award the contract after the design/build contractor is selected. The data analysis shows that the mean contract finalization

duration was 2 working months. The standard deviation of this data shows that there was a large variation in the contract finalization duration. Some highway projects took 3 working days where as other took 3 months to finalize the contract. It can be concluded for this data set that the contract finalization duration is the least time taking activity in DB procurement process.

Table 4: Descriptive Statistics of Contract Finalization Duration in Months

Types of Statistics	Contract Finalization Duration
Mean	2.0
Median	1.4
Maximum	3.0
Minimum	0.1
Standard Deviation	2.2
No. of Samples	19

Descriptive Statistics of Total Procurement Duration

Table 5 shows descriptive statistics of total procurement duration in months. The total procurement duration is the time taken to complete the DB procurement process from the start of RFQ development to award of contract. The mean total procurement duration was found to be 12.4 months. The mean and median total procurement duration were closed to each other. The maximum and minimum values show that there was a large disparity in duration to procure these projects. The high standard deviation shows that there was a large variation in total procurement duration. The variation in the total procurement duration can depend on the project size. Therefore authors try to normalize the total procurement duration by converting this value into new metric called Total Procurement Duration per Project Cost. The data analysis for this metric is explained in the next paragraph.

Table 5: Descriptive Statistics of Total Procurement Duration in Months

Types of Statistics	Total Procurement Duration
Mean	12.4
Median	12.1
Maximum	27.6
Minimum	4.5
Standard Deviation	5.8
No. of Samples	19

Descriptive Statistics of Procurement Duration per Hundred Million Project Cost

Table 6 shows descriptive statistics of total procurement duration per hundred million project cost. The data analysis shows that there was a similar trend as in previous metrics. However the data were more dispersed than the previous one. The standard deviations for these three metrics were higher than those of the previous metrics. This shows that after normalizing the procurement duration with respect to project cost, the data became more skewed.

Table 6: Descriptive Statistics of Procurement Duration per Hundred Million

Types of Statistics	Total RFQ per Project Cost (M/ $HM)	Total RFP per Project Cost (M/ $HM)	Total Duration per Project Cost (M/ $HM)
Mean	9.6	17.9	19.1
Median	4.4	8.1	8.2
Maximum	45.8	95.8	104.3
Minimum	0.3	0.9	1.0
Standard Deviation	13.4	26.0	25.0
No. of Samples	11	12	19

CORRELATION ANALYSIS

Analyses were performed to determine the degree and direction of correlation between total procurement durations and total project cost. The findings of these analyses are described below.

Correlation between Total Procurement Duration and Project Cost

This correlation analysis shows that the total procurement duration was linearly correlated with total construction cost. The total procurement duration increased as the project construction cost increased. Figure 2 shows the graph of total procurement durations and construction cost. The data shows that a linear correlation exists between these two variables. From the plot, it can be clearly seen the total procurement durations increase as the size and hence cost of the project increases. The correlation coefficient was found to be 0.61 and the R-square value of the regression model was about 0.37.

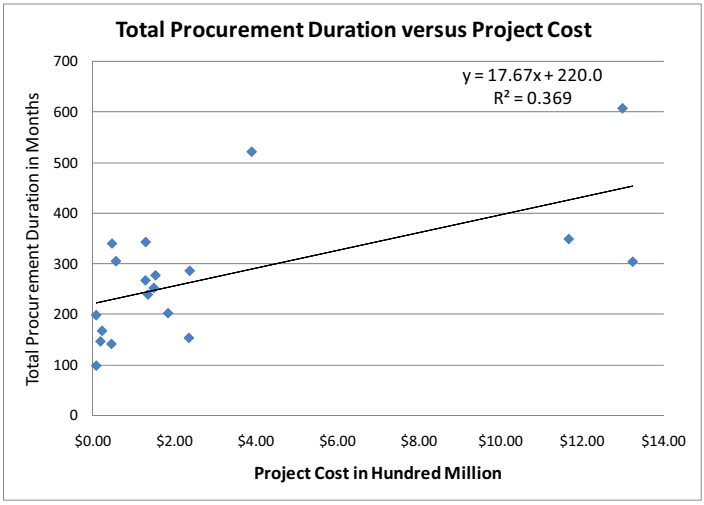


Figure 2: Total Procurement Durations versus Project Cost

The second regression analysis was conducted by removing the large projects and focusing the analysis on projects clustered in the \$0M-\$250M range. In this case, procurement duration and contract price had no relation. Figure 3 shows the scatter plot of total procurement durations in months and project cost in million. The model did not perfectly fit in this case than the previous case. The correlation coefficient and R-square value of model were 0.30 and 0.09 respectively. This shows that the correlation between procurement durations and project cost was very weak among the projects costing less than \$250 million.

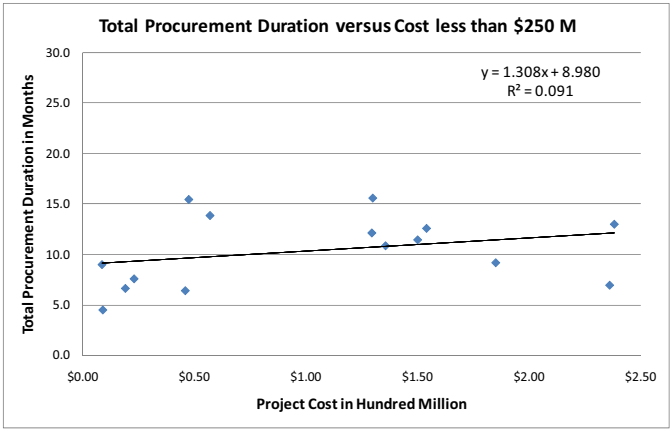


Figure 3: Total Procurement Durations versus Project Cost less than \$250 M

Limitations of Findings

These findings are based on sample size of nineteen projects, whose design and construction cost ranges from $9 million to more than $1.3 billion. The project cost considered in this research is not the actual design and construction cost but the proposal cost of the selected DB builder. Unfortunately, data are lacking for project in the $250M-$1,200 range. Therefore, these relationship must be verified when a more homogeneous data sample will be available.

CONCLUSIONS

This is a first attempt to conduct research on DB contract procurement duration on a statistical basis. This analysis shows that the average duration to complete the RFP is higher than the average duration to complete RFQ. RFQ is first phase of contract procurement development, and then RFP follows RFQ. The analysis shows that owners (DOTs) are spending on average longer time to prepare the DB project documents than to select the DB contractor. Strangely, less time is made available to private parties to prepare a proposal than to owners to prepare the procurement package.

The data analysis also shows that the average total procurement duration for the highway project ranging from $9 million to $1.3 billion was found to be 12.4 working months. Author tried to normalize procurement duration data by dividing procurement duration with project cost. This metric is called “Total Procurement Duration per Project Cost.” However, the analysis shows that there was more disparity in the descriptive statistics of this new metric than in the non-normalized data. Therefore authors did not conduct any further analysis using this metric.

Researchers also attempted to determine a correlation between total procurement duration and project cost. The regression analysis shows that there was a linear correlation between the procurement duration and project cost. This correlation was weaker, when the projects below $250 million were only considered in regression analysis. This confirms that up to certain project cost, the procurement duration will be constant. If the larger projects were included in the analysis, the correlation between these variables became stronger. However, the lack of data in the $250-$1,200 range does not allow concluding if the relationship could be a linear or a laddered one. The regression analyses of total project cost with total RFQ duration, total RFP duration, and total CF duration showed that these correlations had R-square lower than that of between total project cost and total procurement duration.

Authors are collecting more DB highway project data to determine whether there is a significant difference in RFQ and RFP durations in the procurement phase. The future analysis will also determine whether the RFQ, RFP, CF, and total procurement phase duration have a significant correlation with highway project cost, schedule, and change order performance.

ACKNOWLEDGMENTS

The authors gratefully acknowledge individuals from various Department of Transportation for providing the data for this analysis.

REFERENCES

FHWA. (2002). Design-Build Contracting; Final Rule. Federal Register, 67(237), 75901-75935.

Ibbs, C., Kwak, Y., Ng, T., & Odabasi, A. (2003). Project Delivery Systems and Project Change: Quantitative Analysis. Journal of Construction Engineering and Management, 129(4), 382.

Konchar, M., & Sanvido, V. (1998). Comparison of U.S. Project Delivery Systems. Journal of Construction Engineering and Management, 124(6), 435.

Migliaccio, G. (2007). Planning for Strategic Change in the Project Delivery Strategy. The University of Texas at Austin, Civil Engineering Department.

Migliaccio, G., Gibson, G., & O'Connor, J. (2008). Changing Project Delivery Strategy: An Implementation Framework. Public Works Management Policy, 12(3), 483-502. Retrieved from http://pwm.sagepub.com/cgi/content/abstract/12/3/483.

O'Connor, J., Gibson Jr, G., & Migliaccio, G. (2004, August). CDA Procurement Process Model. .

Shrestha, P., Migliaccio, G., O'Connor, J., & Gibson Jr, G. (2007a). Benchmarking of Mega Design/Build Highway Projects: One-To-One Comparison and Comparison with DBB Projects. Transportation Research Record, 1994, 17-25.

Shrestha, P., Migliaccio, G., O'Connor, J., & Gibson Jr, G. (2007b). Comparison Between Design-Build and Design-Bid-Build Transportation Projects Using Lane Mile Data. In Proceedings of the 2007 ASCE Construction Research Congress. Nassau, Grand Bahamas: ASCE.

USDOT-FHWA. (2007a, April 2). Report to Congress on Public-Private Partnerships. . Retrieved from http://www.fhwa.dot.gov/reports/pppdec2004/pppdec2004.pdf.

USDOT-FHWA. (2007b, April 2). Design-Build Effectiveness Study. FHWA Website. Retrieved April 2, 2007, from http://www.fhwa.dot.gov/reports/designbuild/designbuild.pdf.

FACTORS AFFECTING LITIGATION OUTCOMES OF DIFFERING SITE CONDITIONS (DSC) DISPUTES: A LOGISTIC REGRESSION MODELS (LRM)

Tarek Mahfouz[1], and Amr Kandil[2], Associate Member, ASCE

ABSTRACT

Construction is one of the major contributing industries to the US economy. However, its advancement and contribution have always been negatively impacted by the vast number of conflicts associated with it. Traditional conflict resolution methods require legal knowledge and expertise that are not commonly available, thus cost considerable sums of money. A significant number of construction disputes could be attributed to the uncertainty in the conditions under which projects are executed, and especially site conditions. In an attempt to provide an outcome prediction system for differing site conditions (DSC) claims in the construction industry, this paper provides, as a first step, a statistical analysis of set of precedent cases to identify, quantify, and measure the impact of significant legal factors on outcomes prediction of litigation cases. The adopted methodology developed a statistical binary choice Logistic Regression Model (LRM) (a) to identify the effect of each legal factor on the prediction of the winning party; (b) to identify the best combination of factors with the highest prediction precision; and (c) to perform a sensitivity analysis to prioritize the most significant legal factors. Among the major findings of this paper are (1) 23 significant legal factors were identified; (2) A combination of 9 legal factors were found to attain the highest prediction precision of 93.33%; (3) Generally, cases in which the Federal Government is a concerned party, judgments are in its favor.

INTRODUCTION

Construction is one of the main industries that have a major impact on the nation's economy. It is estimated that the world construction market has reached US $5.5 trillion at the end of 2007 (Harmon 2003). In the U.S., the construction industry employs 7.5 million employees and contributes to nearly US $1.2 trillion to its economy (El-adaway 2008). The uniqueness and increasing sophistication of

[1] Research Assistant, Construction Engineering and Management; Department of Civil, Construction, and Environmental Engineering; Iowa State University, Ames, IA, 50010; phone: (515) 294-8553; fax: (515) 294-3845; e-mail: tmahfouz@iastate.edu

[2] Assistant Professor, Construction Engineering and Management; Department of Civil, Construction, and Environmental Engineering; Iowa State University, Ames, IA, 50010; phone: (515) 294-8824; fax: (515) 294-3845; e-mail: kandil@iastate.edu

construction projects demand extensive interaction of diversified parties, thus enhancing the likelihood of conflicts and disputes (Caldas et al. 2002). In a study performed by Ren et al. (2001) it was found that 52% of all construction projects in UK ends up with a claim; while in Canada, 50% of the construction projects claims represent an extra value of 30% of the original contract price, 33% reached up to 60%, and 17% exceeded the original contract price. In large, complex projects, disputes are resolved in courts unless a private construction contract demands a different resolution method (Jervis and Levin 1988). Despite the numerous pros of litigation it has two major shortcomings. First, a complex construction dispute may take anywhere from two to six years before it reaches trial. Second, the prolonged, detailed, factual discovery process makes litigation very expensive (Jervis and Levin 1988). A previous study indicated that fees paid to lawyers and experts in litigation had increased by 425% within the period of 1979–1990 while verdicts had increased only by 309% (Marcotte 1990).

The aforementioned drawbacks motivated research efforts in the Artificial Intelligence (AI) field to developed tools and methodologies for modeling judicial reasoning to resolve them. Attempts ranged from initial Rule Based Reasoning systems (RBR) (Diekmann and Kruppenbacher 1984, Cobb and Diekmann 1986, and Kim 1987), to Artificial Neural Networks (ANN) systems (Arditi 1998, Chau 2005, and Chau 2006a), Case Based Reasoning systems (CBR) (Arditi and Tokdemir 1999, and Chau 2006b), and Hybrid Systems (HS) (Arditi and Pulket 2005, and Chen and Hsu 2007). Despite the success of some of these systems, they were not based on detailed analysis of legal factors that govern litigation outcomes in differing site condition (DSC) claims. The success of any prediction system is always limited by its input parameters. Therefore, in an attempt to provide an outcome prediction system for DSC claims in the construction industry, this paper provides, as a first step, analytical analysis of a set of cases from the Federal Court of New York in an endeavor to derive a set of significant legal factors that governs litigation outcomes concerned with DSC claims. The proposed analysis is performed by utilizing discrete binary choice Logistic Regression Model (LRM) to identify these factors.

BACKGROUND

The first application of a DSC clause is dated November 22nd, 1921. It was first applied under the title of "Change Conditions" by the Federal Government (Tarkoy, unpublished book, 2008). On August 20th, 1926 the first standard general conditions form for construction including "changed conditions" clause was formulated and approved by the president of the United States for use in the federal government contracts (Tarkoy, unpublished book, 2008). From that date on, Federal Regulations made the use of DSC clause compulsory in all U.S. Government Contracts. It was incorporated as part of the Federal Acquisition Regulations (FAR) to prevent contractors from bidding on a worst-case-scenario basis (North Slope 1988). This clause imposes upon the government the risks for conditions that the contract documents fail to disclose, but leaves upon the contractor the costs of encountering those conditions described in the contract (Erickson-Shaver 1985). Subsequently, other standard contract forms like AIA, FIDIC, and the Engineers Joint Contract Committee incorporated similar clauses. Analysis of the language of the DSC clause of the federal government contracts addresses two types of DSCs (Type 1 and Type

2). The former relates to physical conditions which differ materially from those indicated in the contract documents. The latter authorizes compensation "equitable adjustment" for unknown conditions which differ materially from those that would normally be encountered in projects of similar nature. From the literature in the construction legal domain, to prevail on a Type I DSC claim, a plaintiff must show: (1) the contract documents affirmatively indicate subsurface conditions; (2) she acted as a reasonably prudent contractor in interpreting the contract documents; (3) she reasonably relied on the indications of subsurface conditions in the contract; (4) the subsurface conditions actually encountered differed materially from those indicated in the contract; (5) the actual subsurface conditions were not reasonably foreseeable; and (6) her damage was attributable to the materially different subsurface conditions (Weeks 1987). Whereas, to prevail on a Type 2 DSC claims, a plaintiff must show that: (1) the encountered subsurface conditions were not reasonably foreseeable; (2) she did not have prior knowledge of the existence of the subsurface conditions; (3) the encountered conditions vary from the norms in similar construction projects.

The high frequency of occurrence and complicated nature of DSC claims in the construction industry have prompted researchers in the AI field to devise cost and time saving tools to proficiently resolve them. Diversified in nature, these tools include RBR models, ANN systems, CBR models, and Hybrid Systems. The success of RBR models or expert systems was very limited due to (1) the failure of the developer in deducing all the necessary rules upon which the system operates; (2) the assumption of the existence of a full domain model that captures all required rules about a specific claim type. As a result, they are much localized to a specific aspect of a certain domain; (3) their accuracy and performance are crucially affected by the computational limitations. In addition, although ANN had achieved improvements over RBR in this domain (Arditi 1998), their excessive training stage and their ability to deal only with numeric data opened the horizon for the use of other AI techniques like CBR. Despite the success of some of these systems in litigation outcomes prediction, they were not based on detailed analysis of legal concepts that govern such outcomes. Consequently, this paper attempts to fill this gap by implementing LRM analysis.

METHODOLOGY

The objective of this paper is to identifying, quantifying, and measuring the impact of significant legal factors on the prediction of outcomes of DSC claims in the construction industry. In order to achieve this objective, this research, (1) developed a corpus of construction DSC cases that were collected based on the following factors including: jurisdiction, winning side, level of court, presence of appeals and overturning rulings, and utilization of landmarking precedent cases; (2) a set of legal factors that constitute the bases of judgments in construction DSC cases were identified; (3) a Discrete Binary Logistic Regression Model was developed to identify the effect of each extracted factor on the prediction of the winning party, identify the best combination of factors with the highest significance on the prediction model, and perform a sensitivity analysis of identified factors.

Data description

The corpus utilized for this research is gathered from LexixNexis a web legal case retrieval engine. A set of 45 cases filed between 1912 and 2005 were compiled from

the Federal Court of New York due to the large number of construction precedent cases in this jurisdiction. Characteristics of gathered corpus are illustrated in table 1.

Data preparation

For each case, a detailed analysis is performed to extract legal factors upon which judges have based their decisions. Cases in which more than one cause of claim were concerned; only factual concepts related to DSC were utilized. A total of 23 factors were extracted. An analysis of the existence of each of these factors in all cases was performed in the form of binary indicator variables [not existing (0) and existing (1)]. As a measure of choice, an indicator variable for the final judgment was recorded [owner (1) and contractor (0)].

Table 1 Descriptive data of cases

	Owner (%)	Contractor (%)
Judged for	53%	47%
Appeals won	50%	50%
Appeals affirmed	32%	14%
Appeals reversed	36%	18%

Model specification

Non-linear modeling, LRM, is one of the effective methods of analyzing data of a binary nature (Tabachnick and Fidell, 1996). LRM are derived under the assumption that disturbance terms ε within the generated model follow Gumbel distribution. The adopted form of the model is represented in equation 1 where β' is a vector of estimable parameters and x_i is a vector of the observable characteristics that determine outcomes for any individual observation *i*. In this form, outcome 1 (Owner) is the logarithm of the ratio of the probability that a particular choice *i* [Owner (1) or Contractor (0)] will be made to the probability that this choice will not be made. It can be deduced from the exponential form in equation 2 that when a variable x_i increases by 1 unit, with all other factors remaining unchanged, the odds of an outcome will increase by a factor e^{bi}, known as the odds ratio (O.R.). The OR quantifies the relative change by which the odds of the outcome increase or decrease when the value of the predictor is increased by 1 unit.

$$y = \log\left(\frac{P_i}{1-P_i}\right) = a+\beta' \cdot x_i \quad (1)$$

$$\left(\frac{P_i}{1-P_i}\right) = e^{a+b_i \cdot x_i} = e^{a} \cdot e^{b_i \cdot x_i} \quad (2)$$

ESTIMATED RESULTS AND DISCUSSION

Independent variables estimation

The extracted legal factors, upon which the entitlements of 45 litigation cases concerned with DSC claims, were utilized as independent variables for the adopted model. Twenty three (23) indictor variables were extracted from the developed corpus, among which are the presence of factual aspects illustrating the presence of Type 1 and\ or Type 2 DSC, and others. Table 2 provides the description of the extracted legal factors and their individual effect, whether increases or decreases, on the prediction rate.

Prediction Models

The developed LRM identified a combination of 9 legal factors with highest prediction rates of 93.3% (refer to table 4). Results reported in table 3 designate a

number of interesting outcomes. Generally, cases in which the Federal Government is a concerned party of dispute, judgments are in favor of the government (owner) over contractor. This is expected due to the fact that N.Y. Const. art. 3, § 28 it is declared that the legislature shall not, nor shall the common council of any city, nor any board of supervisors, grant any extra compensation to any public officer, servant, agent or contractor (Ralph 1930). Further examination of the developed model demonstrates that the presence of evident facts that the encountered conditions caused a change in the nature and cost of the contract to decrease the prediction of an owner winning a case. While bidding, contractors specify their prices based on decisions concerning methods and resources needed for performing the works. A change in works causing a variation in the nature of these methods may have a great impact on increasing the contractors' costs. Consequently, it is not fair to burden contractors with that increase in cost, leading to a decrease in planed profit or even loss, without equitably adjusting them. Supporting this notion, Judge Goldman, J. W. states that where an operation is not within the original plans and the contractor is forced to use a more expensive operation to perform the work than was originally anticipated and contemplated by the contract, the claimant shall be compensated for this extra work. However, there are two scenarios that should be discussed in this case. The first, if an owner compensates a contractor for his\ her direct or direct and indirect costs. In this case, the owner has rectified a mistake on his side. As a result, the developed models predicted the presence of evidence of this nature in a case as a factor that increases the prediction in favor of owner. The second is when the contract included a clause giving the owner the right to make changes to the project until final completion and acceptance without invalidating the contract provided that it was made due to a necessity (Tony 1919). The presence of similar clause in a contract was interpreted by the model to increase the prediction in favor of the owner.

It was also found that the presence of evident facts that the encountered matter rendered the project impossible to be completed decreases the prediction of owner winning. For example, if the DSC experienced in a project required a redesign that caused the elimination of a major part of the contractor's scope of work to be omitted, which intern affects his methodology of pricing and profit allocation to the extent that he cannot perform the works as specified, he\ she is entitled to be compensated for that loss (Kinser 1912). In addition, if the contractor raised the faced incident as per the Contract documents and in due time was found to decrease the prediction of owner winning a DSC related litigation case. Construction Contracts place a liability on the contractor to inform the owner with any unexpected matters encountered in the project lifetime. Such liability allows the owner and contractor to have enough time to analyze the situation and decide on counter measures. Consequently, if a contractor fulfilled his contract requirement, he\ she will have a better chance proving his case. Furthermore, the presence of evident facts that there was a mutual mistake from both sides in examining the site and contract documents increases the prediction of judgment in favor of owner. In such case, there is no bad faith, concealment or misrepresentation on the side of the owner; therefore, no liability arises for loss resulting from a difference between estimated quantities of material affecting work conditions and those actually found at a job site (Drake 1965). On the other hand, the presence of evident facts that the contract documents included accurate representation

Table 2 Significance of individually tested variables

Factor Symbol	Factor Meaning	Influence on Prediction
TYPEP	Type of project: the higher is the sophistication of the project the higher is the variable. Sophistication level ranges from standard excavation at the lower spectrum range to water related like dams and under water projects at the upper level.	Increase
DSC	The presence of factual facts demonstrating Type 1 or Type 2 DSC	Decrease
WSTOP	Stoppage of work due to the encountered matter, Owner, or Contractor	Statistically not significant
DSCC	The presence of DSC Clause in the Contract	Decrease
REDESIGN	Whether the encountered matter required redesign	Statistically not significant
N&C	Whether the encountered matter imposed changes on the nature and costs of the Contract or not	Decrease
CRAISE	Whether the contractor raised his claim as per the contract clauses or not	Decrease
COMIMPOS	Whether the encountered matter made the project completion impossible or not	Decrease
OCHANGE	Whether the contract clauses allow the owner to perform changes at any time of the project duration without the consent of the contractor or not	Increase
CNPROFIT	Whether the contractor under the conditions of the contract waived his right for profit due to changes or extras or not	Increase
MMISTAKE	Whether the mistake was a mutual one and no bad intentions was meant from any party or not	Increase
VCHANGES	Whether various changes were implemented through the life time of the project or not	Statistically not significant
OCAUSE	Whether the incurred damages were caused due to the owners negligence or any of his representatives or not	Decrease
SPECWARN	Whether the specifications warn against the possibility of DSC existence or not	Increase
SPECREPR	Whether the specifications had a representation of the actual site conditions or not	Decrease
CNEXTRA	Whether the contractor under the conditions of the contract waived his right for compensation due to extras or not	Increase
OFALSELY	Whether The Owner\ Owner Rep. falsely state that the matter encountered in hand, so far as known, was shown in the Contract documents?	Decrease
LUMPUNIT	Whether the contract is a unit price or not	Statistically not significant
OADJUST	Whether the owner equitable adjusted the contractor against extra works performed or not	Decrease
BENEFIT	Whether the contractor benefits from the work done or not	Statistically not significant
NOTIME	The presence of enough evidence demonstrating that there was no time for the Contractor to perform his own investigations	Decrease
WTEMP	Whether the extra works were performed as temporary works or not	Increase
WAPPEAL	In case of appeals, in favor of whom did the court originally rule	Statistically not significant

of the site conditions decreases the prediction in favor of the owner. In this case, the existence of DSC depends upon a comparison of the site conditions actually encountered with the affirmative representations of conditions contained in the bid and contract documents. To the extent that the conditions described in the contract

materialize, the contractor bears the risk, while the owner assumes the risk for conditions that the contract documents fail to disclose.

Interestingly, the presence of evident facts that the specifications included a warning against the presence of DSC from those conveyed in the contract documents increases the prediction of judgment in favor of owner. If the specifications stated that there was no guarantee that adverse conditions did not exist underground at the construction site, the contractor is required to familiarize himself\ herself with the site conditions. In such case, the contractor is held responsible for damages that he\ she might incur due to encountering DSC (All County Paving 2005). In addition, the developed LRM demonstrated that as the complexity of public projects increase, the prediction in favor of owner is increased. The nature in which this variable was integrated is prioritized with Excavation projects being the lowest in complexity to Water related projects being the most complex. Costs associated with performing a construction project is directly related to its level of complexity and size. As mentioned earlier N.Y. Const. art. 3, § 28 does not grant any extra compensation to any public officer, servant, agent or contractor (Ralph 1930). Consequently, as project size increases it is harder for a judge to grant compensation to contractors.

Table 3 Logistic model results at a confidence interval = 0.1

Independent variable	Coeff.	t-stat.	P-value	OR
Constant	2.36	0.25	0.80	
TYPEP	4.23	1.66	0.09	32.314
N&C	-5.69	-2.00	0.04	0.035
CRAISE	-7.54	-1.86	0.06	0.053
COMIMPOS	-3.04	-1.46	0.07	0.047
OCHANGE	9.65	2.13	0.03	15.604
MMISTAKE	2.57	1.05	0.03	13.732
SPECWARN	3.80	2.19	0.02	44.740
SPECREPR	-5.11	-1.58	0.03	0.061
OADJUST	5.67	1.84	0.06	2.353

Table 4 Analysis of Binary Choice Model Predictions (Threshold = 0.5)

Prediction Success	
Sensitivity = actual 1s correctly predicted	90.476%
Specificity = actual 0s correctly predicted	95.833%
Positive predictive value = predicted 1s that were actual 1s Negative predictive value = predicted 0s that were actual 0s	95.000%
Negative predictive value = predicted 0s that were actual 0s	92.000%
Correct prediction = actual 1s and 0s correctly predicted	93.333%
Prediction Failure	
False pos. for true neg. = actual 0s predicted as 1s	4.167%
False neg. for true pos. = actual 1s predicted as 0s	9.524%
False pos. for predicted pos. = predicted 1s actual 0s	5.000%
False neg. for predicted neg. = predicted 0s actual 1s	8.000%
False predictions = actual 1s and 0s incorrectly predicted	6.667%

Sensitivity analysis

The sensitivity of each variable is tested by increasing the variable by 1 while maintaining the rest fixed at their mean value. The estimated results demonstrated in figure 1 illustrate the outcomes of the sensitivity analysis performed on the developed model. The outcomes demonstrate the followings.

- The presence of evident facts that the encountered conditions caused a change in the nature and cost of the contract had the highest impact among variables causing a decrease in the prediction of judgment in favor of owner. An increase of 1 unit results in reducing the odds of an owner wining approximately by a factor of 29 (OR=0.035).
- The presence of evident facts that the contractor raised his claim as per the contract clauses, and the encountered matter rendered the project completion impossible had just about equal decrease on the prediction of judgment in favor of owner. An increase on 1 unit results in reducing the odds of an owner wining approximately by factors of 19 (OR=0.053) and 21 (OR=0.047) respectively.
- The presence of evident facts that the specifications had a representation of the actual site conditions had the lowest effect on decreasing the prediction of judgment in favor of owner. An increase on 1unit results in reducing the odds of an owner wining approximately by factors of 16 (OR=0.061).
- The presence of evident facts that the specifications included a warning against the presence of DSC from those conveyed in the contract documents had the highest increases in the prediction of judgment in favor of owner. An increase on 1 unit results in increasing the odds of an owner wining by a factor of 45.

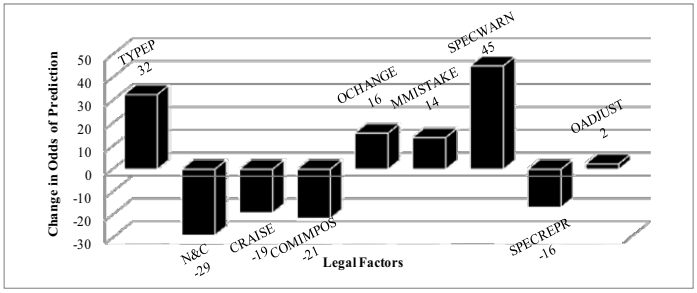


Figure 1 Outcomes of sensitivity analysis

- The complexity level of the project had the second highest effect on increasing the prediction of judgment in favor of owner. An increase on 1 unit results in increasing the odds of an owner wining approximately by a factor of 32.
- The presence of a clause in a contract giving the owner the right to make changes to the project until final completion and acceptance without invalidating the contract provided that it was made due to a necessity, and the presence of evident facts that the mistake was a mutual one and no bad intentions was meant from any party had just about equal increase on the prediction of judgment in favor of owner. An increase on 1 unit results in increasing the odds of an owner wining approximately by factors of 16 and 14 respectively.
- The presence of evident facts that that the owner equitable adjusted the contractor against extra works performed had the lowest effect on increasing the prediction of judgment in favor of owner. An increase on 1unit results in increasing the odds of an owner wining approximately by a factor of 2.

SUMMARY AND CONCLUSION

The attained outcomes of this analysis conclude the followings:

1. Generally, cases in which the Federal Government is a concerned party of dispute, judgments are in favor of the government (owner) over contractor, especially as the complexity of projects increase.
2. The presence of evident facts that the encountered matter imposed changes on the nature and costs of the Contract, the encountered matter made the project completion impossible, the contractor raised his claim as per the contract clauses and in due time, and the specifications had a representation of the actual site conditions are factors that increase the probability of judgment for the contractor.
3. The presence of evident facts that the contract clauses allow the owner to perform changes at any time of the project duration without the consent of the contractor, the owner equitable adjusted the contractor against extra works performed, the mistake was a mutual one and no bad intentions was meant from any party, and the specifications warn against the possibility of DSC existence are factors that increase the probability of judgment in favor of owner.
4. The presence of evident facts that the encountered conditions caused a change in the nature and cost of the contract had the highest impact among variables causing a decrease in the prediction of judgment in favor of owner.
5. The presence of evident facts that the specifications included a warning against the presence of DSC from those conveyed in the contract documents had the highest increases in the prediction of judgment in favor of owner.

LIMITATIONS & FUTURE WORKS

Due to the statistical nature of the developed model, they capture the best combinations of factors that lead to highest predictions value. This leads to undermining some factors although their existence affects the model outcome, which takes place partly due to the inherent correlations between variables due to their binary representation. Consequently, these factors need to be analyzed further through the utilization of proxy variables (variables that convey the same effect of original ones on the judgments, but are not correlated to other derived independent variables) (Washington et al. 2003). In addition, utilizing other discrete binary choice models under the adopted methodology for this analysis is a necessity to achieve a comprehensive set of legal factors. Future works will also address expanding the scope of this research to analyze construction litigation cases in other major states.

REFERENCES

All County Paving Corp. v Suffolk County Water Authority, 20 A.D.3d 438; 798 N.Y.S.2d 523; 2005 N.Y. App. Div.

Arditi, D., Oksay, F.,and Tokdemir, O. (1998). "Predicting the outcomes of construction litigation using neural networks." Comput Aid Civ Infrastruct Eng, 13, 75-81.

Arditi, D., and Pulket, T. (2005). "Predicting the Outcome of Construction Litigation Using Boosted Decision Trees." J. Comput. Civ. Eng., 19(4), 387-393.

Arditi, David, and Tokdemir, Onur Behzat (1999). "Using case-based reasoning to predict the outcome of construction litigation." Comput Aid Civ Infrastruct Eng, 14(6), 385-393.

El-adaway, I. H. (2008). "Construction dispute mitigation through multi-agent based simulation and risk management modeling." Ph. D. thesis, Iowa State Univ., Ames, IA.

Caldas, C. H., Soibelman, L., and Han, J. (2002). "Automated classification of construction project documents." *J. Comput. Civ. Eng.*, 16(4), 234-243.

Chau, K.W. (2005). "Predicting Construction Litigation Outcome using Particle Swarm Optimization. Lecture Notes in Artificial Intelligence 3533. 571-578

Chau, K.W. (2006a). "Application of a PSO-based neural network in analysis of outcomes of construction claims." *Automation in Construction,* 16, 642–646.

Chau, K.W. (2006b). "Prediction of Construction Litigation Outcome – A Case-Based Reasoning Approach." M. Ali and R. Dapoigny (Eds.): IEA/AIE 2006, LNAI 4031, © Springer-Verlag Berlin Heidelberg 2006, 548 – 553.

Chen, J., and Hsu, S.C. (2007). "Hybrid ANN-CBR model for disputed change orders in construction projects." *Automation in Construction*, 17, 56–64.

Cobb, James E., and Diekmann, James E. (1986). "Claims analysis expert system." *Proj Manage J*, 17(2), 39-48.

Diekmann, James E., and Kruppenbacher, Timothy A. (1984). "Claims analysis and computer reasoning." *J. Constr. Eng. Manage.*, 110(4), 391-408.

Drake & Piper v. New York State Thruway Authority, 22 A.D.2d 321; 255 N.Y.S.2d 368; 1965 N.Y. App. Div.

Erickson-Shaver Contracting Corp. v. United States, 9 Cl. Ct. 302, 304; 1985.

Harmon, K. J. (2003). "Dispute review board and construction conflicts: attitude and opinion of construction industry members." J. of Manag. in Eng., 19, 121-125.

Jervis, B. M., & Levin, P. (1988). Construction law principles and practice. New York: McGraw-Hill.

Kim, Moonja Park (1989). "U.S. Army Corps Engineers construction contract claims guidance system." Proc., Constr Congr I Excellence Constr Proj, 203-209.

The Kinser Construction Company v. The State of New York, 204 N.Y. 381; 97 N.E. 871; 1912 N.Y.

Marcotte, P. (1990). "Hastening justice—Biden committee studies task force plan to cut trial delay." Am. Bar Assoc. J., 76(1), 40.

North Slope Technical Ltd. v., 14 Cl. Ct. 242, 257; 1988 U.S. Cl. Ct.

Ralph S. Keep and Others v. The City of New York, 138 Misc. 194; 245 N.Y.S. 321; 1930 N.Y. Misc.

Ren, Z., Anumba, C. J., and Ugwa, O. O. (2001). "Construction claim management: Towards an agent based approach." J. Eng. Constr. Archit. Manage., 8, 185-197.

Tabachnick, B. G. and Fidell, L. S. (1996). "Using Multivariate Statistics." 3rd Edition, Harper Collins, New York, NY, USA.

Tony Carfagno and Others v. The City of New York, 187 A.D. 489; 175 N.Y.S. 682; 1919 N.Y. App. Div.

Washington, S. P., Karlaftis, M. G., and Mannering, F.L. (2003). Statistical and Econometric Methods for Transportation Data Analysis, CHAPMAN & HALL/CRC, New York.

Weeks Dredging & Contracting, Inc. v. United States, 13 Cl. Ct. 193, 219; 1987.

STUDY OF LESS THAN AVERAGE BID METHOD

Rita E. Awwad[1] and Photios G. Ioannou[2] M.ASCE

ABSTRACT

The low bid method is the most frequently used competitive bidding method in the construction industry. However, its main disadvantage is awarding projects to irresponsive extremely low bids which leads to disputes and claims between the owner and the contractor. To remedy this issue, some countries use the average bid method which awards the job to the contractor who submits the closest bid to the average of all submitted bids. A comparison between Friedman's low bid method and the average bid method was conducted by Ioannou and Leu (1993), and showed that although the average bid method protects the owner against extremely low bids, it does not promote fierce competition as is the case in a low bid awarding system. Thus, they suggested another variation of the average bid method which is awarding the job to the contractor whose price is closest to but lower than the average of all submitted bids. This paper uses Monte Carlo simulation to model the less than average bidding method. It explores its merits relative to the other two bidding methods, and proves it to be a compromising middle ground between the low bid method and the regular average bid method.

INTRODUCTION

The low bid system remains the most common contract awarding practice in the public sector of the US construction industry. Awarding a project to the lowest among all submitted bids promotes fierce competition in the construction market. Despite its positive effect of creating a competitive environment in the market, the low bid system leads to more disputes and claims between the different parties, and increases the chance of higher costs, lower quality and extended project duration. That is due to the fact that some contractors try to compromise work quality for the sake of being the lowest bidder and guaranteeing the job. To remedy this drawback,

[1]PhD Candidate, Department of Civil and Environmental Engineering, 1360 G.G. Brown Bldg., University of Michigan, Ann Arbor, MI 48109-2125; PH (734) 709-4810; email: reawwad@umich.edu

[2]Professor and Program Advisor for Construction Engineering and Management Program, Department of Civil and Environmental Engineering, 2350 G.G.Brown Bldg., University of Michigan, Ann Arbor, MI 48109-2125; PH (734) 764-3369; FAX (734) 764-4292; email: photios@umich.edu

some countries such as Italy and Taiwan considered an alternative bid awarding practice called the average bid method which awards the job to the contractor whose bid is closest to the arithmetic average of all submitted bids (Ioannou and Leu 1993). The average bid method ensures that irresponsible extremely low bids are driven out of competition and hence protects the owner and the contractor against unqualified contractors in the market.

But on the other hand, the average bid method does not create a fierce competitive environment as the low bid method. In other words, awarding the job to the contractor whose price is closest to the average does not incite the bidders to lower their costs in order to increase their chance of winning the job. Therefore, a contracting firm that found technological innovations in construction that allow it to charge lower construction costs and hence bid a lower price, would not have a competitive edge over its opponents since the winning bid is now the closest to the average instead of the lowest one.

Ioannou and Leu (1993) studied the average bid method and modeled it through Monte-Carlo simulation. They presented the simulation results through four nomographs that were used to compare the average bid method with the low bid method based on Friedman's model. After they reached the above mentioned conclusions about the average bid method, Ioannou and Leu suggested without exploring it further, that it might be more effective to award contracts to the bid closest to but less than the average bid, an approach practiced in Italy and Taiwan.

The objective of this paper is to investigate more about the less than average bid method. This study uses the Monte Carlo simulation approach and presents a competitive bidding model for the less than average bid method to explore its merits relative to the low bid method and the average bid method. A mathematical formulation for the less than average bid method is also included. The simulation results are presented in four nomographs for the three bid awarding methods, similar to the ones presented by Ioannou and Leu in their study of the average bid method (Ioannou and Leu 1993).

BASIC DEFINITIONS AND ANALYTICAL APPROACH

In this section, we consider the bidding process from the perspective of one contractor A_0 who is bidding for a new project against n competitors A_1, $A_2 \ldots A_n$. Each contractor A_i will have an estimate of the project cost C_i, will add to it a chosen markup M_i, and will subsequently submit its final bid price B_i such that:

$$B_i = C_i + M_i$$

Below, some basic notations that will be used in this paper are presented. Random variables are expressed using capitalized symbols, whereas decision variables pertaining to contractor A_0 and the values of random variables are expressed in lower-case symbols:

c_0 = contractor A_0's cost estimate
b_0 = contractor A_0's bid price
m_0 = contractor A_0's markup
$x_0 = b_0 / c_0 = 1 + m_0 / c_0$ = contractor A_0's bid-to-cost ratio

C_i = contractor A_i's cost estimate
B_i = contractor A_i's bid price
M_i = contractor A_i's markup
$X_i = B_i / c_0$ = ratio of Contractor A_i's bid to Contractor A_0's cost = apparent bid-to-cost ratio of contractor A_i (as viewed by A_0)
$\overline{B} = (b_0+B_1+\ldots+B_n) / (n+1)$ = average of all submitted bid prices
$\overline{X} = (x_0+X_1+\ldots+X_n) / (n+1)$ = average of bid-to-cost ratios (as viewed by A_0)

The apparent bid-to-cost ratios X_i with i ranging from 1 to n are assumed to be independently and identically distributed, following a normal distribution with mean m_x and standard deviation σ_x. This section aims at defining analytically the bid-to-cost ratio regions within which contractor A_0 can guarantee winning the job. To arrive at a solution independent of the mean and standard deviation, standardized forms of the following variables are introduced:

$m'_x = (m_x-1) / \sigma_x$
$x'_0 = (x_0-m_x) / \sigma_x$
$\overline{x'} = (x'_1+x'_2+\ldots\ldots+x'_n) / n$ = average of standardized apparent bid-to-cost ratios
$\overline{x'_0} = (x'_0+x'_1+\ldots..+x'_n) / (n+1) = (n\overline{x'}+x'_0) / (n+1)$ = average of standardized bid-to-cost ratios including contractor A0's bid-to-cost ratio.

Of the n values x'_i, let x'_l be the one that is lower than but closest to the average $\overline{x'}$. Let d_l be the absolute value of the difference between x'_l and the average $\overline{x'}$. First, the authors show that if x'_0 is bigger than the average $\overline{x'}$, there is no chance for A_0 to win the project according to the less than average bid method, and that is shown below:

$x'_0 > \overline{x'}$ leads to the following inequality:

$$\overline{x'_0} > \overline{x'} \tag{1}$$

Now if $x'_0 < \overline{x'_0}$ ➔ $(n+1)\overline{x'_0} - n\overline{x'} < \overline{x'_0}$ ➔ $\overline{x'_0} < \overline{x'}$ which contradicts equation 1. Therefore if $x'_0 > \overline{x'}$, then $\overline{x'} < \overline{x'_0} < x'_0$ which means that contractor A_0 does not have any chance to win since its bid-to-cost ratio is higher than the average whereas the less than average bid method requires it to be lower. Hence, the only interesting case to investigate is when x'_0 is less than $\overline{x'}$ and consequently:

$x'_0 < \overline{x'_0} < \overline{x'}$

Let us determine the winning region for x'_0 if the average $\overline{x'_0}$ is less than $\overline{x'}$ and higher than x'_l:

$\overline{x'_0} \geq x'_l$

$$(n\overline{x'} + x'_0)/(n+1) \geq \overline{x'} - d_l$$
$$x'_0 \geq \overline{x'} - (n+1)d_l \quad (2)$$

In addition to inequality 2, x'_0 must also be higher than x'_l in order to be closer to the average than x'_l, and thus guarantee winning the job. Therefore, if $\overline{x'_0}$ falls within the region below:

$$x'_l \leq \overline{x'_0} < \overline{x'}$$

The following condition is necessary for x'_0 to win:

$$\max(x'_l, \overline{x'} - (n+1)d_l) \leq x'_0 < \overline{x'}$$
$$x'_l \leq x'_0 < \overline{x'}$$

Let x'_{l-1} be the bid-to-cost ratio that falls directly below x'_l, and let d_{l-1} be the absolute distance between the average $\overline{x'}$ and x'_{l-1}. Another case is considered now which is when the average $\overline{x'_0}$ falls between x'_{l-1} and x'_l:

$$\overline{x'_0} < x'_l$$
$$(n\overline{x'} + x'_0)/(n+1) < \overline{x'} - d_l$$
$$x'_0 < \overline{x'} - (n+1)d_l \quad (3)$$

Also,

$$\overline{x'_0} \geq x'_{l-1}$$
$$(n\overline{x'} + x'_0)/(n+1) \geq \overline{x'} - d_{l-1}$$
$$x'_0 \geq \overline{x'} - (n+1)d_{l-1} \quad (4)$$

In addition to inequalities 3 and 4 that define the winning region for x'_0, x'_0 must also satisfy the below condition in order to win:

$$x'_0 \geq x'_{l-1} \quad (5)$$

Combining inequalities 3, 4 and 5 produces:

$$\max(x'_{l-1}, \overline{x'} - (n+1)d_{l-1}) \leq x'_0 < \overline{x'} - (n+1)d_l$$
$$x'_{l-1} \leq x'_0 < \overline{x'} - (n+1)d_l \quad (6)$$

Thus, the winning region for x'_0 is defined through inequality 6 in the case where $\overline{x'_0}$ falls between x'_{l-1} and x'_l. Similarly, there are multiple winning regions for x'_0 depending on the location of the average $\overline{x'_0}$ among the different bid-to-cost ratios. Let x'_{lowest} be the lowest among all submitted apparent bid-to-cost ratios and d_{lowest} to be the absolute distance between $\overline{x'}$ and x'_{lowest}.

Hence, if $\overline{x'_0}$ falls between x'_i and x'_{i+1}, the winning region for x'_0 is defined as follows:

$$x'_i \le x'_0 < \overline{x'} - (n+1)d_{i+1}$$

where

x'_i and x'_{i+1} are two consecutive bid-to-cost ratios satisfying the inequality $x'_i < x'_{i+1}$.
x'_{i+1} ranges from x'_{lowest} to $\overline{x'}$.
And $d_{i+1} = \overline{x'} - x'_{i+1}$.

In the case where $\overline{x'_0} \le x'_{lowest}$, the winning region for x'_0 is defined as follows:

$$x'_0 \le \overline{x'} - (n+1)d_{lowest}$$

SIMULATION APPROACH AND RESULTS

After defining the winning regions for x'_0 in the previous section, we are interested in determining the probability of winning of contractor A_0. According to the less than average bid method, x'_0 should be the closest to but less than the average $\overline{x'_0}$ in order to win:

$$P(A_0 wins / x'_0) = P(\bigcap_{i=1}^{n}(|x'_0 - \overline{x'_0}| < |x'_i - \overline{x'_0}|) \bigcap (x'_0 < \overline{x'_0})) \quad (7)$$

The winning probability expressed in equation 7 can be computed by assuming a particular probability distribution $f_{Xi}(x'_i)$ and performing numerical integration. However this integration is a tedious task and do not provide a closed-form solution for the general probability of winning. The same result can be achieved much easier using the Monte Carlo simulation approach as described in this section.

Let n be the number of competitors, s the number of simulation sets, and m the number of projects per simulation set.

The simulation aims at determining the probability of winning for x'_0 as it varies in the range [-3, 3] with an increment of 0.001. For each value of x'_0, n standardized apparent bid-to-cost ratios are sampled from the standard normal distribution N (0, 1). Then, the average $\overline{x_0}'$ for all n+1 submitted bid-to-cost ratios is determined and the winning x'_i is defined to be the closest to but less than the average. The same process is repeated for m projects. Then, the number of times (k) out of m projects, where x'_0 was determined to be the winning bid-to-cost ratio according to the less than average bid method, is determined. This whole procedure is

repeated for s simulation sets. Then the average ratio k/m over s simulation sets is computed and defined to be the winning probability of x'_0.

Similarly to the average bid analysis graphs presented by Ioannou and Leu, the simulation results for the less than average bid method are presented below through four nomographs. Note that those results correspond to 1000 simulation sets, 1000 projects per simulation set, and an n value of 2, 4 and 8 opponents.

Figure 1 shows the probability of winning versus the standardized bid-to-cost ratio x'_0 of contractor A_0. Figure 2 represents the standardized optimum markup corresponding to the standardized mean m'_x ranging from -0.5 to 3. The optimum bid-to-cost ratio x_0* is determined by maximizing the expected profit (V) expressed in the equations below:

$$E[V / x_0, c_0] / c_0 c_x = ((x_0 - 1) / c_x) P(A_0 wins / x_0)$$

$$E[V / x_0, c_0] / c_0 c_x = (x'_0 + m'_x) P(A_0 wins / x'_0)$$

Figure 3 shows the optimum standardized expected profit as a function of m'_x. And Figure 4 shows the probability of winning corresponding to the optimum markup x'^*_0 versus the standardized mean m'_x. The four corresponding graphs for the average bid method and the low bid method are also drawn in the figures presented in this paper.

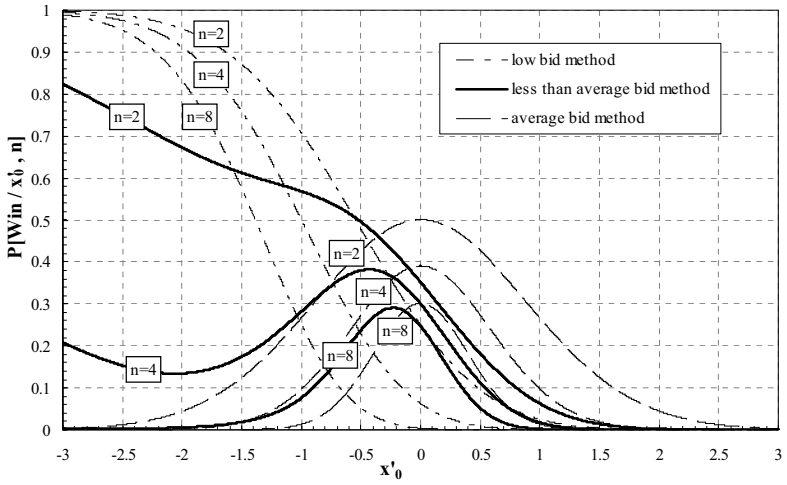


Figure 1.Probability of Winning as Function of x'_0, n

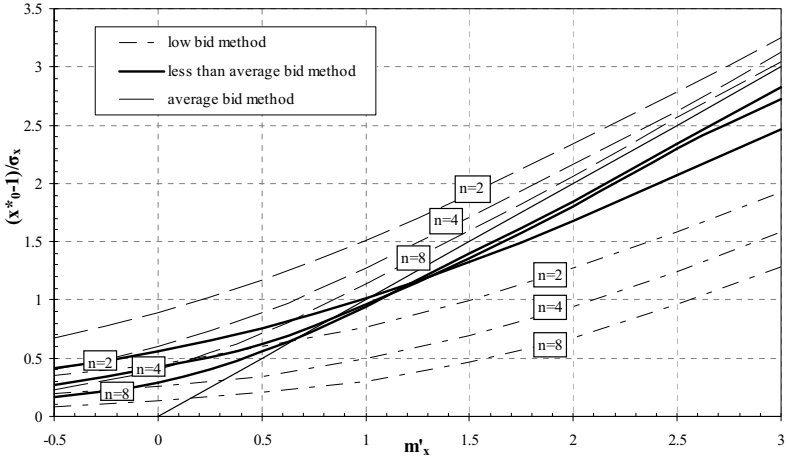


Figure 2.Optimum Markup as Function of m'_x, n

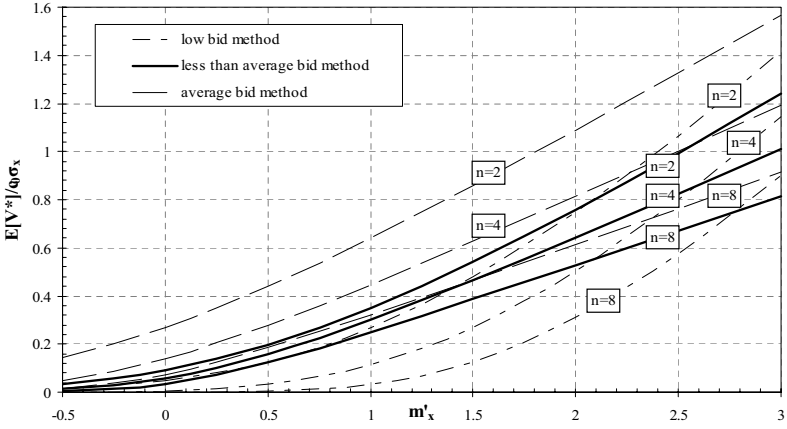


Figure 3.Optimum Expected Profit as Function of m'_x, n

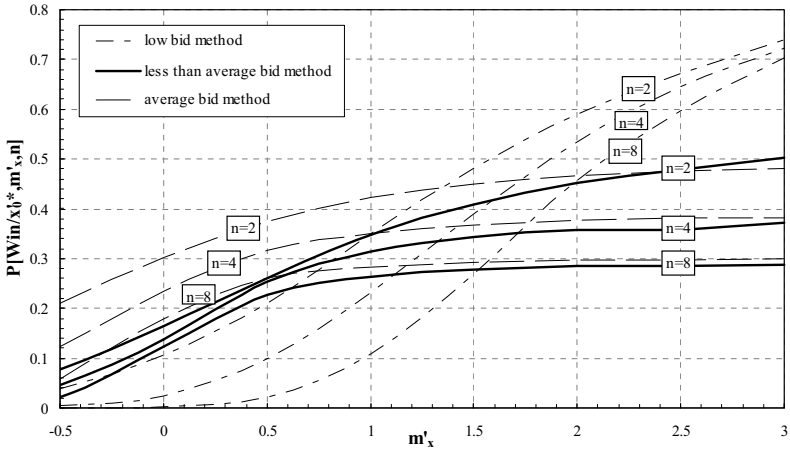


Figure 4.Probability of Winning as Function of m'_x, n

COMPARISON OF BIDDING METHODS

The above figures show many differences between the three bidding methods. The authors will consider each figure sequentially and compare the graphs for the different methods.

Figure 1 shows the probability of winning corresponding to the standardized bid-to-cost ratio x'_0. In contrary to the average bid method curves, the less than average bid method ones are asymmetrical. But as the number of opponents n increases, symmetry starts to show up. Also note that the curves for the less than average bid method are skewed to the left and the highest probability of winning for n=4 and n=8 occurs at $x'_0 < 0$ i.e. at $x_0 < m_x$ and that is explained by the nature of the bidding method since the winning bid is required to be less than the average. In the case of having only two opponents, the less than average bid method allows the contractor to guarantee a higher chance of winning the job by cutting down his bid. For n=2, the highest probability of winning reaches 0.82 approximately as x'_0 approaches -3. However, the situation differs as n increases. The highest probability of winning for n=4 is around 0.375 and occurs at $x'_0 = -0.4$. Whereas for n=8, the highest winning probability is equal to 0.29 and occurs at $x'_0 = -0.2$. And here, it can be concluded that as n increases, the bid-to-cost ratio x'_0 corresponding to the highest winning probability approaches 0. This means that as the number of opponents is higher, the winning bid has to be very close to the average of all submitted bids in order to guarantee winning the job. Furthermore, it is observed that for very small values of n (n<=2) the less than average bid method behaves closer to the low bid method and as n increases and reaches the value of 8 and higher, it identifies more with the average bid method. Another observation is that the less than average bid method curve falls below the low bid method and above the average bid method

toward the lower negative values of x'_0, but the order is reversed as x'_0 moves toward the higher positive values of x'_0. This shows that the less than average bid method is considered as a middle ground between the low bid method and the average bid method. Note that for n>= 4, the highest probability of winning determined by the less than average bid method always occurs at an x'_0 lower than that for the average bid method but higher than that for the low bid method. This indicates that the less than average bid method protects both owner and contractor against extremely low bids, and at the same time encourages lower bid-to-cost ratios and hence lower bid prices than the average bid method.

Second, Figure 2 is considered which shows the optimum standardized bid-to-cost ratio versus the standardized mean m'_x. The first observation is that the curves corresponding to the less than average bid method fall below the ones for the average bid method and above the ones for the low bid method regardless of the number of opponents. Also note that for small values of m'_x, the optimum bid-to-cost ratio increases as n decreases for the less than average bid method. However, as m'_x increases, the order is reversed and the highest optimum bid-to-cost ratio corresponds now to the highest number of opponents n=8. In both situations, the less than average bid method curve corresponding to n=8 is the closest to the 45º straight line which means that as the number of opponents increases, contractor A_0 is better off by bidding closer to the mean in order to guarantee a higher chance of winning the job. Another important observation is that the average bid method curves approach the 45º straight line from above whereas the less than average bid method curves approach it from the lower side of the line. This is explained by the fact that the less than average bid method requires the winning contractor to bid lower than the average, and hence the optimum bid-to-cost ratio x^*_0 approaches but remains lower than the mean m_x, as the variance σ_x decreases. Thus, an owner using the less than average bid method should expect lower bid prices than the ones obtained using the average bid method, and higher than the unrealistically low bid prices obtained using the low bid method.

And now we move to Figure 3 which shows the maximum standardized expected profit versus the standardized mean m'_x. Note that the curves for the less than average bid method fall below the ones for the average bid method and above the curves for the low bid method. Hence, contractors are more likely to favor the average bid method since it provides them with higher profits. On the other hand, owners would prefer the less than average bid method since it implies signing the contract for lower price and at the same time protecting them against extremely low bids submitted under the low bid system. However, for large values of m'_x, the less than average bid method curves become lower than the low bid method curves. A large value of m'_x implies a very small variance σ_x, which means that the submitted bid-to-cost ratios are clustered around the mean m_x. Under such conditions, a contractor would submit a significantly low bid and guarantee a higher chance of winning the job and a higher profit when using the low bid method rather than the less than average bid method. The last observation about Figure 3 is that as n increases the curves for the three bidding methods approach the x-axis i.e. zero profit. That is due to the fact that the probability of winning approaches zero for the less than average bid and the average bid methods. As for the low bid method, both the optimum markup and the winning probability approach zero.

Last, Figure 4 shows the probability of winning at the optimum bid-to-cost ratio $(x^*_0-1)/\sigma_x$ for a given m'_x. It is observed that for small values of m'_x, the less than average bid method curves are higher than the low bid method curves and lower than the average bid method ones. However, for larger values of m'_x, the rank of the three bidding methods differs as the low bid method curves become the highest ones, followed consecutively by the average bid method curves and the less than average bid method ones. And that is because a small variance favors winning under the low bid method and a larger one favors winning under the average bid method. In addition, the average bid method always shows a higher probability of winning than the less than average bid method, and that is explained by the fact that the latter method forces an additional requirement over the former one which is bidding less than the average in order to win. However, an exception is noticed in the case of two opponents where the less than average bid method curve goes higher than the average bid method curve for higher values of m'_x. This is expected since as the number of opponents and the variance σ_x decrease, the less than average bid method guarantees a higher probability of winning when x'_0 takes significantly small values relative to the other bid-to-cost ratios clustered around the mean.

CONCLUSIONS

The less than average bid method has the same advantages as the average bid method discussed by Ioannou and Leu (1993) such as protecting the owner against unrealistically low bid prices faced in a low bid award system. It also helps contractors avoid competition against irresponsible and unethical bidders, and reduce the amount of disputes and claims between both parties during the construction phase.

Moreover, the study conducted in this paper shows that the less than average bid method promotes fiercer market competition than the regular average bid method because it requires contractors to bid less than the average. Consequently, it implies lower bid prices which is to the advantage of the owner as shown in Figure 2.

In conclusion, the less than average bid method has the same advantages as the average bid method and overcomes its drawback. It also remedies the main disadvantage of the low bid method. Hence, this study proves the less than average bid method as a compromising middle ground between the low bid and the average bid methods, and thus it deserves the industry's attention.

REFERENCES

Ioannou, P., and Leu, S. (1993). "Average-Bid Method-Competitive Bidding Strategy" Journal of Construction Engineering and Management, 119(1), 131-147.

INVESTIGATION OF SUPPLY CHAIN MANAGEMENT PRACTICES IN INDUSTRIAL PROJECTS: STATE OF PRACTICE VS. STATE OF KNOWLEDGE

Marcelo M. Azambuja[1] and William J. O'Brien[2]

Abstract
This paper focuses on strategic sourcing and planning issues and describes a set of supply chain practices implemented by leading EPC firms and owners executing industrial projects worldwide. Industrial projects include suppliers who are located overseas, a major part of installed items are long lead engineered equipment, shop fabrication capacity is limited and their prices are escalating. Our main purpose is to contrast current practices against the ones presented in the current body of knowledge. The authors conducted interviews with experienced Procurement and Materials Management managers and analyzed documents supporting supply decisions. This study provides an up-to-date description on how firms have been mitigating material supply risks in such complex environment via supplier integration, relationships, supply chain planning, and use of market knowledge information.

INTRODUCTION

Supply chain management (SCM) is an emerging field of research and practice in construction. Researchers and practitioners have been proposing the application of SCM concepts to improve coordination on construction projects, to reduce costs, and increase the speed and reliability of project execution.

Case studies have described common inter-organizational problems and their associated impact on the final delivery of materials on site. These studies mostly focus on understanding how different processes can be modified or improved in order to reduce total lead time or material inventory in the supply chain for specific materials (e.g. rebar, HVAC, pipe supports). Concepts and practices from manufacturing especially lean manufacturing (e.g. pulled production, just in time deliveries, kanban) have been suggested as alternative to promote supply chain re-engineering and improvement. Other studies propose the development of

[1] Ph.D. Candidate, Dept. of Civil, Architectural, & Environmental Engineering, The University of Texas at Austin, USA, azambuja@mail.utexas.edu
[2] Assistant Professor, Dept. of Civil, Architectural, & Environmental Engineering, The University of Texas at Austin, USA, wjob@mail.utexas.edu

collaborative relations such as partnerships between clients, suppliers, and general contractors to enable process improvement.

Little research has been done to evaluate how companies plan their supply chains during early phases of project lifecycle (e.g. pre-project phase). Usually, major supply risks and constraints need to be identified and strategic decisions have to be made in order to mitigate these risks and ensure materials can be delivered on time at the job site. The process-oriented approach is very useful to support tactical or operational decisions (e.g. construction phase) because knowledge of process details is already known, however this information is not available at this level of detail in the very beginning of a project. Moreover, contractors and owners procure a wide range of materials and detailing each supply chain can be burdensome.

This paper presents the results of a set of case studies aimed at identifying supply chain practices implemented by leading global firms performing industrial projects. First, we summarize the state of knowledge in construction supply chain management. Second, we explain the study sample, current challenges in the execution of industrial construction, and describe firms' practices. Finally, we discuss differences between current practices and literature, and suggest future research based on our findings.

CONSTRUCTION SUPPLY CHAIN MANAGEMENT – STATE OF KNOWLEDGE

Symptoms of the need for improvement in construction supply chains include issues such as: excessive engineering change orders, unavailability of materials when needed, excessive lead times and unnecessary inventories of materials, communication errors and delays, and adversarial relationships. The occurrence of these problems is interrelated with causes in prior stages of the supply chain, for example, deficient early planning and design process (Vrijhoef and Koskela 2000).

Isolated approaches and tools have been developed to solve those problems and promote changes. Process modeling (Arbulu and Tommelein 2002, Elfving 2003, Polat and Ballard 2003) and simulation models (Al-Sudairi et al. 1999, Polat et al. 2007, Walsh et al. 2004) support evaluation of different supply chain configurations and provide insights to improve performance (e.g. lead time, inventories, and throughput). These examples demonstrate the potential benefits that could be achieved via supply chain planning however implementation is very limited in the industry.

Supply chain practices have been successfully implemented via Last Planner system (Ballard 2000). Last Planner supports the control of production on site on a daily basis increasing workflow reliability. Suppliers and subcontractors collaborate in the preparation of realistic production plans via identification and removal of constraints (e.g. materials, information, space, people) that may hamper site productivity. As a result, site production and supply of materials are better integrated. Meetings ensure that weekly and lookahead plans are updated based on those constraints. Arbulu et al. (2005) presented a web-based tool designed based on the Last Planner that overcomes potential communication barriers associated with suppliers located in different geographic areas. However, recent implementation studies still indicate that lack of materials on site is one of the main causes affecting

site production (Alarcon et al. 2005). This is a clear indication of inefficient procurement planning. Usually, ordering and deliveries take place when the production comes to a halt due to lack of materials required. Additionally, suppliers are also chosen very late, making it difficult to anticipate their needs in terms of storage area, paths for handling products, among others. Sterzi et al. (2007) present a case of strategic suppliers' integration however this only occurred at the project execution phase.

Early supplier involvement and integration, information technology support and attitudinal changes are needed to improve the performance of construction supply chains (Naim and Barlow 2003). Early supplier involvement is recognized by Vorster et al. (1998). In their report, they suggest that most strategic and project critical procurement transactions should occur prior to detail engineering. Suppliers of those items can then influence and define detailed engineering, and provide unique input to project business and execution plans.

In their study of information technology (IT) to support construction SCM, Vaidyanathan and O'Brien (2003) proposed the development of tools capable of providing procurement visibility and constrained capacity planning to ensure project plans are realistic, feasible and achievable. Advanced IT application for supply chain planning is still missing in residential and commercial construction.

Finally, closer and trusting relationships with key suppliers (e.g. partnerships) facilitate both early involvement and increase communication between firms. It usually allows the alignment of strategic objectives, operational activities and processes that need to be coordinated to provide optimum value for the client. Tommelein et al. (2003) performed an extensive study on capital projects supply chains in which they concluded that firms have feared that enter a long-term transparent relationships might place them in disadvantageous negotiating position. Their study also shows that alliance relationship is not a common practice in construction and relationships are usually set up on project by project basis and are often characterized by adversarial contract management styles aiming at pricing reduction rather than a holistic improvement strategy.

STUDY ON SUPPLY CHAIN PRACTICES APPLIED IN INDUSTRIAL PROJECTS

Research Method

This study is focused on firms within industrial construction. Most of supply chain research and implementation has taken place on commercial and residential construction. Little is know on practices implemented by sophisticated EPC companies which execute projects worldwide, sourcing mostly engineered equipment from different parts of the globe.

EPC firms and owners form our sample population. We had initial access to these firms via contact with a Construction Industry Institute (CII) member. Other contacts were made during a CII research meeting and also via researchers networking. Our final sample includes 4 EPC firms and 3 owners. Table 1 lists the firms and interviewees' position. Their identities have been kept confidential.

Experienced Procurement and materials management managers were interviewed. Data was collected via open-ended questions in order to understand

current challenges these firms have been managing, learn their planning practices and strategic decisions, know current issues on relationship and integration with suppliers and get a big picture on how they mitigate supply risks. Additionally, some companies gave us access to documents currently used for planning their project sourcing strategy.

Table 1- Study sample

Firm	Interviewees
EPC-1	VP (Vice President) Procurement, Senior Director, Senior Director – Logistics, Senior Director - Materials Management, Executive Director – Material Management, Senior Director – Strategic Sourcing, Executive Director – Strategy and Risk
EPC-2	Purchasing Manager, Materials Manager
EPC-3	Director Procurement & Materials, Director (Supply Technology Systems), Subcontracting Manager, and Manager (Logistics Simulation)
EPC-4	VP Procurement, Procurement Manager
Owner-A	Contracting Manager, Upstream Sourcing Manager, Market Intelligence Owner
Owner-B	Associate Director for Capital System Management organization
Owner-C	Manager –Energy Projects Implementation

Industrial Projects – Supply Chain Constraints and Current Challenges

Mounting global demand for oil and gas, energy, infrastructure has been stressing the supply chain as never seen in the last 30 years. As a result, supply risks have been increasing at the same rate and various constraints need to be taken into account when planning the execution of industrial projects.

Supplier capacity is a major concern. Suppliers are declining attractive awards, because they are simply out of shop capacity to fulfill world current demand (e.g. especially from China). One manager described this problem as follows "3 or 4 years ago, lots of capacity was available and we used to make decisions based on price. Now, the question is how to find suppliers with enough capacity." This lack of availability of material/equipment (e.g. steel, pipes) is a serious constraint that needs to be included in early sourcing plans.

This capacity problem has caused increases in lead times and prices. For example, equipment which used to take 15 months to deliver, now takes 24, 26 months. Continuous price fluctuation and escalation of raw materials (e.g. scraps, copper, and carbon steel - 100% increase in one quarter) and engineered products have been impacting final customers. This is a key issue because high percentage of materials acquired by industrial firms is engineered to order - only approximately 13 % of products are commodities. In the past, firms had firm prices good for delivery, now prices are good for 10 days due to escalation costs.

Transportation is another potential constraint in the supply chain. Suppliers are getting out of the transportation business and these risks are being transferred to EPCs and Owners. Moreover, there is also a capacity shortage to transport materials around the globe, especially ocean freight and rail transportation. A 12-18 month booking on heavy and extra heavy shipping is a common practice. Escalating

transportation costs is also a major concern particularly for air freight, trucking and inland waterway.

In summary, the main challenge EPCs and owners are facing is: how to assure supply and control pricing the best they can to increase execution certainty. Meeting project schedule is considered the main performance driver. However, being part of a very dynamic market poses additional challenges to these firms. For example, getting and keeping updated market intelligence data is hard but fundamental to identify sourcing alternatives, opportunities and reduce supply risks. Moreover, fully engagement and integration of suppliers is essential to compete in this scenario. Next section details how firms are handling these issues.

CURRENT PRACTICES

Supply planning during pre-project phase - strategic decisions and tools

Project sourcing strategy is part of any project execution plan. It is drafted before contract is awarded and further detailed to support project execution. EPCs are being pushed to build realistic supply plans based on market constraints. Many projects have been awarded due to effective and detailed plans which consider market constraints.

EPC-1 preliminary supply plans include decisions on standardization (motors, switchgear, etc), modularization, on site vs. offsite fabrication, procurement master schedule, contracting strategy, scope of responsibility, and logistics (shipping capacities, ports, access, ability to bring heavy equipment, volume, customs clearances). Models including detailed financial and economics analysis of different sourcing alternatives (also risk mitigation plans) are presented to clients. Decisions are heavily supported by the information and intelligence of the sourcing group, industry experts and supplier contacts. Visiting suppliers around the globe is a common practice as well. The executive director who manages this process said "I need to understand supplier capabilities and market characteristics and be on top of this information. Strategy comes when you got something different - a constraint – and constraints are driving changes in Procurement."

The other three EPCs listed a very similar set of decisions. These firms are usually concerned with the following issues: commodities availability, potential suppliers in different countries, low cost country options, cost behaviour and currency fluctuation data (pricing), logistics, and long lead items. *EPC-3* typically focus on identifying long lead equipment (e.g. reactor, compressor), and determining the strategy around these pieces. According to the procurement director a key decision is determining how early they need to commit and what the associated risk of ordering early is. A strategy to support schedule is needed and directly supports estimates.

All owner firms also evaluate when to purchase long lead materials and how they can get them earlier on the job site. An additional decision is: who will buy the material? Owner-A usually buys pipes and tanks in advance because the bidder may not be awarded and the firm has money to invest. In this case, Owner-A cannot expect for the bidding process. A contract manager said that his firm has been working with EPCs to understand their capabilities and negotiation power with suppliers, because sometimes EPC firms are in a better position to manage these risks.

Dealing with this huge number of decisions and alternatives is not an easy task and requires the integration of information from multiple procurement functions, information systems, and firms. EPCs have reported that there is no specific tool that integrates this information and support decision making during pre-project planning. In general, project teams either retrieve information from different information systems or have to schedule several meetings to discuss the sourcing strategy. In the latter case – most common - questionnaires and text-based documents detail purchasing responsibilities (EPC or owner), and list major supply risks, approved bidders, procedures for approving orders, transportation concerns, inspection needed among others. EPC-2 and Owner-A use historical models to guide their decisions before detailed engineering phase. Managers have a rough idea (baseline) and can somewhat predict the quantity of materials needed (e.g. steel, pipes, concrete) depending on the type of project. EPC-3 uses simulation to plan and communicate logistics decisions to their clients. Monte Carlo and discrete event simulation models (e.g. Arena) are used to predict schedule risks, ocean transportation planning (number of ships and barges, their capacity), job site logistics planning (e.g. unloading zones and flows), warehouse space planning, among others.

Supply Risk - Mitigation strategies

EPC-1 common practice is sharing demand and supplier capacity information with strategic suppliers. This information is used for early planning and negotiations (e.g. buy/commit shop capacity in advance). The annual market report is also used as input to understand price/lead times/shop load forecasts, and other market constraints. Daily basis communication with industry experts, fabricators to get market intelligence data is usual. *EPC-1* has been extensively using strategic supplier agreements and aggressive supplier integration before detailed engineering. Alliance with freight forwarders is also viewed as fundamental. In the last few years *EPC-1* has reduced the number of partners from 17 to 4, which helped streamlining operations and improved the monitoring effort. Information on global logistics capabilities is also paramount to reduce supply risks. *EPC-1* usually books transportation in advance, especially when offsite modules or heavy equipment needs special planning.

All EPCs stated that schedule delay is the most costly problem that can happen to a project. Nothing is worse than having a crew running out of material on site. Therefore, EPCs need to increase delivery certainty, i.e. have the material available on site when needed. *EPC-2* does not evaluate inventory costs resulting from this strategy. A manager quoted "inventory is not the key driver. Space conflicts are very rare to happen but we are aware of it. We do not practice JIT because the key driver is to have a sufficient margin of material buffer to work on site. It is unusual to have warehouses outside our project sites." Managers of *EPC-3* mentioned that security of execution is as important as price, and if the firm does not know or trust the supplier, a float (time buffer) will be introduced in the schedule. *EPC-4* order materials "very early" in the project lifecycle in order to make sure they will be delivered on time. Materials are only ordered from a list of suppliers which are rigorously pre-qualified and evaluated according to their work history, financial, operations, insurance, and safety performance. Any supplier can only supply from its approved plants. *EPC-4* also requests information on shop load (e.g. monthly

fabrication capacity, monthly estimated loading) during bid phase to evaluate supply risks.

Increasing price certainty is also important in such turbulent and dynamic environment. EPCs are working with strategic suppliers to achieve this goal. *EPC-3* managers said some major suppliers have agreed to maintain a fixed price.

Owners have their own particular strategies to mitigate supply risks. *Owner-A* analyzes the marketplace to understand supply risks (currency exchange, prices, capacity constraints) and assign them to who is better able to control it. This is done by an aggressive allocation of risks in contracts. Sometimes, Owner A pays only for getting detailed execution plans from EPCs. *Owner-B* is working with strategic alliances and unit cost pricing agreements in order to know which reliable contractors are available in the marketplace and reduce the time spent bidding. Other practice is receiving early funding to buy long lead equipment. *Owner-C* requires detailed supply and logistics plans from potential EPCs and also enforces them to work with a predetermined list of suppliers.

Knowledge of the US and international markets

All studied firms execute projects around the world. Their goal is to develop knowledge of key markets and suppliers to create competitive advantage through informed supply decisions. EPC-1 and Owner-A publish very detailed market intelligence reports one or twice a year. These reports include historical data and forecasting on equipment and materials prices, lead times, shop capacity around the globe, global demand, and major risks and challenges. Information is provided by product directors who are responsible for understanding suppliers' capabilities, cost drivers and market conditions. Centralized sourcing group use this report to support early procurement decisions. Owner-A also maintain a market intelligence website with other owners including detailed information about EPCs and suppliers. EPC-2, EPC-3, Owner-B also utilize databases to monitor their supply base. EPC-2 maintains a global supplier and contractor information system. This system includes around 100,000 suppliers/contractors from different countries for 300 to 400 products. One procurement manager said that this system provides global visibility and competitive advantage – especially when a firm execute projects in different geographic locations. A quotation from the same manager points to a trend that goes against the supply chain concepts found in the literature: "SC strategies say that we need to consolidate suppliers, reducing the number and standardizing the product. We don't do that. It does not work in our environment, our dynamic is different, and we need to consider different frontier locations." EPC-4 does not have staff supporting the collection of market intelligence data. Experienced buyers and managers make decisions based on their own knowledge. The VP of Procurement however, acknowledges that market is very dynamic and has been spending part of his time summarizing market outlooks (forecasts) provided by third-party companies or suppliers. These summaries include three subjects - price escalation, lead times and material availability – and are sent to the whole procurement group.

Supplier integration and involvement in early phases - relationships, contracts

EPC-1 considers supplier integration a catalyst that generates competitive advantage. Suppliers of critical components are involved since conceptual project

engineering. This practice helps to reduce engineering effort, rework, shortens cycle times and project risks. The firm will not consider building a strategic relation with suppliers if they are able to integrate their systems (automation, interfaces). One executive director said: "Engineering integration enables the use of more standard components, save fabrication time "fabricability concept" and engineering cost. Integration with suppliers is a must; together we can do more work. Engineering resources are scarce for suppliers as well." EPC-1 is moving to a direct integration with suppliers, where the procurement effort will be reduced and commercial frameworks will be already in place from engineering to execution. Examples of best practices are: 100% vendor design, performance specifications (equipment); model based engineering – vendor extract 3D models for detailed design; and their main electrical vendor which already designs and execute everything.

EPC-2 and EPC-3 do not have global alliances, agreements, partnership with suppliers. Their relation is informal and based on communication between top managers. EPC-2 usually works with 15000 suppliers. 1000 are considered core or strategic suppliers because work with the firm every time. Suppliers of major equipment exchange their standard 3D models which can be directly imported in EPC's design tool, others (e.g. piping, structural steel, electrical), work on EPC-2's digital models. 3D models are utilized during the whole project lifecycle. During construction, EPC-2 uses the models to check space conflicts and construction execution status. EPC-3 has also been working on design and work process integration. In the future, the firm plans to involve suppliers in engineering efforts, pricing agreements, and partnerships.

EPC-4 has only project agreements with pre-qualified suppliers. There is no design integration via advanced technology or aggressive participation of suppliers in early engineering phases.

As for the owners, many changes have been occurring regarding relationships and contracting approaches with EPCs and suppliers. There are fewer big players in the market due to firms' consolidation, joint ventures, and consortiums. Strategic agreements are taking place more than ever. Owner-A quoted a strategic decision on selecting a supplier as an exclusive sourcing for some products. This relationship reduced inventory costs, the owner got better deals, and it improved maintenance and operations as well.

Monitoring of supplier and logistics information – project execution

All EPCs have a pretty complex materials management information system which contains equipment and materials data (drawings, schedule, purchase order, approvals) and tracks their status through procurement lifecycle – from pre-ordering process, purchase, fabrication, shipments, until receiving on site. Any change or update is reflected real time on the system. This way managers have supply chain visibility and can anticipate delays, place time buffers if needed (before final installation) as wells as assess the costs associated with required actions to manage deliveries more effectively. The expediting team is in the frontline monitoring if the supplier fabrication is on schedule and delivery is on time. The information system also includes supplier evaluation data. This evaluation is saved for supporting future decisions and may determine further awards. Suppliers are rated based on their performance regarding cooperation (e.g. problem solving and timeliness), quality (e.g.

adherence to specifications, tolerances), schedule (e.g. meeting required delivery, maintain scheduling), and commercial (e.g. effort needed to ensure performance) criteria.

Owners' teams also tracks order status of critical equipment. Owner-B has what is called "Equipment status memorandum" which shows current delivery status. Videos and photos are also collected to check fabrication status.

CONCLUSIONS

This paper presented the findings of exploratory case studies with global EPCs and owners performing industrial construction. Observation of the state of practice illustrates a variety of issues involved in the planning of construction supply chains at early phases of capital projects. In addition, analysis of the results allowed us to compare them against the body of knowledge.

Current practices emphasize the importance of strategic relationships and alliances with key suppliers, integration with these suppliers in the early phases of the project (e.g. pre-project and engineering phase), and advanced planning and analysis of supply risks via continuous exchange of fabrication and logistics information and forecasting of market conditions. These practices are poorly implemented in residential and commercial construction. Literature indicates that there is a lack of supplier integration and planning focus on tactical and operational issues late in the project lifecycle- usually during construction phase. The state of practice in industrial construction shows that strategic planning and knowledge of suppliers' capabilities is crucial to increase schedule and cost certainty.

Supply risks are usually mitigated via early ordering of equipment. This way, equipment can arrive on the job site much before installation. This practice is against the principles of lean construction (e.g. pulled deliveries, JIT) advocated in the literature, however market constraints and uncertainty as well as geographic location of suppliers make lean implementation almost unfeasible. Research effort is needed to understand how to apply lean concepts and methods in the execution of global projects.

We also identified a lack of tools to support early planning and identification of supply risks. Market knowledge information (forecasting), historical data on supplier performance are not integrated with scheduling and estimate tools. Thus, identification of supply chain constraints is complex and usually takes weeks or months. A decision support tool is being developed to improve this process and help managers build more realistic procurement plans based on market knowledge data.

REFERENCES

Al-Sudairi, A. A., Diekman, J. E., Songer, A. D., and Brown, H. M. (1999). "Simulation of construction processes: traditional practices versus lean construction." *Proceedings of the 7th Annual Conference of the International Group for Lean Construction*, IGLC 7, Berkeley, Calif., 39-50.

Alarcon, L.F., Diethelm, S., Rojo, O., and Calderon, R. (2005). "Assessing the Impacts of Implementing Lean Construction," *Proceedings of the 13th Annual Conference of the International Group for Lean Construction*, IGLC 13, Sydney, 387-393.

Arbulu, R.J., and Tommelein, I.D. (2002). "Alternative supply-chain configurations for engineered or catalogued made-to-order components: case study on pipe supports used in power plants." *Proceedings of the 10th Annual Conference of the International Group for Lean Construction*, IGLC 10, Gramado, Brazil, 197-209.

Arbulu, R., Koerckel, A., and Espana, F. (2005). "Linking Production-Level Workflow with Materials Supply," *Proceedings of the 13th Annual Conference of the International Group for Lean Construction*, IGLC 13, Sydney, 199-206.

Ballard, G. (2000) "The Last Planner System of Production Control." Ph.D. Dissertation, University of Birmingham, Birmingham, UK.

Elfving, J.A. (2003) "Exploration of Opportunities to Reduce Lead Times for Engineered-to-Order Products." PhD dissertation, University of California, Berkeley, Calif.

Naim, M., and Barlow, J. (2003). "An innovative supply chain strategy for customized housing." *Construction Management and Economics*, 21, 593-602.

Polat, G., and Ballard, G. (2003). "Construction Supply Chains: Turkish Supply Chain Configurations for Cut and Bent Rebar." *Proceedings of the 11th annual conference of the International Group for Lean Construction*, IGLC 11, Blacksburg, Va., 14 pp.

Polat, G., Arditi, D., and Mungen, U. (2007). "Simulation-Based Decision Support System for Economical Supply Chain Management of Rebar," *Journal of Construction Engineering and Management*, 133, 29-39.

Sterzi, M., Isatto, E., and Formoso, C.T. (2007). "Integrating Strategic Project Supply Chain Members in Production Planning and Control." *Proceedings of the 15th Annual Conference of the International Group for Lean Construction*, IGLC 15, East Lansing, Michigan. 159-169.

Tommelein, I.D, Walsh, K.D., and Hershauer, J.C. (2003). "Improving Capital Projects Supply Chain Performance." *Research Report PT 172-11*, CII, Austin, TX, 241pp.

Vaidyanathan, K., and O'Brien, W.J. (2003). "Opportunities for IT to Support the Construction Supply Chain." *Proceedings of the 4th Joint International Symposium on Information Technology in Civil Engineering*, Nashville, Tenn., 19 pp.

Vorster, M.C., Magrogan, S.A., and McNeil, B.W. (1998) "PEpC – A Breakthrough Project Delivery System that Improves Performance by Reforming Owner, Contractor, Supplier Relationships." *Research Report 130*, CII, Austin, TX, 310pp.

Vrijhoef, R., and Koskela, L. (2000). "The four roles of supply chain management in construction." *European Journal of Purchasing & Supply Management*, 6, 169-178.

Walsh, K.D., Hershauer, J.C., Tommelein, I.D., and Walsh, T.A. (2004). "Strategic Positioning of Inventory to Match Demand in a Capital Projects Supply Chain," *Journal of Construction Engineering and Management*, 130, 818-826.

A NEW APPROACH TO CONTRACTING DESIGN PROFESSIONALS

John K. Michael[1], Brad D. Carey[1], and Kenneth T. Sullivan, PhD, MBA[2]

[1]Graduate Student, Del E. Webb School of Construction, Arizona State University, PO Box 0204, Tempe, AZ 85287
[2]Assistant Professor, Del E. Webb School of Construction, Arizona State University, PO Box 0204, Tempe, AZ 85287; Kenneth.Sullivan@asu.edu; 480-965-4213

Abstract
In a recent survey of clients and buyers of construction, the Construction Management Association of America (CMAA) found that over 50% of design efforts finish behind or significantly behind schedule. Furthermore it found that 70% of clients have seen the quality of design documents decrease over the past ten years with 97% of clients agreeing that designers should be held more accountable for the quality of the designs that are delivered. This paper presents the research results of applying a new approach to contracting design professionals that enforces accountability and minimizes risk through the adaptation of six sigma and lean principles. The new approach theorizes that the inefficiencies in the design industry are due to the selection and contract management system used by most clients. The first 39 design project test results are presented in the paper, along with the evolution of the design delivery model. Key finding include the threat of political risk to change, the inability of most design professional to address specific project risk, and the lack of preplanning evident in most design projects.

Introduction
In the Fifth Annual Survey of Owners, conducted by FMI in partnership with the Construction Management Association of America (CMAA) (FMI/CMAA, 2004), clients and buyers of construction expressed that over 50 percent of design efforts finish behind or significantly behind schedule, that 70 percent of clients have seen the quality of design documents decrease over the past ten years, and 97 percent of the clients agreeing that designers need to be held more accountable for the quality of their designs. Upon examination of the issues faced in the design industry, which in the context of this paper incorporates both architects, designers, engineers, and subconsultants the following were identified (Butt & Clinton, 2005; EC&M, 2005; Shuster, 2005; Stuttel, 2005; ENR, 2004; ENR, 2003; HC&O, 2004; Parks, 2006; Sturts & Griffis, 2005; Carr & Beyor, 2005; Parks, 2006; FMI/CMAA, 2004; Roe, 2002, Sullivan, et al. 2006).

1. Construction performance is decreasing.
2. Designers have been identified as one of the major sources of reduced performance in construction.
3. Designers are required to put together specifications/drawings for a contractor base that is continually deteriorating.
4. Clients have started to review and correct designer specifications and drawings.
5. The quality of design documents has declined to the point where subcontractors, such as electrical and mechanical, are actually completing the design through the shop drawing, basically filling in the gaps of insufficient design information.
6. Designer functions and fees have been reduced.
7. Designers are being forced into a commodity environment, relationships are more important, and it has become more important to get work than it is to do high performance work.
8. The majority, 83 percent, of change orders are due to design issues
9. There has been a decline in the quality of design drawings despite increasing levels of CAD and BIM technology.

An additional problem is that when designers are responsible for minimizing risk, they look to errors and omissions insurance and have a tendency to minimize their accountability and liability (ENR 2003). Designers are known for minimizing internal decision making and moving risk and decision making to the client via partnering. As a result, the design industry has become more reactive, more client focused than project focused, which has caused a decrease in preplanning and risk minimization. From the 2004 CMAA survey it was noted that, "Once there is a project in hand, everyone is anxious to get it started, and get it done. That is one of the reasons it is so difficult to spend time in pre-planning, pre-design, or pre-anything. 21 percent responded that they spend a lot of time in pre-design, but do not create a thorough project definition (FMI/CMAA 2004)."

After an extensive literature review and discussion with industry professionals, the authors identify the following as reasons for the issues in the design industry (Harness 2001; ENR 2005; ENR 2003; Harness 2001; Gransberg & Molenaar 2004; Christodoulou et al, 2004; Perng et al, 2006; Chang 2002; Kilian & Gibson 2005; Conklin 2005; Puddicombe 2006; Lyer & Jha, 2006):

1. Lack of a definition of performance.
2. Lack of accountability and clear assignment of responsibility for the AE firm.
3. Selection mechanism relies heavily upon marketing and relationships.
4. Number of uncontrolled factors with which the AE team must interface.
5. The lack of clear preplanning and use of a risk minimization.
6. The type of direction given by the client to the AE design team.
7. The use of low bid award contracts that add to the confusion of liability.
8. The lack of accountability of the client's representatives.
9. The lack of timely, clear, and a readily available performance measurement

This paper presents a new contracting and design delivery approach, with results and modifications based upon the first 39 test applications. The process presented is an information-driven delivery process that uses a data-based selection structure and a rigorous preplanning phase before a contract in negotiated. The model enables design professionals to be the project leaders, holding all parties accountable for their actions or inactions. The initial results of the research have shown that a large barrier to changing the process of design procurement and delivery is political pushback. Specific to design, the research has also found that design professionals struggle to specifically identify and minimize risk, often needing client support to develop design solutions.

Process Overview

In response to the issues identified, the researchers looked to an approach which has realized success with contractors in the construction industry. The approach is known as best value Performance Information Procurement System (PIPS), which is based upon six sigma and lean production principles (Kashiwagi 2008). The process has been tested over 500 times on over $680 million in procured construction and has resulted with 98 percent of the projects finishing on-time, on-budget, and with high levels of customer satisfaction (Kashiwagi 2008). The success of the process is due to the structure it creates where owner decisions are minimized and performance is measured continuously. In this structure, the vendor's expertise is maximized as it fills in the voids of traditional owner decisions. The process thus transfers the risk of those decisions from the owner to the expert (vendor), who is actually the most appropriate party for such responsibility. Because the vendor is providing the suggested methods, they are then accountable for the project's success, where on the other hand, when the owner is requiring the methods (making decisions), they are accountable for the project's success. By then continuously measuring the vendor's performance, accountability is sustained for the entire project duration, and accountability breeds higher performance. This process gives the competitive advantage to high performing vendors.

Best value PIPS is broken into three phases. The first phase is the Selection phase. The function of the Selection phase is to utilize non-technical information to identify the highest performing (smartest) vendor. This is accomplished via three core filters, which consist of Past Performance Information (PPI), a Risk Assessment and Value Added Plan (RAVA), and Interviews.

PPI is collected on each competing firm and their critical team personnel specific to each project. The competing vendors are responsible for distributing a standardized eight question PPI survey to the past clients of their choice, who then send the completed surveys to the PBSRG to be entered into a database. This is technically a one time function, unless the vendor is interested in trying to improve their score. Once the surveys are entered into the database they are never removed, and for every future project on which the vendors compete, for that specific owner/client, their database score is utilized in the Selection phase. This criterion holds vendors accountable for their past performance. When a vendor is awarded a best value PIPS

contract, they are further held accountable with a close-out rating provided by the owner at the completion of the project, which impacts their PPI database score by 50 percent.

The RAVA plan is a two page document that must be written in non-technical terms. The objective of the risk assessment portion of the RAVA plan is for each vendor to identify, prioritize, and minimize the risks on the project that will have the greatest impact to either the budget, the schedule, or to client satisfaction, while focusing specifically on the risks outside the vendor's control. The value added aspect of the RAVA plan is for the vendor to differentiate themselves from their competitor by expressing value adding options that their competitors most likely do not offer. The function of the RAVA plan is to identify the highest performing vendor by seeing who best has the ability to visualize the project from beginning to end and can identify and minimize the major risks. This criterion gives the advantage to the highest performing vendor, as those with limited expertise struggle to identify, prioritize, and minimize the risk they do not control. Where the PPI criterion identifies a vendor's past performance, the RAVA identifies the vendor's current performance ability. And, from an owner's point of view, because it is more important to know what the vendor is going to do for that owner's project than what they did on past projects, the RAVA plan is weighted higher than PPI in the evaluation, making it the most important of the shortlist criterion, prior to interviews.

The interviews are conducted individually with each of the critical team members on which PPI was required and who will ultimately be running the project if selected. The interviews are the most important criterion in the Selection phase because they allow the owner to identify the highest performing personnel. The best value PIPS process is ultimately a tool for identifying the best people; with best being defined as those people most capable of minimizing risk. The majority of questions asked in the interviews are based upon the project risk, which serves the same purpose as the risk assessment plan, to find the people who can visualize the project from beginning to end, before they start, and are able to foresee potential risks and know how to minimize those risks.

Once the highest performing vendor has been identified in the Selection phase, they are solely moved forward into the second phase of the process, known as the Pre-Planning and Quality Control phase. The Pre-Planning and Quality Control phase is a pre-award period which requires the vendor to pre-plan their service in great detail. While the Selection phase focused on non-technical information, the Pre-Planning and Quality Control phase is where the details of the project are addressed. The vendor is told to focus on identifying and minimizing the risks they do not control. It is during this phase that the risk is transferred to the vendor. By having the vendor identify and minimize the risks they do not control, the vendor is minimizing all foreseeable roadblocks in the project and is thus creating the most efficient approach possible. The details laid out by the vendor in the Pre-Planning and Quality Control phase are documented by the vendor in what is known as their Quality Control (QC) plan, which ultimately becomes a contractual document. If the owner is satisfied with

the vendor's pre-planning efforts and QC plan, they will then award the contract and move into the third and final phase, known as Management by Risk Minimization. If the owner is not satisfied with the vendor's pre-planning efforts, they may substitute them with the next best ranked vendor, and have the substitute create their own QC plan. Once the owner has awarded the contract and moved into the Management by Risk Minimization phase, the vendor is then responsible for tracking and minimizing risk on a weekly basis throughout the life of the project via a Weekly Risk Report. Each week, the report is filled out by the vendor and submitted to the owner. The owner rates the report with a one-to-ten (ten being best) owner satisfaction rating, which promotes accountability as well as closes the communication loop by immediately letting the vendor know how they are doing. Once rated, the report is then sent to all stakeholders each week. At the conclusion of the project, the owner will complete a close-out satisfaction survey. The survey asks the same eight questions as the PPI survey utilized in the Selection phase of the bidding process. The close-out satisfaction survey affects the vendor's PPI score by 50 percent. Because a vendor's PPI score is compounded and reused on every project bid for that client, the impact of the close-out survey on the vendor's future competiveness holds them accountable throughout the entire project.

Test Application of PIPS for Design Professionals

Due to the success of best value PIPS with contractors in the construction industry, the process function of transferring risk to the expert, generating accountability via the Weekly Risk Report, and therefore increasing the performance of a vendor, the authors began testing best value PIPS in the design industry, to address the issues of low quality (performance) and lack of accountability. Research partners that allowed the authors to apply the PIPS process on design included:

1. City of Peoria, Arizona
2. State of Wyoming, Wyoming Military Department
3. State of Missouri, Division of Facility Management, Design, & Construction
4. Arizona State Parks
5. Arizona State University, University Architect Office

The first three applications were all incomplete applications of the process, not at the project level, but instead at the political level due to the new environment of performance measurement and accountability created.

City of Peoria

The first tests were run with the City of Peoria, Arizona. In 2004, the City of Peoria began implementing best value PIPS testing on their design and construction procurement and management. The first project tested was a design-build project, which incorporated the evaluation of both the contractor and designer components of each proposing team. Upon successful results, the City tested the process on two more design-build projects and one design project in 2004. The process was proving valuable for the City, which became evident when they implemented it on two more design-build projects and three more design projects in 2005.

Later in 2005, the process met political tension as a local professional group of engineers and consultant became adversarial to the post-project performance measurement requirement under the PIPS system. The extreme levels of accountability would change the dynamic of work procurement from one of marketing, relationships, and name recognition to one of documented performance and measured design capability. The group met with the mayor, an architect by trade, and attempted to shut down the PIPS process. However, due to the success with contractors, this was not politically feasible for the mayor, so instead the mayor discontinued PIPS for design professionals noting that the quality of design cannot be measured. The City thus refrained from utilizing best value PIPS to select any additional designers. (The mayor has recently left office and the City has commenced testing again.)

State of Wyoming

In January 2007, the authors formed a research partnership with the State of Wyoming. The State was aggressive, and resistant to advice of patient application from the authors. They began by testing the process on six design projects simultaneously. Multiple state statute requirements were inflexible that resulted in adjustments to the best value PIPS process. Upon executing the evaluation, it was learned that many of the requirements the State representatives had expressed as mandatory had never actually been included on previous Wyoming design professional procurements. Regardless, once the Selection phase results were tallied, the State was not comfortable with the data driven selection nor the risk and performance measurement system of the best value PIPS process. The State representatives felt they had "lost control" of being able to select the designer they wanted and feared the performance numbers would inhibit their ability to spread work to where they thought appropriate. As a result only one of the six projects was awarded, and the second and third phase of the best value PIPS were abandoned for the project. The research partnership with the State of Wyoming ceased in December 2007.

State of Missouri

The State of Missouri also partnered with the authors in 2007. While Missouri began slowly with a pilot project, which finished successfully, they too went against the advice of the researchers and expanded very quickly thereafter. Within the first year of the research partnership, Missouri implemented best value PIPS on eleven projects, seven of which incorporated designer procurement, and fully integrated the best value PIPS process into their new software package. During this period, the State simultaneously underwent downsizing by releasing 60 percent of their project manager. As a result of the State attempting to deal with the downsizing of their department, a brand new software package, a new procurement/management process (best value PIPS), and the same workload, they were unable to learn and implement the best value PIPS process, and ultimately decided to suspend working with the researchers in early 2008, with the possibility of resuming testing once their internal structure stabilized.

Other Applications

The research has since also applied PIPS for design services for Arizona State Parks and Arizona State University. These applications will be discussed later in the paper.

Results to Date

The research has completed two projects incorporating designer selection through the PIPS process. The first was an A/E selection for a fire station design, with a final customer satisfaction of the design work of 99 percent. The second was a design-build contract for a $1.2M park with a final customer satisfaction of the design work of 96 percent. All other applications have yet to finish construction.

Application Data

The PIPS process has been applied on 39 projects incorporating the procurement, contract structure, and contract management of a design professional. Table 1 contains accumulated data generated from those 39 projects.

Table 1: Design Professional (DP) Procurement Data

Total # of projects tested	39
Total # of design projects tested	25
Total # of design-build projects tested	14
Avg. # of proposers per project	8
# of DP firms with PPI in database	170
# of DP individuals with PPI in database	530
Total # of PPI surveys in database	5440
# of PPI survey for DP firms	2416
# of PPI survey for DP individuals	3024
Avg. PPI score - firms (1-10)	9.4
Avg. PPI score - individuals (1-10)	9.4
Avg. # of surveys submitted per DP firm (1-25)	14
Avg. # of surveys submitted per DP individual (1-10)	6
Avg. PPI score for shortlisted teams (1-10)	9.3
Avg. RAVA rating (1-10)	5.4
Standard deviation of RAVA ratings	2.5
Avg. shortlisted RAVA rating (1-10)	6.0
Standard deviation of shortlisted RAVA ratings	2.9

Process Inefficiencies and Problems

Though the first completed projects achieved success, inefficiencies and weakness were identified in the process. The first problem faced when implementing best value PIPS on design projects, besides the consistent political pushback as a result of moving from a relationship to data based selection, was the designers' inability to produce a quality RAVA plan. As this is the most important of the pre-shortlist criteria, the inability of design professionals to generate quality RAVA plans made it difficult to differentiate their capabilities. It was found that design professionals struggle at identifying project specific risks. Of the 300+ RAVA plans created on the 39 aforementioned projects, a random sampling yielded that 87 percent of the risks identified were generic risks, or risks not specific to the project at hand. Approximately 50 percent of RAVA plans also contained marketing material, which was highly discouraged in the RFPs because it adds no value with respect to

portraying the performance capability of a designer. The RAVA plan's function of identifying the designer who can best see the project before it begins was deflated. The analysis of risks, which have a relatively high potential of negatively impacting the owner's budget, schedule, or satisfaction in general, was difficult for nearly all design proposers.

The second difficulty faced was during the second phase of the process, Pre-Planning and Quality Control. (To quickly summarize the second phase, the designer is responsible for creating a Quality Control plan that addresses all the risks identified by every party involved, includes a detailed project schedule, and an owner action item list). In this second phase, the control is shifted to the designer, who becomes the leader and who attains responsibility and accountability for the project success. The first time the second phase of the best value PIPS process was run on a design procurement was in the State of Missouri. The designers had trouble minimizing the risks, but it was additionally found that they also struggle with control and accountability. The designers were uncomfortable with having minimal direction and being held accountable for their decisions. On the other hand, the State of Missouri project manager struggled with releasing control and minimizing direction. This observation was repeatedly seen for all design test projects.

Modification

As a result of the lessons learned from the research conducted at the City of Peoria, the State of Wyoming, and the State of Missouri, the researchers modified the best value PIPS process for its application on designer procurements. The concern addressed was the void in the process left from the design professional's inability to generate a quality RAVA and QC plan, or in other words visualize the project from beginning to end, before it begins, and to identify, prioritize, and minimize potential risks to the success of the project. Therefore, a criterion was added to the pre-shortlist criteria. The added criterion is called a Workplan. The Workplan is a two page summary. It is not for programming nor is it a legally binding document, but rather an additional medium for identifying which designer can actually visualize what they are going to do, and what will transpire as a result of their expertise, before they actually do anything. The sub-objectives are for the designers to show what they think of the project, to show why and how they know the design and construction are doable within the budget and expectations, have a conservative vision of how they are going to do the project, know the key milestones, and to help them foresee risks that may prevent their success. The hypothesis was that by requiring designers to document their plan for the project (taking it one step further than visualizing their plan), before actually beginning the project, they would have an easier time identifying the risks or obstacles threatening their plan's success. Additionally, the Workplan was theorized to help the designers take control of the project apposed to relying on owner direction, and to provide the owner with a clear understanding of project expectations from expert perceptions.

The Workplan has thus far been tested on two projects, one was a design-build project with Arizona State Parks (ASP), and another was a designer selection for a CMAR project with Arizona State University (ASU). On the ASU project, ASU

insisted that the designers would not be able to complete the Workplan, as it was something too foreign to the industry. The resistance to incorporate the plan resulted in its exclusion as a pre-shortlist criterion. Though, the authors were able to convince ASU to incorporate the Workplan in the interview process. Ultimately, the designers had little to no difficulty creating the Workplan and unsurprisingly, the designer with the best Workplan was also the designer chosen to move into the second phase of the process, as they were the most prepared.

An additional modification to the process for designer selection was to the Weekly Risk Report. In the previous version, the designer only tracked risks that impacted money and time as it related to the design. The new version requires the designer to also track risks that impact money and time to the construction aspect of the project. This responsibility holds the designer accountable for the impact of their decisions on the construction aspect of the project, and keeps the owner informed of the status of the entire project.

Conclusions

The application of the PIPS process to design has confirmed the finding the previous literature. The design industry does struggle with accountability and preparing a project plan. It also relies upon relationships and marketing to procure work and uses customer interactions and satisfaction as the basis of a design's success. The actual functionality and quality of the design are of secondary importance.

In application of the PIPS process it was found that the greatest barrier to changing designer and client interactions is political risk. Additionally, it was found that designers, on average, lack the capability to clearly identify project specific risk and offer non-generic solutions for risk minimization. Furthermore, it was observed that client project managers have a very difficult time releasing the responsibility for decision making. Traditionally, the design professional prepares thoughts for multiple design solutions for a project problem, brings them to the client, and the client decides the course of action. The designer then reacts to this direction. In PIPS, the client only identifies needs and constraints. The designer makes all decisions for design solutions. This change in interaction caused great unrest amongst clients and designers, as it increased accountability for designers and required a release of control for clients. Though it creates a purer outsourcing environment, the change is difficult and requires constant education and reinforcement from the research team. Moving forward to the future, the authors will track the success of the current projects underway and present the findings in a following publication.

References

Butt, T., and Clinton, J. (2005*) Limiting Construction Failure Losses - A Challenge for the Insurance Industry.* Interactive Resources, retrieved June 7, 2005 form http://www.intres.com/about/pub/construction_failure.shtml

Carr, P., and Beyor, P. (2005). *Design Fees, the State of the Profession, and a Time for Corrective Action.* Journal of Management in Engineering, 21 (3), 110-117,

Chang, A. (2002). *Reasons for Cost and Schedule Increase for Engineering Design Projects.* Journal of Management in Engineering, 18 (1), pp. 29-36, January.

Christodoulou, S., Griffis, F., Barrett, L., and Okungbowa, M. (2004). *Qualifications-Based Selection of Professional A'E Services*. Journal of Management in Engineering, 20 (2), pp.34-41, April.

Conklin, G. (2005). *Risk Management Issues of Branch Engineering Offices.* Journal of Professional Issues in Engineering Education and Practice, 284-287, October.

EC&M Web Editor. (2005). *Contractor Failure Rate Increases With Age.* http://www.ecmweb.com/mag/eletric_contractor_failure_rate/index.html

ENR Staff Writer (2004,). *Liability Insurance Price Hikes Push U.K. Designers to limit.* Engineering News Record, 252 (15), pp. 7, April.

ENR Staff Writer (2004) *Top 500 Executives Focus on Deepest Industry Challenges.* Engineering News Record, 253 (23), pp.14, December.

ENR Staff Writer (2005). *The Industry Searches for a Swift Turnaround*. Engineering News Record, 252(26), pp. 4-6, July.

FMI / CMAA Fifth Annual Survey of Owners (2004). *Management Consulting - Investment Banking for the Construction Industry.* Retrieved September 27, 2006 from http://cmaanet.org/user_images/fmi_owners_survey2004.pdf

Gransberg. D., and Molenaar, K. (2004). *Analysis of Owner's Design and Construction Quality Management Approaches in Design/Build Projects*. Journal of Management in Engineering, 20 (4), pp.162-169, October.

Harness, S.(2001) *Architect Wins Entitlement to Damages, but Recovers Nothing, Because it Failed to Keep Adequate Cost Records.* Retrieved September 27, 2006, from http://www.constructionrisk.com/newsletter/articles/newsletter01-05.htm#2.

HC&O Editor (2004) *Survey Reveals Construction Challenges and Trends*. HC&O, 3 (1), January.

Iyer, K., and Jha, K.(2006). *Critical Factors Affecting Schedule Performance: Evidence from Indian Construction Projects*. Journal of Construction Engineering and Management, 132 (8), pp. 871-881, August.

Kashiwagi, D. (2008). *Best Value Procurement.* Tempe, Arizona. Performance Based Studies Research Group.

Kilian J., and Gibson, G. (2005). *Construction Litigation for the U.S. Naval Facilities Engineering Command, 1982–2002.* Journal of Construction Engineering and Management, 131 (9), pp. 945-952, September.

Parks, G. (2006). *At a Crossroads-Is Value-Based Compensation the Answer?* Leadership and Management in Engineering, pp. 144-149, October.

Perng, Y., Juan, Y., and Chien, S. (2006). *Exploring the Bidding Situation for economically Most Advantageous Tender Projects Using a Bidding Game*. Journal of Construction Engineering and Management, 132 (10), 1037-1042.

Puddicombe, M. (2006). *The Limitations of Planning: The Importance of Learning.* Journal of Construction Engineering and Management, 132 (9), 949-955, September.

Roe, Andrew G. (2002). *The Corps' Doctor Will Make House Calls to Check Design*. Engineering News Record, 248(21), pp. 55-56, June.

Sullivan, K., Kashiwagi, D., Koebergen, H., and Zenko, D. (2006) "Bridging the Gap: Performance and Efficiency in Design Build Delivery." *ASC International Proceeding of the 42nd Annual Conference*, Colorado State University, Fort Collins, CO, on CD-T20 (April 19-22, 2006).

MAPPING THE VALUE THREAD IN LOCAL GOVERNMENT SERVICE DELIVERY IN SOUTH AFRICA

C.I. Jay, P.A. Bowen, and K.S. Cattell

Department of Construction Economics and Management, University of Cape Town, Private Bag, Rondebosch 7701, Cape Town, South Africa; PH (+27) 21 – 650-3443; FAX (+27) 21 – 6897564; email: Ian.Jay@uct.ac.za

Abstract
A framework for understanding public sector decision-making in relation to projects, programmes and policy is presented. The framework builds on Value Management (VM) theory by adding a component to the classical VM model. The framework demonstrates that, apart from the functional value of alternative materials and their costs, a choice of one particular technical solution also requires consideration of moral issues. The model is illustrated within the context of housing policy in South Africa. The paper concludes by examining some published measures of project success and indicates that more work is needed to establish what constitutes real value add in project delivery in this sector.

Introduction
South Africa faces an enormous housing problem. Nearly half of all households report monthly incomes of less than R1000 (R7.71 = 1 US$ as at 28 Aug. 2008), and three million people are thought to lack adequate shelter (Wilkinson, 1998). This sector of the population is predominantly but not exclusively African, and is the 'target' for the national housing policy (Wilkinson, 1998). By 2006 over one million families have been provided with housing grants under this policy (Goebel, 2007).

The South African Constitution states that "*Everyone has the right to have access to adequate housing*" (RSA,1996; 9). It continues this theme saying "*The state must take reasonable legislative and other measures, within its available resources, to achieve the progressive realisation of this right*" (RSA,1996; 9). The Local Government Services Act No 32 of 2000, devolved this responsibility to local authorities, stating that they

are required to improve the quality of life of the poor and other disadvantaged sections of the community, in a sustainable manner (RSA, 2000). Local authorities are mandated to act in their citizens' best interests.

With the advent of democracy in South Africa in 1994, the government sought to address the problems of living standards and housing (Jones and Datta, 2000). More than half the urban population lived in informal settlements and lacked services such as electricity and water. These conditions were due to rising unemployment and migration from rural areas (Mackay, 1999). Economic growth, health, water access and education became priorities for the new government (Albier, 2003).

To address these priorities, the government attempted to formulate a policy to provide 'decent' homes for lower income groups (Mackay, 1999) by engaging with the financial institutions and other interested parties (Huchzermeyer, 2003). A policy to provide a once-off capital grant to each household emerged from this. Families were expected to purchase freehold land on which small permanent structures could be built. Local authorities were expected to make land available at a reduced cost, engage developers to install infrastructure, and then service the new community (Tomlinson, 1999). The outcome has been a standard product with little flexibility to meet individual needs (Lizarralde and Massyn, 2008).

This paper presents a framework that models decision-making in relation to public sector projects and programmes. The context described above will be used to illustrate the features of the model.

Values and decision-making

Value Management has been suggested as an approach to improving public sector service delivery (Bowen *et al.,* 2007). A key component of the model is the concept of the 'Value Thread'; an issue that has emerged from the Value Management literature (Kelly *et al*., 2004). The term 'value thread' was first used by K. Bell, a PhD student at Herriot-Watt University. The idea behind the 'value thread' is that the original intent of the project or programme initiator is passed through the chain of actors involved in delivery. It was originally used to describe the transition of custody of the 'value' of the project from the client organization to the project team.

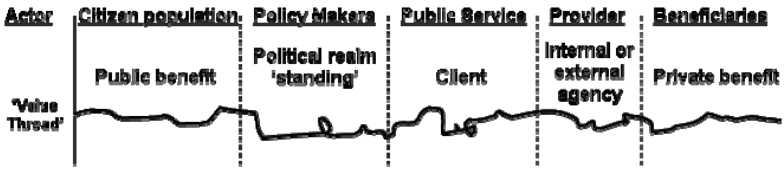


Fig. 1 The 'Value Thread'

Figure 1 depicts the framework portraying the idea that citizens' values have to negotiate a number of custodians prior to being articulated in delivery to the beneficiaries. Values are expressed by politically active groups, who seek to influence or formulate policy, which in turn instructs public servants. The public service, guided by policy, commissions internal agencies or external contractors to deliver services deemed appropriate to achieving policy goals.

The main reason the initiating values may not remain intact through the chain of actors is because each custodian applies its own values to the problem. With any project or programme the sponsor or client articulates an overarching choice of a future state. With each successive stage of the project additional detail is added by different actors (Morris, 1988). Each detail added requires the input of different decision-makers, and it is with each decision made that the originating values are placed in jeopardy, and the original intent is compromised. This is because different groups have different perspectives on the project (Morris, 1988).

Decisions involve value choices (Simon, 1997). Simon (1997) explained that each decision has two parts, a technical or factual part, and a moral or ethical part. Terms differentiating these two aspects are 'facts' on the one hand, and 'ought', 'desirable' or 'preferable' on the other. To understand these concepts it helps to think of a decision as a choice of a future state from a number of alternatives.

In the context of housing provision in South Africa, facts indicate that people need shelter (Wilkinson, 1998). Values indicate they require a higher standard of living. The standard of living, embodied in more permanent housing with services such as water and lights, is a value choice. The 'ought' component becomes more elaborate when deciding on the type of house and its setting. These are selected from the many possible alternatives. Even when all constraints, economic, technical, and so on are accounted for, a choice of alternative solutions will remain (Simon, 1997).

'Value' is a term with several meanings, one of which is 'moral' value and is explained above (Moore, 1910; Sheldon, 1914). Two other uses of the term 'value' relate to cost benefit analysis (Hanley and Spash, 1993).

The first is monetary value, the economic or 'exchange value' of the component which is reflected in the market price of an item. The second is 'value added', referring to the functionality; this is the 'potentiality' value of the item being evaluated (Brown, 1914).

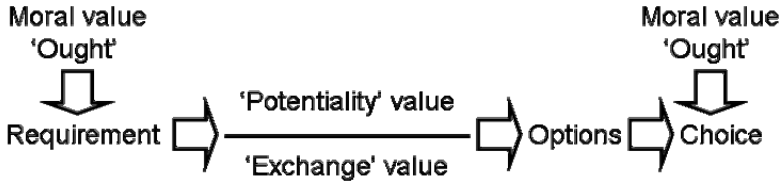


Fig. 2 The decision model

Figure 2 portrays the application of moral values to the statement of requirements. Options to deliver the requirement are evaluated with different approaches being considered against their costs, and potentiality being considered against exchange value. The choice of solution is again a moral one. Decision making as depicted in Figure 2 is embedded at various points within the Value Thread shown in Figure 1.

The rest of this paper applies this thinking to public service value chains. It looks at each part and demonstrates how differing values, rooted in the history of each actor, impact on choices from policy to project level. The model is illustrated within the context of low cost housing delivery in South Africa.

The public service value chain

The view of who the 'client' is in any value chain will depend on where the actor is positioned within that chain. Private sector and commercial value chains have a customer or end user. That party is normally the final arbiter selecting what is delivered (Alford, 2002). In this sector the benefits that are delivered are essentially for 'private' consumption. That is to say, the value delivered is wholly intended for the recipient; this is a 'private' benefit. Such arrangements are common, described in great detail in marketing texts, and well understood. They normally involve two parties, a buyer and a seller (Alford, 2002).

Public value chains involve three or more parties and this makes the exchange complex (Alford, 2002). There is a provider who is guided by public policy. The provider delivers services to a recipient, who enjoys a 'private' benefit from the exchange. In addition, there is the general public. The public are the citizens of the community who derive a 'public' benefit from the policy. Examples of public service value chains include: subsidised housing; social security; and infrastructure. Note that a citizen

may receive 'public' benefit without being a recipient of 'private' benefit (Alford, 2002).

Ideally, managers delivering a public service factor the values of the public into their decisions. This is not as easy as it may sound. The value set that 'ought' to be used is not clearly articulated. Policy choices are made not by the citizens themselves, but by those who have some political 'standing' in policy setting (Trumbull, 1990). In addition, multi-cultural societies may have very different value systems in different parts of the population (Inglehart and Carballo, 1997; Inglehart and Baker, 2000). It is argued here that these circumstances can work towards the delivery of inappropriate solutions and public policy failure.

In South Africa the majority of the citizens are from rural African communities, and now represent a significant number of the urban population (Wilkinson, 2000). Migration of rural poor to the cities has created a 'first world', 'third world', dichotomy in urban areas (Mackay, 1999). The provision of a brick house on a freehold plot of land has not always proved to be the appropriate solution to the needs of recipients. One reason is sustainability. The obligation to pay for services each month from low earnings is a problem for some (Huchzermeyer, 2001). Rental property would provide a 'better' solution for the poor with uncertain incomes, as they can then migrate back to their rural homes, between jobs. The government's provision of a once-off capital grant to buy a freehold house fails to acknowledge the life-style of the recipients (Goebel, 2007; Lizarralde and Massyn, 2008).

The political process that gave rise to the current housing policy lacked the involvement of community representatives (Huchzermeyer, 2001). It was assumed that the ANC (African National Congress) filled this role. The ANC, for its part, believed it could better represent the 'masses', and thus avoid their 'exploitation' by other parties involved in the policy setting process. The situation translated 'decent' housing into a basic structure on a freehold plot. This vision fitted the values of the parties to the negotiation, but with no clear view of the beneficiaries' needs or expectations (Jones and Datta, 2000).

Public policy is also impacted in the delivery process. Values held by public servants, and contractors to the public service have a part to play. The distinctive cultures of these different organisations will impact on how specific problems are perceived and addressed (Jorgensen *et al*., 1998). In addition, standards, such as existing building codes reflect value choices made in the past; and are often rooted in colonial history. These values also shape the outcomes of service delivery. In reality South African building standards are not considered excessively onerous and

prevent the sort of urban decay found in some African cities (Mackay, 1999).

The role of local government in South Africa has been limited to a delivery agent due to the inflexible nature of the subsidy policy (Huchzermeyer, 2003). Either the local government or the developer of a housing scheme was expected to engage directly with the local community to decide on precise requirements (Tomlinson, 1999). In practice this meant that communities specified the 'house on a stand' because this is what they knew they could expect. Little effort was made to design solutions better fitted to the local needs (Jones and Datta, 2000; Goebel, 2007).

The concepts described above and illustrated in the South African context suggest that the problems are due to inappropriate values being applied to policy decisions. The factors that need to be considered to address this problem are discussed next.

Decision-making becomes more complex when made by professionals on behalf of their clients (Martin and Schinzinger, 2005). Each individual has a single value system that applies to the self (Rohan, 2000). Each individual also has knowledge of various value models that are appropriate to others; we use these latter sets when making decisions on behalf of other people. However, the construct we hold for others is built up on our own personal values and those that they have expressed (Rohan, 2000).

Measures of project success

To assess value choices, an approach may be to review them for congruence against project success measures. Two research studies of success measures are discussed here. The first of these was developed from data on engineering projects (Shenhar *et al*., 1997). This work identified four different sets of metrics that were relevant at different points in time. During the currency of the project, *execution efficiency* measures were considered most important. Once the project was complete, the *commercial success* and the *impact on customers* became critical measures. As the product matured, the *long term contribution* of the project output to future growth and opportunity was the key criterion used.

A second study looked at construction projects, and aimed to identify client values (Kelly, 2007). The outcomes were project-related metrics of capital, time and the exchange value of the product. Four additional metrics relevant to the product after project completion were identified, these being operating costs, environmental impact, utility to the client and esteem value.

A limitation on the relevance to the current discussion of Shenhar *et al.'s* (1997) work is that it seems closely related to commercial products and may be less relevant to public service decisions. The metrics derived from Kelly's (2007) study were related to the core business of the construction client, however, representing the consensual view of all the players in the value chain.

The way forward

Additional work is needed that looks explicitly at the values of the key players and the beneficiaries of the value chain. The values of local government employees, and other sponsoring parties need to be identified along with those of the beneficiaries.

The values of different stakeholders all have some impact on the final project outcome. The challenge is to find a suitable means of incorporating the value criteria of the different stakeholders into the programme design. Further work is needed in this area to identify exactly what these stakeholders value criteria are and how they can be articulated at the briefing stage of the project. Some can be deduced from publicly available policy and strategy statements but others have to be identified by other means.

Conclusions

From a national housing perspective, no studies explicitly address the overarching public policy goals, nor the values of the end users; in this case the home owners. Of particular relevance is the issue of the sustainability of the arrangement. The policy did not consider the beneficiaries ability to afford service costs incurred by municipalities through rates payments, and longer term their ability to maintain and upgrade the structures provided.

Our conclusion on how to solve the problem is to elicit and articulate the values of local beneficiaries and provide local government with a framework to guide decision-making. Greater sensitivity to differences at a local level would inform the need for a more flexible approach to policy.

References

Albier, M. (2003) Chronic Poverty in South Africa: Incidence, Causes and Policies. *World Development*, **31**(3), 473-490.

Alford, J. (2002) Defining the Client in the Public Sector: A Social-Exchange Perspective. *Public Administration Review*, **62**(3), 337-346.

Bowen, P. A. Pearl, R. Cattell, K. Hunter, K. and Kelly, J. (2007) The role of value management in achieving best value in public sector service delivery in South Africa: a research agenda. *Acta Structilia,* **14**(2), 58-75.

Brown, H. C. (1914) Value and Potentiality. *The Journal of Philosophy, Psychology and Scientific Methods*, **11**(2), 29-37.

Goebel, A. (2007) Sustainable urban development? Low-cost housing challenges in South Africa. *Habitat International*, **31**(3-4), 291-302.

Hanley, N. and Spash, C. L. (1993) *Cost-benefit analysis and the environment*. Aldershot: Edward Elgar Publishing.

Huchzermeyer, M. (2003) A Legacy of Control? The Capital Subsidy for Housing, and Informal Settlement Intervention in South Africa. *International Journal of Urban and Regional Research*, **27**(3), 591-612.

Inglehart, R. and Carballo, E. (1997) Does Latin America Exist? (And Is There a Confucian Culture?): A Global Analysis of Cross Cultural Differences. *PS: Political Science and Politics*, **30**(1), 34-47.

Inglehart, R. and Baker, W. E. (2000) Modernization, Cultural Change, and the Persistence of Traditional Values. *American Sociological Review*, **65**(1), 19-51.

Jones, G. A. and Datta, K. (2000) Enabling Markets to Work? Housing Policy in the 'New' South Africa. *International Planning Studies*, **5**(3), 393-416.

Jorgensen, T. B. Hansen, F. Antonsen, M. and Melander, P. (1998) Public Organizations, Multiple Constituencies, and Governance. *Public Administration*, **76**(3), 499-518.

Kelly, J. Male, S. and Drummond, G. (2004) *Value Management of Construction Projects*. Oxford: Blackwell Publishing.

Kelly, J. (2007) Making client values explicit in value management workshops. *Construction Management and Economics*, **25**(4), 435-442.

Lizarralde, G. and Massyn, M. (2008) Unexpected negative outcomes of community participation in low-cost housing projects in South Africa. *Habitat International*, **32**(1), 1-14.

Mackay, C. J. (1999) Housing Policy in South Africa: The Challenge of Delivery. *Housing Studies*, **14**(3), 387-399.

Martin, M. W. and Schinzinger, R. (2005) *Ethics in Engineering.* Fourth Edition. New York: McGraw-Hill.

Moore, J. S. (1910) The System of Values. *The Journal of Philosophy, Psychology and Scientific Methods*, **7**(11), 282-291.

Morris, P. W. G. (1988) Managing Project Interfaces – Key Points for Project Success, *In*: (Eds) Cleland, D. I. and King, W. R. *Project Management Handbook*. New York: John Wiley and Sons: New York.

Republic of South Africa (RSA) (1996) Constitution of the Republic of South Africa. Government Printer, Pretoria.

Republic of South Africa (RSA) (2000) Local Government Municipal Systems Act. *Government Gazette*, **425**(21776), Government Printer, Pretoria.

Rohan, M. J. (2000) A Rose by Any Name? The Values Construct. *Personality and Social Psychology Review*, **4**(3), 255-277.

Sheldon, W. H. (1914) An Empirical Definition of Value. *The Journal of Philosophy, Psychology and Scientific Methods*, **11**(5), 113-124.

Shenhar, A. J. Levy, O. and Dvir, D. (1997) Mapping the Dimensions of Project Success. *Project Management Journa,*. **28**(2), 5-13.

Simon, H. A. (1997) *Administrative Behaviour: a study of decision-making processes in administrative organizations*. 4th Edition, New York: The Free Press.

Tomlinson, M. R. (1999) From Rejection to Resignation: Beneficiaries' Views on the South African Government's New Housing Subsidy System. *Urban Studies*, **36**(8), 1349-1359.

Trumbull, W. N. (1990) Who Has Standing in Cost-Benefit Analysis? *Journal of Policy Analysis and Management*, **9**(2), 201-218.

Wilkinson, P. (1998) Housing Policy in South Africa. *Habitat International*, **22**(3), 215-229.

Wilkinson, P. (2000) City Profile, Cape Town. *Cities*, **17**(3), 195-205.

HOW FAR A CONTRACT CAN BE STRETCHED? THE FIRST BUILDING BLOCK FOR PROCUREMENT ENGINEERING

Chen-Yu Chang[1]

[1]Bartlett School of Construction and Project Management, University College London, Wates House, 22 Gordon Street, London WC1H 0QB; PH (20) 76794818; FAX (20) 76794818; email: chen-yu.chang@ucl.ac.uk

Abstract

This research is a first attempt to develop the new research field of Procurement Engineering. Just as Earthquake Engineering can instruct us how to design a building in order to mitigate the damages caused by natural uncertainty, Procurement Engineering hopes to offer methods to design project governance in order to reduce the adverse impacts of risk on projects. Just as Earthquake Engineering is founded on the basic law of mechanics that can precisely describe the movement of structural components under different loading conditions, Procurement Engineering needs to develop a fundamental law that governs the interaction between the procurer and the contractor in the face of uncertainty. This research aims to answer this call by first defining the risk-bearing capability of project governance, and second developing a mathematical equation for its measurement. The formal modeling of this concept can inform the design of project governance by integrating contract form, payment mechanism, financing structure of the contractor and choice of procurement systems into a logical coherent framework.

Introduction

How a project should be governed is an essential issue to the success of the project. In its simplest form, project governance is no more than a contract. Contracts provide security to traders in the same sense as buildings provide shelters to people- mitigate damages caused by uncertainties. We have earthquake engineers to assure us of the maximum magnitude of earthquake a building can survive, but we don't have procurement engineers to inform us of the maximum extent of risk exposure a contract can withstand. We know how to design an earthquake-resistant building using the methods of Earthquake Engineering; but we don't have a quantitative approach to enlighten us on how to craft a contract for a specific contracting environment. Earthquake Engineering is built on the fundamental laws of mechanics that are able to predict the movement of structural components under different earthquake impacts, so should Procurement Engineering be founded on the basic economic rules that can govern the interaction between contracting parties and thereby compute the maximum risk exposure a contract can manage. This purpose of

this research aims to lay down the basis for further development of an analytical method for assessing the cost-bearing capacity of a contract.

Contract as a risk-managing tool

The efficacy of contract is treated differently in economic theory. In the Arrow & Debreu world, contract is state-contingent, containing a set of rules that can fully govern all contingencies likely to happen in the course of a transaction [Arrow,1964; Debreu,1959]. The completeness of contract is also implicitly assumed in the influential Principle-Agent theory, where contract is regarded as a costless mechanism for dividing the gains from trade [Laffont & Martimort, 2002]. As everything is foreseen and governed in the contract, the main problem of contract design is reduced to how to achieve incentive compatibility. A theoretical solution to this problem is to induce the informed party to truthfully reveal his/her private information by giving him/her a menu of contracts (schedule of tariffs) to choose from. However, the strong assumption of complete contracting is countered by transaction cost economists who argue contract design should focus on contractual adaptability to unforeseen contingencies at post-contract stage [Williamson,1996]. As we have observed, construction projects are fraught with claims and disputes. For the one-off economic activity, such as a project, *ex post* adaptability should be the focus of analysis in understanding the nature of risk-bearing capability of project governance.

Risk-bearing capacity

Chang (2008a,b) suggests that quasi-rent based reasoning offers a robust theoretical underpinning for explaining the contracting process between the procurer and the contractor of private finance projects and hence holds the potential to form the foundations for Procurement Engineering. On the way to a full-fledged approach, the first theoretical block should be laid on how to evaluate the risk-bearing capacity of a contract. The central question we want to ask is: how much risk a contract can take on without causing it to break down? A straight answer is the level of risk exposure that won't cause any of the traders to opt out in the course of a transaction. Therefore, the issue we are concerned with here is the condition under which a trader would rather terminate than carry on the original deal. The economic concept of quasi-rent is just the answer we are looking for. By definition, quasi-rent is the return required by the traders to stay in the original transaction. The higher quasi-rent held by a trader, the more desirable for her/him to compete the transaction. A positive quasi-rent for all traders therefore offers the ultimate guarantee for the consummation of the transaction. However, negative quasi-rent doesn't always lead to breakup of the contract. To clarify the complications involved, we have to introduce a pair of terms, advantaged and vulnerable party. A trader is said to be vulnerable if his/her quasi-rent is higher than his/her trading party. If both parties have positive quasi-rents, the transaction will continue (Case 1 in Table 1). In contrast, if both parties face negative quasi-rents, neither of them is willing to continue (Case 3). The complication arises when only one party faces negative quasi-rent. If the advantaged party faces a negative quasi-rent, he/she would possibly appropriate a part of the vulnerable party's quasi-rent to bring her own one back to positive (Case 2). Conversely, if the

vulnerable party gets into negative quasi-rent, there is no chance that his/her quasi-rent can be reverted back to positive and thus he/she will choose to pull out, grinding the transaction to a halt.

This discussion implies that we should differentiate two types of risk-bearing capacity:

(1) direct risk-bearing capacity (direct RBC):

This term indicates the upper limit of risk exposure under which none of the traders prefers to opt out. In a bilateral trading scenario, it equals the lower value of quasi-rents held by two traders.

(2) adjusted risk-bearing capacity (adjusted RBC):

When direct RBC is reached, the party on brink of opting out would seek redistribution of quasi-rents, making the contract able to absorb more risks. Normally, the transfer of quasi-rent takes place in subtle ways, such as through charging higher than prevailing market prices in renegotiations. Certainly, only when ungovernable events happen can make this strategy feasible.

Table 1 shows three cases classified according to the quasi-rents of the advantaged and vulnerable party in the context of bilateral trading. Applying two types of RBC to these three cases leads to the following results:

Table 1 Classification of four cases

Quasi-rent Holder		**Advantaged party (QR_A)**	
		+	−
Vulnerable party (QR_V)	+	**Case 1** Transaction continues RBC: QR_A Adjustable RBC: QR_A+QR_V	**Case 2** Transaction may continue RBC: 0 Adjustable RBC: $QR_V - QR_A$
	−	N/A	**Case 3** Transaction terminates RBC: 0 Adjustable 0

Note: QR_A and QR_A indicate the absolute values of these two terms.

Case 1

This is the most common case in construction projects. Contractors enjoy advantages in post-contract negotiation. The maximum risk exposure that the contractor can buffer is no more than QR_A (the contractor's quasi-rent). Any loss exceeding QR_A may drive the contractor to exploit his/her counterparty's weakness (the procurer) up to the point at which the vulnerable party would rather pull out. For example, in most infrastructure projects, the upper limit of quasi-rent that the public procurer would possibly concede should equal the net social benefit the project is expected to generate. As long as the quasi-rent to be appropriated lies within this bound, the government would rather see the project completed than disrupted. In other words, the RBC adjusted for quasi-rent transfer is QR_A+QR_V.

Case 2
In this case, the advantaged party will keep in the transaction if the quasi-rent of the vulnerable party can be transferred to cover his/her negative quasi-rent. In other words, this contract is able to bear no risk (i.e. RBC<0), but, if allowing for appropriation of quasi-rent, the amount of risk that can be accommodated is $QR_V - QR_A$.
Case 3
In this case, both parties fall into negative quasi-rent, meaning that the contract will break up immediately and therefore has no capacity for assuming risk at all.

The standard contracting context in construction projects
In traditional capital project procurement, the procurer retains the contractor to build the project in accordance with design drawing and specifications. As opposed to economic rent that incentivizes the trader to participate in a transaction, quasi-rent is the expected return that keeps the trader in the transaction. It simply equals the expected revenue net of cost from the remaining part of the transaction. Quasi-rent offers a measure for bargaining power of the trader. Of central concern here is the difference in quasi-rent between traders, so quasi-rent for each trader needs to be discussed separately.

The Procurer's quasi-rent
The procurer of a project has to raise the capital needed for construction of the project. As the project reaches milestones, the contractor will get interim payments for the work done, i.e. the procurer's money is gradually converted into physical assets. Now we want to understand how the procurer's quasi-rent changes in the meantime.

Theoretically, the client faces two levels of quasi-rent: on the contract level, it is equivalent to the cost of replacing the original contractor. The client would rather absorb any extra payment below this cost, than switch to an alternative contractor; on the project level, the upper ceiling of acceptable extra payment is the net project benefit of the project (social benefit net of social cost). This value is normally far greater than the replacement cost, implying that there is more buffer in accommodating shocks before getting to the decision of abandoning the whole project. Largely speaking, replacement cost is the binding condition in construction projects and should be the focus of our analysis.

To investigate the evolving path of bargaining power between traders, we need to find the formula for describing the relationship between quasi-rent and time. The question to be answered is: at a point in time at post-contract stage, what price the procurer is willing to pay in order to bring the project forward to the end? Two key components are involved here: re-tender costs and quality premium

The procedure for letting a part-completed project to a replacement contractor is similar to that for a new one. Apart from the cost involved in preparation of documents and the opportunity cost of time spent in the process, duplicate setup of

temporary works on site should be counted as well. These three cost items are largely independent of when the project is re-tendered and can be modeled as a constant (independent of time).

When a project is let through competition, its risks will be fully priced. What interests us is the amount of premium that the procurer should compensate the bidders for taking on the quality risk inherent in the part-completed project. Normally, the disruption of a project is perceived as something wrong, particularly about the quality of work. As a result, potential bidders naturally will charge a premium on this risk (quality premium henceforth). But, the problem is how to find its estimate. In the following section, an attempt will be made to develop a model for measuring quality premium based on a set of plausible assumptions.

Quality premium demanded over the course of the project

Before going into derivation of formula for quality premium, a numerical example can help readers establish an intuitive meaning of this term. Suppose a project worth one million pounds was disrupted and forced to re-tender after half of the project is completed on site. At this point, half-a-million pounds work remains to be done according to the original schedule of rates. Suppose the price that the replacement contractor charges is 0.6 million pounds. The 0.1 million on top of the 0.5 million originally budgeted for is the charge for assuming uncertainty over the quality of the part-completed project.

Assumption 1

Potential bidders for the re-tendered project displays constant absolute risk aversion.

The first step to attack a decision problem is to specify the decision maker's utility function *U*. Several tractable utility functions have been developed in the literature (eg. Goldberg,1987). They differ in the way risk attitudes are treated, i.e. how utility changes with different levels of wealth (W). One of the most commonly used forms is to assume

$$-U''(W) = \alpha U'(W)$$

α is the measure of absolute risk aversion. Solving this differential equation, we can get a general form of

$$U_b = -e^{(-\alpha W)}$$

In our case, W represents the bidder's wealth increase resulting from undertaking the project.

Assumption 2

The quality risk follows a normal distribution and is stationary over time.

The hidden quality defects of the part-completed project would result in an expected loss to the replacement contractor. Assume this risk follows a normal distribution, $N(\mu, \sigma^2)$ and invariant to when the project is re-let (i.e. the assumption of stationarity). The only thing that matters is the size of the part-completed project (*r*), measured by its building costs. This is what we will turn to in the next assumption.

Assumption 3

In pricing the premium for quality risk of the part-completed project, the bidders

only consider the mean and variance of this risk.

The mean-variance model is a well established economics approach in explaining decision behavior under uncertainty. Easy to operate is the main reason why it is popular in the economic literature [Stiglitz,1972]. Using this approach, we want to develop a formula for expressing the premium *P(r)* demanded by the replacement contractor for taking the quality risk. Letland(1972) suggests that, in a standard mean-variance framework, together with the assumption of no entry/no exit, it is easy to derive a well-known result for the premium schedule:

$$P(r) = r\mu + (\alpha / 2)r^2\sigma^2 \qquad (1)$$

This equation indicates that the premium demanded by the replacement contractor depends on the coverage level required (*r*), the bidder's risk preference (α) and two parameters of the underlying quality risk, its mean (μ) and standard deviation (σ).

Assumption 4

The cost for building the part-completed project according to original budget plan is common knowledge to all bidders and the re-tender mechanism adopted can induce bidders to reveal their true costs.

This assumption consists of two parts: the first part assumes that the original estimated cost for the uncompleted part of the project is in the public domain; the second part stipulates that the tender mechanism is efficient enough to induce the bidder to price on the basis of the available information. This is a standard result of the common values model in auction theory (eg. Menezes and Monteiro**,** 2005; Klemperer,2004). It follows that the prices the bidders charge on top of the original cost can be attributed to the premium for quality risk.

Assumption 5

The exposure from quality risk increases with the cost at which the part-completed project is built.

To precisely describe how quasi-rent changes with time, we need to find a way to introduce time dimension into Eq.1. This assumption implies that the coverage of insurance demanded by the replacement contractor equals the size of the project to be let. For ease of exposition, assume *ex ante* completion wipes out the contractor's excess profit, making the procurer's payment just enough to cover the contractor's cost. As the project is progressing on site, increasing quality risk is being buried in the concrete, making the replacement contractor face greater uncertainty and thus demand greater coverage.

Now the problem is how to model the development of project cost over time. Generally speaking, a project starts out slowly, accelerating in the middle and slowing down again in the end. This stylized fact is normally visually captured by an S-curve. Johansson (1979) develops a formula for the S-curve that is easy to implement in empirical investigation. Applying to this study, we can get the relationship between accumulative cost (*C(t)*) and time (*t*) (defined as a proportion of total duration (T)).

$$C(t) = \frac{(1+a)t^b}{1+at^b} \qquad (2)$$

Assumption 4 suggests that risk exposure and hence the coverage demanded increases with the cost of the part-completed project. Setting *C(t) = r(t)* and substituting (2) into (1) will give a full expression for equity premium.

Putting the above discussion together, the procurer's quasi-rent at time t can be expressed as

$$QR_t^p(t) = A + \left\{C(t)\mu + (\alpha/2)C(t)^2\sigma^2\right\} \quad (3)$$

The contractor's quasi-rent

Chang(2008b) derives a general formula for the contractor's quasi-rent (QR_t^c),

$$QR_t^c(t) = (D(t) - C(t)) + (I - S(t)) \quad (3)$$

This equation indicates that the contractor's quasi-rent consists of two elements: (1) the different between the payment received at time t ($D(t)$) and the cost incurred at that time ($C(t)$); (2) value loss of the sunk fixed assets involved in the production of the project (mainly machinery) resulting from its *ex ante* value (I) lower than *ex post* value (S). The first item largely depends on contract form (e.g. lump-sum or cost-plus) and the way interim payments are made; the second item is associated with the ownership of the machinery employed, either self-owned (newly purchased or already owned), or hired from a rental company. The functional form of the contractor's quasi-rent should be discussed in different cases accordingly[1].

Case I: Newly purchased assets

The first case is when fixed assets are purchased and owned by the procurer. The initial value of the physical asset (I) will reduce to S_0 immediately after the asset is delivered at t = 0. The magnitude of value reduction (I-S_0) depends on how much value the assets will lose if switched to an alternative use. Along with the progress of the project, the asset employed will gradually wear down and lose its value in alternative use gradually (see Figure 1(a)).

Case II: Already owned assets

If the contractor has already owned the assets employed, the initial value reduction no longer applies, but the linear reduction over the project period still needs to be considered (see Figure 1(b)).

Case III: hired from a rental company

Construction plant may be hired from rental companies. In this case, the contractor has to pay rental charges. The only thing that matters in determining the contractor's quasi rent is how much loss the contractor will assume if the project is disrupted. Therefore, the loss that should be counted in this case is the compensation for early termination of plant-hire contract. In practice, not all hire contracts include early termination compensation. For those that do, the amount of compensation is relatively small to the total capital value of the project. In principle, compensation slides down as the contract is nearing the end. As a result, a down-sloping line is assumed in Figure 1(c).

[1] It should be noted that Eq.(4) only applies to Case I.

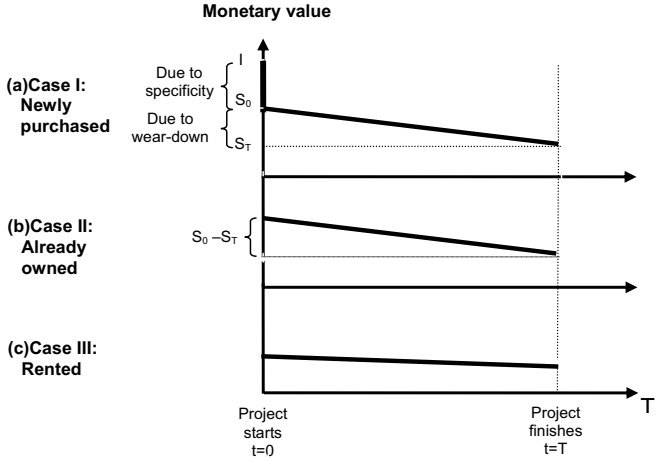


Figure.1 Two Cases for the Contractor's Quasi-Rent

Bargaining power balance

Transaction cost economics, a mainstream approach to analysis of organization, claims that the central tenet of organization management lies in the alignment of governance structures with transaction attributes [Williamson,2005]. The presence of asset specificity would put the investing party in a vulnerable position. The weak bargaining power resulting from lack of outside options would cause the advantaged party to opportunistically exploit the other party's vulnerability. A more balanced distribution of bargaining power between traders can keep the transaction on track. Similarly, in non-cooperative bargaining theory, the strength of bargaining power substantially depends on what outside options a trader has [Binmore,1987; Muthoo, 1995]. Accordingly, it is plausible to argue that the balance of bargaining power between traders is beneficial to maintain the stability of a contractual relationship to a great extent. A precise description of the change in bargaining power balance in terms of quasi-rents help set basis for a full approach for project governance design. From Eq.(3) and Eq.(4), we can find the difference in quasi-rent of the procurer and the contractor,

$$DQR = QR_t^p(t) - QR_t^c(t)$$

$$= \left\{A + C(t)\mu + (\alpha/2)C(t)^2\sigma^2\right\} - \left\{(D(t) - C(t)) + (I - S(t))\right\}$$

This equation reveals that five key components in the design of project governance would possibly find their way into an integrated model.

(1) Contract form and payment mechanism: The combined effect of these two components is reflected in *D(t)*.

(2) Types of procurement systems: If the contractor undertakes the project in the form of high-leverage project company, the sunk investment (*I*) does not have the same lock-in effect as in the high equity funded case. A case in point is the Channel Tunnel Rail Link project (Chang,2008a). Therefore, the effect of capital

structure should be taken into account in the further study.

(3) Attributes of the project: The specificity of physical assets involved in the project affects *I-S(t)*.

(4) DQR is made a function of t to capture the dynamic characteristics of construction contracting.

An Illustrated Example for Three Cases

The easiest way to understand such novel concepts as contained in Table 1 is perhaps through an example. Suppose the revenue of a property development project is just enough to cover its investment cost, say \$100m. Prior to contract signature, none of the two parties expects to receive an excessive profit. To undertake this project, the contractor has to purchase a \$10m machine designed specifically for the project. This machine will lose half of its value if sold to other contractors in the market. By contrast, the procurer's cost for replacing the current contractor is \$10m. Assume this cost is constant over the duration of the project and the effect of payment lag can be ignored. Now we are in a good position to explain when three cases in Table 1 would happen:

(1) Case 1: As the project moves into a point in time at post-contract stage, the contractor will bear a loss of \$5m if the project is not brought to completion. It implies that any cost overrun below \$5m (QR_A) will be absorbed by the contractor. If the procurer issues a significant design change, the extra work is priced \$10m higher than the market price in order to completely appropriate the procurer's quasi rent. Since QR_A now goes up to \$15m, the cost overrun that can be accommodated in the contract rises to this value as well.

(2) Case 2: In slump times, tough competition may result in the contractor taking the strategy of getting the work first and making up loss through variations later. Suppose that, before going into the contract, the contractor's expected loss is \$15m, which will drag the contractor's quasi-rent down to -\$5m ($-QR_A$). In principle, this contract should break down immediately, but, with a quasi-rent transfer of \$10m (QR_V)in sight (assume the same changes happen as in Case 1), the maximum cost overrun the contractor can bear increases to \$5m (QR_V-QR_A).

(3) Case 3: Let's imagine a situation where the economy gets worsening as the project progresses on site. On the one hand, the developer foresees a revenue shortfall of \$10m, which will leave him/her indifferent between switching over to a replacement contractor and abandoning the project. On the other hand, the contractor faces an unfortunate price hike of building materials which pushes up the construction cost by \$5m. Both parties now have no leeway to bear any more adverse impacts.

Conclusions

The analogy of Earthquake Engineering can inspire us on what Procurement Engineering would look like. Just as an earthquake may devastate the wellbeing of human being, uncertainty may pose great threats to market transactions. We need earthquake engineers to tell us how to design a safe structure for a given level of earthquake. Similarly, we also need procurement engineer to instruct us how to design a robust contract for a level of risk exposure. On the way to a full-fledged

approach, the first building block that should be laid down is how resilient a contract is in withstanding risk. This research makes a first attempt to define the meaning of risk-bearing capacity of a contract, and develops a set of formula for measuring it. The formal modeling of this concept can shed light on the outcome of interaction between client and contractor and inform the design of project governance by integrating the principal components of project governance into a single framework.

References

Arrow, K.L. (1964). "The Role of Securities in the Optimal Allocation of Risk-Bearing," Review of Economic Studies, 31, 91-6.

Binmore K. (1987). "The Economics of Bargaining." Basil Blackwell, London.

Chang, C.Y. (2008a). "Understanding The Hold-Up Problem In The Management Of Megaprojects: The Case Of The Channel Tunnel Rail Link." Proc., 2008 Academy of Management Annual Meeting, Anaheim, California, US.

Chang, C.Y. (2008b). "When A Project Company May Break Up? A case study of National Physical Laboratory PFI project." Proc., EURAM 2008, Ljubljana and Bled, Slovenia.

Debreu, G.(1959). "The Theory of Value: An Axiomatic Analysis of Economic Equilibrium." Wiley, New York.

Goldberger A.S. (1987). "Functional form and utility. A Review of Consumer Demand Theory." Westview Press, Boulder, Colorado, US.

J. K. Johansson (1979). "Advertising and the S-Curve: A New Approach." J. Marketing Research, XVI (August), 346-54.

Klemperer, P. (2004). "Auctions: Theory and Practice." Princeton University Press, Princeton.

Laffont J.J. and D. Martimort (2002) "Theory of Incentives: The Principal-Agent Model." Princeton University Press, Princeton.

Leland, H. E. (1974). "Production theory and the stock market." Bell Journal of Economics, 5, 125-44.

Menezes F.M. and Monteiro P.K. (2005) "An Introduction to Auction Theory." Oxford University Press, Oxford, UK.

Muthoo, A.(1995) "On the Strategic Role of Outside Options in Bilateral Bargaining." Operations Research, 292-297.

Stiglitz, J. (1972). "On the Optimality of the Stock Market Allocation of Investment." Quarterly Journal of Economics, 86(1), 25-60.

Williamson, O. (1996) "The Mechanics of Governance." Oxford University Press, Oxford.

Williamson, O. (2005). "The Economics of Governance." American Economic Review, 95(May), 1-18.

EXPLORING THE LEARNING STYLES OF THE CONSTRUCTION PRACTITIONERS IN HONG KONG

Peter S.P. Wong[1], Sai On Cheung[2] and Wally S.W. Lai[3]

[1]Department of Building and Construction, City University of Hong Kong, 83, Tat Chee Avenue, Kowloon Tong, Hong Kong; PH (852) 2194-2309; Fax: (852) 2788-7612; E-mail: spwong@cityu.edu.hk (Corresponding Author)
[2]Department of Building and Construction, City University of Hong Kong, 83, Tat Chee Avenue, Kowloon Tong, Hong Kong; E-mail: bcsoc@cityu.edu.hk
[3]Construction Dispute Resolution Research Unit, Department of Building and Construction, City University of Hong Kong, 83, Tat Chee Avenue, Kowloon Tong, Hong Kong; PH (852) 2823-1823; Fax: (852) 2788-7612; E-mail: jwally1127@yahoo.com.hk

ABSTRACT

There has been strong advocate that through effective inter-organizational learning (inter-OL), construction project efficiency and effectiveness can be improved. In this regard, some researchers recommended exploring the possible ways to facilitate inter-OL. It has been suggested that project team members may have different learning styles that shape how they imbibe knowledge, communicate, solve problems and make decisions. Through understanding the learning styles, members can realize each others' strengths and weaknesses in learning. Thus, appropriate strategies can be adopted for facilitating others' learning. Some researchers have used the Learning Style Questionnaire (LSQ) developed by Honey and Mumford (1982) to measure the learning styles of the individuals. Nevertheless, the reliability of the LSQ in measuring the learning styles of the project team members has yet been examined. This paper reports a study that aims to examine the use of the LSQ in identifying the learning styles of members from two types of firms: the contractor firms and the consultant firms. Data were obtained from a questionnaire survey in Hong Kong and were analyzed by using Cronbach alphas reliability testing, Pearson correlation Analysis and Analysis of Variance. The results suggested that LSQ is reliable in identifying the learning styles of the respondents. Furthermore, the respondents from the consultant firms are found to be flexible in adopting different learning styles to grasp experience and transform it to knowledge. In contrast, respondents from the contractor firms are oriented towards a Reflector learning style when transforming experience to knowledge. This suggests that longer time is needed when actions are required to be taken in response to environmental change.

INTRODUCTION

Inter-organizational learning (inter-OL) can be defined as a process of imbibing knowledge among members from different collaborating firms (Wong and Cheung

2008). In construction, there has been strong advocate that inter-OL is pivotal for sustaining the project performance not only in terms of achieving time, cost and quality targets, but also in terms of generating innovative ideas to fulfill the end-users' demand (Love et al. 2000, Love and Joesphson 2004, Wong and Cheung 2008). Based on a literature review, Love et al. (2000) described that project performance can be improved by an effective inter-OL among the project team members. Through some case studies conducted in Sweden, Love and Joesphson (2004) found that greater project cost saving had been attained by those members who could effectively learn from others. Based on a questionnaire survey conducted in Hong Kong, Wong and Cheung (2008) found a positive effect of the team members' engagement in inter-OL on the project performance improvement.

Nevertheless, fostering inter-OL in construction projects is no easy task. One of the main reasons is that inter-OL is largely achieved through the members from different firms who typically collaborate under a transient nature (Chan et al. 2005). In this connection, project team members may not know each other well, especially at the project inception stage. In this aspect, there have been voluminous studies in the literature exploring the possible ways to facilitate learning among project team members (Newton 1997, Fu et al. 2002). One of the proposed approaches is to enrich the project team members understanding each others' learning styles (Newton 1997, Fu et al. 2002). Learning style can be defined as 'the attitudes and behaviors which determine an individual's preferred way of learning' (Honey and Mumford 1992). Based on a literature review, Newton (1997) described learning styles as the key to understanding people's different approaches to imbibe knowledge, communicate, solve problem and make decisions. By the same token, Fu et al. (2002) pinpointed that the learning styles determine how project team members share experience and respond to others' feedback. Through understanding the learning styles, project team members can realize each others' strengths and weaknesses in learning. Thus, appropriate strategies can be adopted for facilitating others to learn effectively. Lowe and Skitmore (2001) recognized that learning styles affect the ways that project team members learn from others. Nevertheless, they criticized that the project team members typically do not understand each others' learning styles. This inevitably stifles effective inter-OL. In this regard, an instrumental starting point of research would seem to be the exploration of methods to identify the project team members' learning styles. Using a Learning Style Inventory (LSI) developed by Kolb (1976), Lowe and Skitmore (2001) identified the learning styles of the quantity surveyors who have experience in contract price forecasting in northwest England. Based on the collected data from a questionnaire survey, they found that respondents are able to employ various learning styles in tackling difficulties related to construction cost estimation. Having considered the critics about the reliability of the LSI, Newton (1997) employed a Learning Style Questionnaire (LSQ) developed by Honey and Mumford (1992) as an alternative to identify the learning styles of the quantity surveyors in the United Kingdom. Nevertheless, she reminded that her study 'is very much embryonic in nature' and broader investigation on the learning styles of other project team members in construction is suggested (Newton 1997).

While the above studies have provided sound references for the use of some established learning style diagnostic instruments in construction, focus of these studies were seldom placed on understanding the learning strengths and weaknesses of the project team members. Furthermore, the reliability of the learning style diagnostic instruments that were employed in these studies has yet to be examined.

This paper reports a study that aims to examine the use of the LSQ in identifying the learning styles of members from two types of firms: the contractor firms and the engineering and surveying consultant firms. To achieve the research objective, this paper begins by briefly reviewing the concept of learning styles, follows by an introduction of the use of LSQ as the learning style diagnostic instrument in this study. Next, research methodologies for examining the use of LSQ to identify the project team members' learning styles are introduced. Finally, the research findings and the implications thereof are discussed.

THE CONCEPT OF LEARNING STYLES

Early conceptualization of learning styles can be traced back to the work of Kolb (1976) who firstly based on Lewin's (1951) Model of Experiential Learning and conceptualized learning as a continuous cycle with four stages: Concrete experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC) and Active Experimentation (AE) (Figure 1 refers). CE occurs whereby the individuals acquire information openly without bias in accepting new experience. The experiences are then observed in different perspectives and organized by the individuals at the RO stage. At AC, the individuals integrate observations into logically sound principles. The principles are then employed for making decisions and solving problems at AE. As the learning experience is determined by the individual's needs and goals, one can start his learning from any stage of the cycle (Kolb 1985). Furthermore, the four stages of learning are considered mutually supportive and equally important. Thus, none of them is 'fully effective as a learning process on its own' (Honey and Mumford 1992). Nevertheless, Kolb (1976) described that individuals typically have preference on some learning stages over the others. He further described such preference by the use of two bi-polar learning dimensions: Prehension and Transformation (Figure 1 refers).

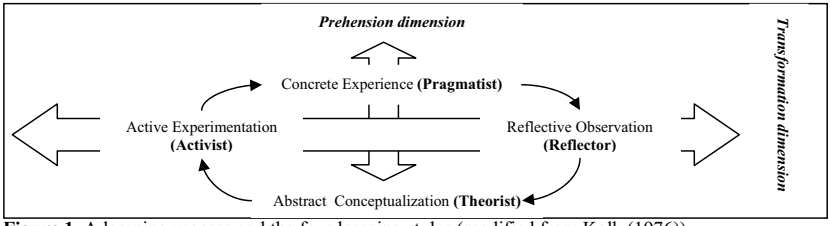


Figure 1. A learning process and the four learning styles (modified from Kolb (1976))

Prehension dimension

Prehension dimension indicates the individuals' preference on grasping experience (Kolb 1976, 1985). Kolb (1976) conceptualized that concrete experience (CE) and abstract conceptualization (AC) are the two dialectically opposed orientations towards grasping experience. CE refers to an emphasis on personal feeling as opposed to thinking. People who prefer CE are open-minded and often base on their intuition to make decision. AC refers to a reliance on logics and theories as opposed to intuition. Kolb (1976) described that an individual who prefer AC is good at 'systematic planning, quantitative analysis and manipulation of the abstract theories'.

Transformation dimension

To transform the grasped experience to knowledge, Kolb (1976) described that individuals have preference on one of these two dialectically opposed forms: reflective observation (RO) and active experimentation (AE). Individuals with greater preference on RO prefer taking actions after considering the reflections from others.

To avoid making mistakes, they may sacrifice opportunities to rectify problems immediately until fully understanding their working partner's reflections. Conversely, people with stronger preference on AE emphasize 'a pragmatic concern with what works as opposed to what is absolute truth' (Kolb 1976). They prefer taking immediate action which consists of potential risk, because their focus is often put to maximizing success instead of concerning others' feelings (Kolb 1976, 1985).

Stemming from his conceptual framework, Kolb (1976) further developed a Learning Styles Inventory (LSI) to measure the learning styles of individuals. The LSI consists of nine sets of four descriptions against which respondents should rank their suitability to describe their learning[1]. Nevertheless, the validity of the LSI was challenged by a number of researchers (Wilson 1986, Ruble and Stout 1991). Criticisms were mainly found in the poor test-retest reliabilities of the scales used in the LSI (Wilson 1986, Ruble and Stout 1991). In this aspect, Honey and Mumford (1982) pinpointed that the reported poor test-retest reliabilities of the LSI may due to the questionnaire design problem. Indeed, the LSI directly asked respondents to express 'how they learn' in a particular situation. Nevertheless, Honey and Mumford (1982) argued that most people do not consider consciously how they learn in real situation. If people were asked directly how they learn prior to inducing them to the continuous learning cycle, they may answer 'just do' and are often incapable of conveying the process they go through. Therefore, it is not expedient to measure learning styles by asking direct questions (Honey and Mumford 1982, 1992).

Having considered the limitations of the LSI, Honey and Mumford (1992) developed a Learning Style Questionnaire (LSQ). Instead of asking direct questions about how people learn, the LSQ consists of questions that review 'what the learner's did' in order to identify the learner's strengths and weaknesses at each stage of the learning cycle as proposed by Kolb (1976). Furthermore, Honey and Mumford (1992) simply described the individual's strengths of a particular stage of the learning cycle as the learning styles. Four learning styles are then proposed: Activist, Reflector, Theorist and Pragmatists.

Activist (individuals with a preference on AE)

People with a preference on AE are described as Activists. They involve themselves fully and without bias in new experiences. They are open-minded, not skeptical, and happy to be dominated by immediate experiences. They are strong in brainstorming ideas and tend to act first and consider the consequences afterwards. They tend to thrive on the challenge of new experiences but are bored with implementation and longer term consolidation. They often appear to be active among teammates. By doing so, they seek to take a dominant role in the team (Honey and Mumford 1982, 1992).

Reflector (individuals with a preference on RO)

Reflectors prefer standing back from pondering experiences and taking improvement actions after considering the reflections from others. They listen to others and get the drift of the discussion before having their own point of view. They prefer analyzing the collected data thoroughly before coming to any conclusion. They are cautious and thoughtful people who like to consider all possible angles and implications before making a move. Their strengths of learning are derived from their ability to consider a situation with different perspectives. Nevertheless, they are often worried by the

[1] A sample of the LSI can be found in Kolb (1976) Learning Style inventory: Technical manual. McBer & Co., Boston.

limitation of time. In case of running out of time, Reflectors may 'make short cuts or do superficial job' as their expediency (Honey and Mumford 1982, 1992).

Theorist (individuals with a preference on AC)
Theorists are good at integrating observations into a complex but logically sound theory. They prefer to address problems through a vertical, step by step, and logical approach. They are keen on analyzing and then generalizing the reasons for success or failure. With this strength, they tend to be perfectionists who won't rest easy until things can be fitted into a rational scheme. Theorists prefer maximizing certainty and feel uncomfortable with subjective judgments and anything flippant. They are comparatively weak in making decision in face of a hotchpotch of alternative methods that they do not familiar with (Honey and Mumford 1982, 1992).

Pragmatist (individuals with a preference on CE)
Pragmatists are keen on trying out ideas, theories and techniques to see if they work in practice. They positively search for new ideas and take the first opportunity to experiment with applications. They like to act quickly and confidently on ideas that attract them. They are essentially practical, down to earth people who like making practical decisions and solving problems. Nevertheless, Pragmatists tend to be impatient with ruminating and open-ended discussions. They have low motivation to sustain learning when the immediate effect is not apparent or the benefits received are less than perceived (Honey and Mumford 1982, 1992).

LSQ has been described as a better diagnostic instrument to identify the learning styles of individuals by many researchers (Duff and Duffy 2002). A number of studies have validated the use of LSQ to probe the individuals' relative strengths and weaknesses of learning (Rodwell 2005). Based on a review of various studies using LSQ, Duff and Duffy (2002) reported a high internal consistency of the results produced by LSQ. By conducting a Cronbach alphas reliability testing, Rodwell (2005) found that the questions asked are reliable for use in identifying the four types of learning styles. In this study, LSQ is adopted for identifying the learning styles of the project team members from the contractor firms and the engineering and surveying consultant firms.

LEARNING STYLE QUESTIONNAIRE (LSQ)
LSQ has 40 statements that described how an individual learn[2]. Respondents are required to circle whether they agree or disagree with these statements. A score of '1' would be given to a statement circled 'Agree' and a score of '0' to a statement circled 'Disagree'. Each of the four learning styles was assessed by 10 statements. (i.e. a maximum score of 10 represents the highest degree of an individual's preference on a particular learning style) (Honey and Mumford 1992). The statements and the respective learning styles they intend to assess are presented in Table 1. In this study, respondents were asked to express their agreement (or disagreement) of the statements to describe their behaviors when working with other project team members.

TESTING THE RELIABILITY OF LSI
Previous studies in construction seldom examined the reliability of using LSI to identify the learning styles of the project team members (Newton 1997). In this aspect, researchers from other research fields applied two methods to test the

[2] There are two versions of the Learning Styles Questionnaire. The original version consists of 80 questions in which each of the four learning styles are assessed by 20 items (Honey and Mumford 1992). By using more concise wordings in describing learning styles, the total question number of the revised version of LSQ is reduced to 40. 10 instead of 20 questions are used to assess each of the four learning styles (Honey and Mumford 2000).

reliability of LSI: Test of internal consistency and Test of construct validity (Zywno 2003). Internal consistency refers to the extent of homogeneity of a set of questions in measuring the underlying construct (Zywno 2003). A method typically used for evaluating the internal consistency is Cronbach alphas reliability testing (Zywno 2003, Rodwell 2005). The Cronbach alphas coefficient falls within the range from 0 to 1. The higher the coefficient value, the greater the internal consistency of the set of questions in measuring the underlying constructs. A value from 0.6 to 0.7 is regarded as 'sufficient' and a value higher than 0.7 is regarded as 'good' internal consistency (Sharma 1996). Construct validity refers to the extent to which a set of questions actually measures the characteristic that it purports to measure (Zywno 2003). Based on the work of Kolb (1985), learning styles are expected to influence the individuals' attitudes in considering improvement action in the following aspects:

- The higher the Prehension score [i.e. Theorist (AC) minus Pragmatist(CE)], the greater the individual's preference on certainty of project conditions;
- The lower the Prehension score, the greater the individual's preference on practical rather than theoretical deliberations when considering improvement actions;
- The higher the Transformation [i.e. Activist (AE) minus Reflector (RO)] score, the greater the individual's preference on expedition rather than precision when considering improvement actions;
- The higher the Transformation score, the greater the individual's preference on accepting immediate improvement actions suggested by others;
- The lower the Transformation score, the greater the individual's preference on considering reflections before jumping to decision of improvement action.

Zywno (2003) suggested that Pearson Correlation analysis can be used to examine the effect 'of presumed measure of the construct on some behavior that it is hypothesized to underlie'. In other words, a significant correlation between the construct and the anticipated behavior represents the validity of the measure (Felder and Spurlin 2005). Based on the work of Kolb (1985), the anticipated effect of learning styles on the individuals' attitudes on improvement actions are summarized in Table 2. In this study, the reliability of use of LSQ in identifying the learning styles of the project team members was examined by using the Cronbach alpha reliability testing and the Pearson correlation analysis. The applications of the Cronbach alphas reliability testing and the Pearson correlation analysis within this study were executed by using the Statistical Package for Social Sciences (SPSS) - Version 11.0.

	When I work with other project team members	Learning style
Q1	I often take reasonable risk, if I feel it is justified.	Activist
Q2	I tend to solve problems using a step-by-step approach.	Theorist
Q3	I have reputation for having a non-nonsense direct style.	Pragmatist
Q4	I often find that actions based on feelings are as sound as those based on careful thought and analysis.	Activist
Q5	The key factor in judging a proposed idea or solution is whether it works in practice or not.	Pragmatist
Q6	When I hear about a new idea or approach I like to start working out how to apply it in practice as soon as possible.	Pragmatist
Q7	I like to follow a self-disciplined approach, establish clear routines and logical thinking patterns.	Theorist
Q8	I take pride in doing a thorough, methodical job.	Reflector
Q9	I get on best with logical, analytical people and less well with spontaneous, 'irrational' people.	Theorist
Q10	I take care over the interpretation of data available to me, and avoid jumping to conclusions.	Reflector
Q11	I like to reach a decision carefully after weighing up many alternatives.	Reflector
Q12	I am attracted more to new, unusual ideas than to practical ones.	Activist
Q13	I dislike situations that I cannot fit into a coherent pattern.	Theorist
Q14	I like to relate my actions to a general principle.	Theorist
Q15	In meeting I have a reputation of going straight to the point, no matter what other feel.	Pragmatist
Q16	I prefer to have as many sources of information as possible - the more data to consider the better.	Reflector
Q17	Flippant people who don't take things seriously enough usually irritate me.	Theorist

Q18	I prefer to respond to events on a spontaneous, flexible basis rather than plan things out in advance.	Activist
Q19	I dislike very much having to present my conclusions under the time pressure of tight deadlines, when I could have spent more time thinking about the problem.	Reflector
Q20	I usually judge other people's ideas principally on their practical merits.	Pragmatist
Q21	I often get irritated by people who want to rush headlong into things.	Reflector
Q22	The present is much more important than thinking about the past or future.	Activist
Q23	I think that decisions based on a thorough analysis of all the information are sounder than those based on intuition.	Reflector
Q24	In meeting I enjoy contributing ideas to the group, just as they occur to me.	Activist
Q25	On balance I tend to talk more than I should, and ought to develop my listening skills.	Activist
Q26	In meeting I get very impatient with people who lose sight of the objectives.	Pragmatist
Q27	I enjoy communicating my ideas and opinions to others	Activist
Q28	People in meetings should be realistic, keep to the point, and avoid indulging in fancy ideas and speculations.	Pragmatist
Q29	I like to ponder many alternatives before making up my mind.	Reflector
Q30	Considering the way my colleagues react in meetings, I reckon on the whole I am more objective and unemotional.	Theorist
Q31	At meetings I'm more likely to keep in the background, than to take the lead and do most of the talking.	Reflector
Q32	On balance I prefer to do the listening rather than the talking.	Reflector
Q33	Most times I believe the end justifies the means.	Pragmatist
Q34	Reaching the group's objectives and targets, should take precedence over individual feelings and objections.	Pragmatist
Q35	I do whatever seems necessary to get the job done.	Pragmatist
Q36	I quickly get bored with methodical, detailed work.	Activist
Q37	I am keen on exploring the basic assumptions, principles and theories underpinning things and events.	Theorist
Q38	I like meetings to be run on methodical lines, sticking to laid down agenda, etc.	Theorist
Q39	I steer clear of subjective or ambiguous topics.	Theorist
Q40	I enjoy the drama and excitement of a crisis.	Activist

Table 1. Learning styles that the questions from the LSQ assessed

The respondent's degree of agreement of the following statements when considering improvement actions:	**Prehension [Theorist (AC) minus Pragmatist(CE)] score**	**Transformation [Activist (AE) minus Reflector (RO)] score**
I found it difficult to consider improvement actions when the project condition is uncertain, disorder and ambiguous.	Positive Correlation	
Practicality is more important than theoretical support	Negative Correlation	
Expedition is more important than precision		Positive Correlation
I prefer accepting immediate improvement actions suggested by others		Positive Correlation
I prefer considering reflections from all collaborating parties before reaching a decision to decision of improvement action		Negative Correlation

Table 2. The anticipated effect of learning styles on the individuals' attitudes on improvement actions

DATA COLLECTION

Data was collected by way of questionnaire. The questionnaire designed for this study consists of three parts. Part 1 includes questions designed to solicit the respondents' demographic information. Part 2 of the questionnaire consists of the 40-item LSQ developed by Honey and Mumford (2000). Respondents were asked to indicate his agreement of the 40 statements as shown in Table 1 for identifying the learning styles. Part 3 of the questionnaire contains 5 statements. Respondents were asked to assess the degree of agreement of the 5 statements (as shown in Table 2) on behavior towards improvement actions by using a seven-point likert scale (from 1:"Strongly Disagree" to 7: "Strongly Agree"). In this study, the targeted respondents were randomly selected from the contractor, engineering consultant and surveying consultant firms which are listed in the latest edition of the Hong Kong Builders' Directory (Far East Trade 2003), and the official webpage of the Hong Kong Institution of Engineers (HKIE) and the Hong Kong Institute of Surveyors (HKIS). They are directors, project managers and professional grade staffs. A total of 380 questionnaires were sent to the identified respondents by post or fax. A total of 111

usable responses were used in the analysis (Table 3 refers). The valid response rate, therefore, is 30.0%. Similar research studies about identifying learning styles of the quantity surveyors conducted by Lowe and Skitmore (2001) were based on 84 responses (equivalent to 45% of the response rate). Easterby-Smith *et al.* (2000) suggested that a reasonable response rate of a questionnaire surveys study conducted in construction industry is around 25%-30%. Thus, the both sample size and response rate in this study are considered reasonable.

	No. of questionnaire sent (No.)	No. of valid responses (No.)	% received
Consultant firms	250	72	28.8%
Contractor firms	120	39	32.5%
Total	370	111	30.0%

Table 3. The Response rate

THE RESULTS

Reliability of the LSQ

In order to ensure the extent of homogeneity of the four sets of questions in identifying learning styles, internal consistency has to be checked. Cronbach alphas reliability testing was conducted in this connection. The results are presented in Table 4. The Cronbach alphas coefficient values ranged from 0.74 to 0.81. The results indicate a good internal consistency of the sets of questions used in the LSQ for identifying the learning styles (Lowe and Skitmore 2001).

Pearson correlation analyses were used to examine the effect of the learning dimensions on the individuals' attitudes in considering improvement actions. The results are shown in Table 5. Significant correlations were found between the Prehension dimension and the individuals' attitudes on (i) project certainty ($r=0.73$ at $\rho<0.01$) and (ii) practicality vs theoretical support ($r=-0.67$ at $\rho<0.01$). The findings are compatible with Kolb's (1976) assertion that individuals with high Prehension dimension score prefer maximizing certainty and seeking theoretical support rather than practical deliberations when grasping experience. Furthermore, the Transformation dimension score was found to have significant relationship with the individuals' attitudes on (i) expedition vs precision ($r=0.64$ at $\rho<0.01$), (ii) taking immediate responses ($r=0.65$ at $\rho<0.01$), and (iii) considering others' reflections ($r=-0.77$ at $\rho<0.01$). The findings echo with Kolb's (1976) descriptions about the learning attitudes of the individuals with different Transformation scores. As a positive Transformation score represents a preference of Activist over Reflector learning styles, the respective individuals typically prefer taking immediate actions before thorough consideration of others' opinions. The results obtained from the Pearson correlation analyses revealed that the questions in the LSQ can sufficiently be used for identifying the learning styles it purports to identify (Zywno 2003). As such, LSQ is considered as a reliable tool for identifying the learning style of the project team members from the contractors and the engineering and surveying firms in this study.

Learning style	Respective questions designed for identifying learning styles	Cronbach alpha coefficient value
Theorist	Q1, Q4, Q12, Q18, Q22, Q24, Q25, Q27, Q26, Q40	0.78
Pragmatist	Q8, Q10, Q11, Q16, Q19, Q21, Q23, Q29, Q31, Q32	0.74
Activist	Q2, Q7, Q9, Q13, Q14, Q17, Q30, Q37, Q38, Q39	0.81
Reflector	Q3, Q5, Q6, Q15, Q20, Q26, Q28, Q33, Q34, Q35	0.74

Table 4. Internal consistency of the sets of questions to identify learning styles

Attitudes toward improvement action	Prehension	Transformation
I found it difficult to consider improvement actions when the project condition is uncertain, disorder and ambiguous	0.73*	-0.04
Practicality is more important than theoretical support	-0.67*	0.39
Expedition is more important than precision	-0.29	0.65*
I prefer accepting immediate improvement actions suggested by others	-0.24	0.64*
I prefer considering reflections from all collaborating parties before reaching a decision to decision of improvement action	0.26	-0.77*

* Correlation is significant at the 0.01 level (2-tailed)

Table 5. Pearson correlation of the respondents' attitudes toward improvement action and the learning dimension scores

Learning styles of the respondents

The mean scores of the learning styles and dimensions of the two groups of respondents are summarized in Table 6. To investigate whether the learning style preferences of the two groups of respondents are different, the group means of the learning style and dimension scores were compared by the use of Analyses of Variance (ANOVA). The results indicate that the respondents have high mean scores on Theorist (Mean= 7.39, S.D. =1.97) and Pragmatist (Mean= 7.04, S.D. =1.59) learning styles. The Prehension score is thus close to 0 (Mean= 0.34, S.D. =2.41). This represents a strong preference of the respondents in utilizing both Theorist and Pragmatist learning styles when working with others in a construction project. No significant difference in mean scores was found between groups in these items.

Theorist is considered the polar opposite of Pragmatist in the Prehension dimension (Kolb 1976). Honey and Mumford (1992) described that people with strong preference on the pair of polar opposite learning styles as the 'all-round' learners who can be benefited from a wide range of learning opportunities. The results of this study seems indicating that the respondents are flexible in grasping experiences from other project team members. Such flexibility is vital for sustaining an effective coordination among firms, especially for those who often need to cope with the project uncertainties (Astin et al. 2006).

	Contractors		Consultants		Overall		ANOVA	
Learning style	Mean	S.D.	Mean	S.D.	Mean	S.D.	F-value	Sig.
Theorist	7.41	1.62	7.37	2.15	7.39	1.97	0.13	0.91
Pragmatist	6.65	1.35	7.26	1.69	7.04	1.59	3.81	0.06
Activist	4.70	2.07	5.91	2.07	6.13	2.14	9.01	0.003*
Reflector	7.15	1.89	7.14	1.86	7.14	1.87	0.00	0.98
Learning dimension								
Prehension	0.76	2.19	0.11	2.51	0.34	2.41	1.80	0.17
Transformation	-2.44	3.08	-0.22	3.12	-0.85	3.15	8.84	0.06

* Significant at the 0.01 level (2-tailed)

Table 6. The learning style preferences of the project team members from the contractors and engineering and surveying consultant firms

Nevertheless, with regard to the prevalence of the two learning styles: Activist and Reflector in the Transformation dimension, the respondents showed a stronger preference on the Reflector learning styles (Table 5 refers). This yielded a negative Transformation dimension score (Mean= -0.85, S.D. =3.15). In particular, a significant difference ($F=4.14$ at $\rho<0.05$) is found between the mean Activist scores of the contractor group (Mean= 4.70, S.D. =2.07) and the consultant group (Mean= 6.91, S.D. =2.07). As Honey and Mumford (1992) described, individuals who gravitate towards the Reflective learning styles are good at listening to others' opinion and prefer taking thoughtful approach in their operations. The respondents' preference towards the Reflector learning style appears to be associated with their roles played in a construction project. Being charged to design and manage the

`

construction project, engineers and surveyors should be 'good listeners' in fulfillment of the client's demands. Furthermore, having considered the low profit margin and the liability to building qualities and delay, contractors have to be thoughtful and cautious when deliberating actions in response to the clients' and consultants' instructions.

Despite individuals with a preference on the Reflector learning style are good at listening others' reflections, they also have weakness in taking prompt action to cope with the change of demand (Honey and Mumford 1992). In this aspect, the high Activist score of the respondents from the consultant group may imply the ability of the engineers and surveyors to mitigate such weakness through utilizing the Activist learning style. Nevertheless, a comparatively low Activist score is found in the contractors' group. This may help to explain why the contractors have been criticized as being incapable of solving unprecedented problems and slow in responding to the client's and consultants' feedback (Wong and Cheung 2008). A practical approach to rectify this problem is to help the contractors to tackle with their learning weaknesses. Honey and Mumford (1992) suggested that by providing tangible data or feedback, Reflectors' performance evaluation process can be accelerated. In this aspect, a number of construction researchers echoed this sentiment by developing various Performance Measurement Systems with which feedback sharing among the project team members can be formalized and systematized (Wong and Cheung 2005, 2008).

LIMITATIONS AND RECOMMENDATIONS

The data for the study was collected in Hong Kong and therefore findings are subjected to this locality factor. In addition, a greater sample size would enhance the authenticity of the findings. It is suggested that exploring methods to tackle the learning weaknesses associated with the contractors' preference on the Reflector learning style would be an amicable topic for further study.

CONCLUDING REMARKS

The use of LSQ for identifying the learning styles of contractors and the engineering and surveying consultant firms was investigated in this study. Data was collected from a questionnaire survey and analyzed by using Cronbach alpha reliability testing, Pearson correlation analysis and Analysis of Variance. The findings suggested that the LSQ is a reliable tool for identifying the learning styles of the respondents. Furthermore, the results indicated that project team members from both contractors and consultants' group are flexible in adopting different learning styles to grasp experience. Nevertheless, regarding transforming the grasped experience to knowledge, respondents from the contractor firms displayed an imbalanced preference of utilizing Activist and Reflectors learning styles. Their orientation towards the Reflector learning style appears to be helpful in explaining why some contractors are less responsive in taking action in response to the change of the clients' requirement. Learning weaknesses associated with the preference of the Reflector learning style can be tackled by providing tangible feedback to facilitate a speedy performance evaluation process.

REFERENCES

Astin F., Closs S.J., and Hughes N. (2006) "The self-reported learning style preferences of female Macmillan clinical nurse specialists." Nurse Education Today, 26(6), 475-483.

Chan P., Cooper R. and Tzortzopoulos P. (2005) "Organizational learning: conceptual challenges from a project perspective." Construction Management & Economics, 23(7), 747-756.

Duff A., and Duffy T. (2002). "Psychometric properties of Honey and Mumford's learning styles questionnaire" Personality and Individual Differences 33(1), 147-163.
Easterby-Smith M., Crossan M., and Nicolini D. (2000) "Organisational learning: Debates past, present and future." Journal of Management Studies, 37(6), 783-796.
Far East Trade (2003) "Hong Kong Builder Directory." Far East Trade Press (No. 35), Hong Kong.
Felder R., and Spurlin J. (2005) "Applications, reliability and validity of the index of learning styles." International Journal of Engineering Education 21(1), 103-112.
Fu, W.K., Drew, D.S., and Lo, H.P. (2002). "The effect of experience on contractors' competitiveness in recurrent bidding." Construction Management and Economics, 20(8), 655-666.
Honey P., and Mumford A. (2000) "The Learning Styles Questionnaire: 80-item version." Peter Honey Publications Ltd., Berkshire, UK.

`

INTEGRATING UNCERTAINTY MANAGEMENT IN STRATEGIC PLANNING PRACTICE

Robby Soetanto[1] and Andrew R.J. Dainty[2]

[1] Department of Built Environment, Coventry University, Coventry, CV1 5FB, United Kingdom; e-mail: Robby.Soetanto@coventry.ac.uk

[2] Department of Civil and Building Engineering, Loughborough University, Leicestershire, LE11 3TU, United Kingdom; e-mail: A.R.J.Dainty@lboro.ac.uk

Abstract

Despite competing in highly turbulent and competitive industry, evidence suggests that construction firms have not put sufficient emphasis on strategic planning. Further, the practice of strategic planning in construction is dominated by informal and sporadic approaches/ processes, which rely heavily on the subjective judgement of top management and tacit knowledge of individuals involved. Literature indicates that the identification of possible risks and opportunities is the most critical in this process, but little guidance is available with regards to the most effective approaches in dealing with the inherent characteristics of strategic planning. A review of underlying aspects (including decision theory, cognitive and behavioural psychology) is presented with a view of developing a framework for improving this process in a construction firm. The framework attempts to engage stakeholders and capture both explicit and tacit knowledge in the strategic thinking for organisational learning. The framework is viewed as a better alternative to the top-down approach of strategic decision making in the construction industry. Benefits from adopting such an approach and future direction of research in this area are then discussed.

Introduction

Thinking about and planning for the future is an integral part of human life. An example of its simplest form is the plans that most people make in the early morning, when they think about their activities for the day. For business, future plan guides current activities/ actions and enables business entities to prepare for the future and achieve the intended objectives. A critical activity of developing a future plan is indeed a complex exercise, largely due to various uncertainties, which inevitably present during the decision making process. There are inherent uncertainties over which environment external to the firms may play out, as well as internal uncertainties within the firms. As the creator of the plan, the stakeholders of the firm also impose a degree of 'unknown' to the process due to their individual perception of future uncertainty and the manner with which they articulate their perception to others within the group. It is therefore critical that their underlying pre-conception of

thinking about the future is well understood for enhancing the process and output of the future plan.

Construction is well known for highly dynamic and competitive sector in which firms have to operate. Greater preoccupation of 'getting the job done' and 'winning the next project' may have denied construction firms for thinking strategically for their future. The lack of strategic thinking is further exacerbated by the prevalence of small construction companies in the sector. Inadequate resource capacities, fierce competition and the transient nature of construction employment often results in smaller companies struggling to survive, let alone plan for the long term. Although there is little capacity for strategic planning and little emphasis on the need for long-term planning, greater emphasis on 'sustainability' has underlined the importance of thinking longer term for survival and competitiveness. Indeed, it is prudent that construction firms equip themselves with appropriate skills and well-developed approaches that are required for thinking about the future.

Thinking longer-term future demands exploration of intuition and creativity within the mind of individuals and organisational stakeholders. The processes of strategic decision making have remained under-explored. Based on review of literature in relevant domains, this paper attempts to enhance understanding of thinking about future uncertainties as experienced by individuals and firms (as a group), in relation to their identification of risks and uncertainties. An activity framework for enhancing the process is then proposed. The aim of the framework is not to present well-defined steps and analytical formulae for developing strategic plan, but to facilitate effective and efficient mobilisation of organisation capitals in a quest to learn about the future. First, a review of strategic planning and its practice in construction is presented. Then, the concept of uncertainty, risk and opportunity is described with particular focus on the human factors involved in the process. A conceptual model of individual and collective perception of the future is developed and explained. Proposed framework is finally presented. The paper is concluded with a presentation of how this framework may be compared with the existing common process, and identification of research areas to harnessed the understanding (or the lack of it) of this subject domain.

Strategic planning: a process perspectives

The lack of emphasis on strategic planning in construction relative to other sectors has been established by many scholars (Chinowsky and Meredith 2000, Price 2003, Dansoh 2005). As a project-based industry, greater focus has traditionally been expended upon shorter-term, operational and tactical planning to execute projects (Chinowsky and Byrd 2001, Dansoh 2005). Often, strategic planning process may be unstructured, non-routine, non-repetitive, and more complex than operational planning (Junnonen 1998). In a survey of strategic management practice of US major contracting and design firms, Chinowsky *et al*. (2000, 2001) concluded that firms generally emphasised on technology and its integration for knowledge transfer, and awareness of the need for market expansion, whilst they put less attention to long-life education for middle and upper-level employees and lack understanding of securing

their competitive advantage and of financial instruments for achieving long-term objectives. This suggests little long-term investment in human capital and organisation learning for developing 'future-proof' organisations.

Recently, Soetanto *et al*. (2007) conducted a questionnaire survey of construction directors and managers to explore current strategic planning practices in construction organisations in the UK. The findings indicate that strategic planning is an informal process relying on personal experience and intuition. For some, planning longer-term seems difficult given the way construction order is made. This confirms the belief that construction is dynamic, highly turbulent, rapidly changing industry and therefore a low level of strategic planning (Price and Newson, 2003). Most respondents used fairly simple tools, such as SWOT and competitor analyses; few exercised 'what-if' analysis within top management circle. The approaches tended to be 'top-down' in orientation, where senior managers determined the company strategic plan and then they communicated this to staff. This policy could potentially negate innovative ideas which may emerge from staff at the lower levels within the management hierarchy. The majority had a fairly shorter-term orientation to the future and admitted to having experienced external events that had changed the course of their plan. In an in-depth case study of medium-size contractor, Green *et al*. (2008) suggested that strategy is a collective endeavour by a loosely defined group of organisation members. The members shape strategy through their actions rather than through any formal plan, within social and physical context of the organisation. Further, they found no evidence to suggest that formal strategic planning have any significant influence on the enacted strategy. Although based on only one historical case study, the work has nevertheless elaborated the idiosyncratic process by which construction firm interacts with its environment and reconfigures resources and capabilities over time.

Strategic process

In construction, a number of scholars have developed formal methodological procedures and processes for helping firms doing strategic planning. Warszawski (1996) adopted a problem-solving approach of system analysis, for developing a strategic planning procedure. Venegas and Alarcon (1997) proposed a framework, which provides a structured procedure and tools to carry out the strategic planning process. Using case studies of large construction organisations, Price (2003) developed a conceptual framework for strategic management process, which serves as a flexible guidance for firms to develop their own bespoke framework. Such a framework provides a checklist while at the same time, emphasises the need to accommodate flexibility and creativity (Price and Newson, 2003). These methodologies have their merit for providing formal guidance for strategic planning process and ensuring appropriate outcome of the process. Here, planning aided by the rationally-derived methodologies may be closely associated with shorter time horizon and within relatively stable environment where many parameters influencing the efficacy of the plan are known. In reality, Minztberg (1994) and Junnonen (1998) argued that formation of strategy in a highly turbulent, uncertain and competitive environment as in the construction sector often takes place as an emergent (rather

than deliberate) and iterative process within the firm, resulting from social interactions involving various activities.

In strategic decision-making process, political behaviour and intuitive synthesis provide alternatives to the rational procedure, to explain the manner in which organisations actually make strategic decisions (Elbanna, 2006). The rationality paradigm attempts to adopt analytical approach to develop strategies which are logical and backed up with evidence in pursuing corporate goals. In practice, this paradigm are often hindered by cognitive limitation of the decision makers (i.e. bounded rationality), complexity of the problem, conflict among decision maker, and non-linearity of the actual strategic process, resulting in lack of consensus on the relationship between rational process and achievement of corporate objectives (Elbanna, 2006). Political paradigm studies how individuals with differing interests attempt to influence the outcome of the strategic decision process to their favour through the use of political tactics such as coalition formation, negotiation or bargaining, the use of power. The role of intuition is recognised when managers have to make quick decisions based on incomplete information, in a highly complex and dynamic environment. Hence, the decisions made are difficult to explain rationally, or the managers are unable to articulate rational reasons for taking a particular decision. Indeed, Henden (2004) found that top managers put more emphasis on intuition (rather than rational analysis) in strategic thinking and foresight. Elbanna (2006) argued that strategic planning is characterised by a combination of rational, political and intuition synthesis. The interplay between these will exert significantly influence upon the perception of strategic issues, uncertainties and risks, and communication of this perception amongst organisation members in the formation of strategy.

In sum, the practice of making strategy has little resemblance to the 'strategic planning' as a formal, purely rational and structured process, but more of a process of 'strategic thinking' within the mind of organisation members. The manner by which organisation members perceive the future (and its associated uncertainties and risks) and mobilise this perceptive thinking (specifically, in terms of cognition and intuition) in the formulation of strategy is indeed little understood. The literature has also suggested that managers rely heavily on intuition in corporate strategic thinking, which is characterised by high degree of uncertainty and ambiguity (Sadler-Smith and Shefy 2004). Further, there seems to be little belief upon the merit of engaging and mobilising human capitals in strategic thinking. Implementing strategy requires a great deal of support and commitment from organisational members who will be affected (either negatively or positively). It is therefore critical that members of the organisation are involved in the strategic process. Review of individual and group perception of uncertainty and risk are described as follows.

Uncertainty, risk and opportunity

Discourse about the future and uncertainty is commonly associated with risk (Tonn *et al*. 2006). Risk can be taken to mean an uncertainty that influence the achievement of objectives (Hillson and Murray-Webster 2005). The term 'risk' is often associated

with adversity or threats to an entity. Although there are conflicting views upon the definition of risk and what constitutes risk in risk management literature, some scholar have realised the need to treat opportunities (the up-side of risk) in an equal footing as threats (the down-side of risk). The reason is simply that threat and opportunity are seldom independent (Ward and Chapman 2003), and an event may be a threat and at the same time opportunity for an entity or different parts of an entity.

Managing risk generally involves activities of identifying, assessing, responding and monitoring the risks (Cooper *et al*. 2005). Early literature suggests heavy reliance on intuition, judgement, experience in managing construction risks (Akintoye and MacLeod 1997) and the need to accommodate this 'softer' aspect for effectiveness (Mak 1995). Nevertheless, the research on the operationalisation of this aspect in practice is scant. Identification of risks and opportunities is the first and most important stage in the process because uncertainties which have not identified, can not be managed (Maytorena *et al*. 2007). Despite many techniques for identifying uncertainties, brainstorming session is seen as the preferred approach if there is little previous experience and information (Cooper *et al*. 2005). In contrast to the other activities, identification session is characterised by high degree subjectivity, heuristic, bias, intuition, utilising tacit knowledge of individuals and groups. In this case, there is little understanding on how individuals imagine uncertainties (over future events) and perceive these as risks or opportunities, and how these perceptions are communicated and mobilised within the group. What is the role of emotion and politics in the process? How are perceptions of uncertainty shaped by the interaction of individual members of a group?

A conceptual model for enhancing understanding of this phenomenon is presented in Figure 1. The model was developed based on an in-depth review of empirical research in perception of risk (e.g. Slovic 2000), decision making under uncertainty (e.g. Tversky and Kahneman 1974, Sadler-Smith and Shefy 2004, Miller and Ireland 2005), risk attitude of individual and group (e.g. Hillson and Murray-Webster 2005). The model postulates two levels of analysis, namely individual and group levels. Perception of uncertainty and identification of risks and opportunities at group level can be considered as the composite of those at individual level, although this does not mean that they are equal to the sum of those at individual level (Hillson and Murray-Webster 2005). The model identifies factors which may influence the way the future is perceived and the identification of risks and opportunities arising from plausible future events. It is understood that perceptions of the future may be influenced by numerous factors, but the model suggests salient factors as identified by previous scholars. In a certain situation, the factors may independently influence the perception, however, a combination of factors is expected in most circumstances to exert their influence on perception, on an equal or non-equal basis (where one factor is more dominant than others). Also the factors may influence each other, e.g. culture and value. As a consequence, it could be difficult to identify influencing factors definitively from an expressed perception and behaviour.

At individual level, the perception of the future is a product of heuristics, intuitions, affective, value, and other socio-political and cultural factors. Some consider heuristics and intuition as a common term, but here they are differentiated as intuitions can include heuristics. Heuristics can be a source of biases for the intuitions. In their seminal work, Tversky and Kahneman (1974) first coined the operationalisation of heuristics of thinking under uncertainty. Their proposed heuristics are still adopted in recent researches in decision making and risk (e.g. Hillson and Murray-Webster 2005). The heuristics are commonly subsumed under availability, representativeness, anchoring and adjustment, and confirmation trap (see Hillson and Murray-Webster 2005 for description). The form of intuition is subdivided into 'expertise' and 'feeling' (Sadler-Smith and Shefy 2004, Miller and Ireland 2005). Intuition-as-expertise is an accumulation of conscious and unconscious learning over time, and often overlapped with the heuristics, whereas intuition-as-feeling is more dominant in the exploration of future uncertainty. In this case, the reasons behind decisions based on 'feeling' often can not be totally articulated, but the decisions are just felt right (Miller and Ireland 2005). Affective is a form of emotion and defined as positive ('like') and negative ('dislike') evaluative feeling towards a particular issue (Slovic 2000). Individuals hold their value and belief in considering the future course of actions. Value is related to 'worldviews', ideology and belief, which are often overlapped and related to each other. Dake (1991) described 'worldview' as 'orienting dispositions' which guide people response and judgement about complex issues. Individuals may have different orientations towards significant societal issues, such as the use of nuclear energy, stem-cell research, human cloning, sustainability agenda. The other influencing factors may be categorised into sociopolitical and cultural factors, such as religion (Tonn *et al*. 2006).

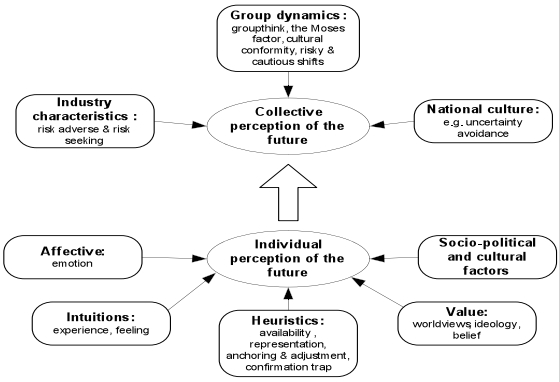


Figure 1 A conceptual model of factors influencing individual and collective perceptions of the future

At collective level, the factors at individual level may exert their same influence. Many factors are thought to influence perception at collective level, but there is little

empirical evidence of their significance and manner by which they are related with collective perception and possibly amplified the factors from individual level. In an attempt to understand collective risk attitude, Hillson and Murray-Webster (2005) identified common heuristics related to group dynamics, namely group think, the Moses factor, cultural conformity, risky/cautious shifts. These heuristics may influence the perception of individuals within a group, forming a significantly different collective perception and resulting behaviour. Corporate perception and behaviour is also thought to be associated with the inherent characteristics of the sector in which it operates. In his ground breaking theory of national culture, Hofstede (1984) proposed dimensions which explain national cultural differences, namely power distance, individualism or collectivism, masculinity or feminity, uncertainty avoidance, and time orientation. Of particular relevance is the uncertainty avoidance, although the other dimensions may also influence upon how organisations perceive the future and uncertainty. Elaboration of how each dimension influences perception of the future is beyond the scope of the paper.

In sum, the model has illuminated a number of factors that may influence individual and collective's perception of the future. Investigation of how these factors work in practice should be conducted in such a manner which appreciates interplay between these factors with other essential aspects of strategic thinking in a real organisational context. The following section presents the proposed framework, which is aimed to enhancing the capacity and capability of construction organisations for thinking about the future.

Towards an activity framework for improving strategic planning process

Figure 2 depicts a visual representation of the proposed activity framework. The framework comprises five independent but closely related activities. The pyramidal form with an activity in each corner is considered an appropriate representation of the framework as it suggests the nature of the interrelationships between activities. The framework embraces a sense of flexibility, in which activities can be undertaken in no particular order, although the first iteration would intuitively commence with establishing business goals.

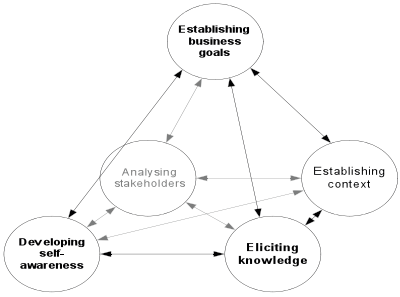


Figure 2 An activity framework for strategic planning

Establishing business goals

Business goals are derived from corporate mission and provide the purpose of a business unit for undertaking a particular action in relation to the strategic plan. Business goals are usually determined by higher level management within organisation, but sometimes, they are deemed as a given. Increased emphasis on the role of public stakeholders in corporate governance has elevated the act of establishing business goals to higher level of complexity. This nevertheless has provided an opportunity to infuse the spirit of social responsibility and sustainability agenda within the firm.

Establishing context

Business does not exist in vacuum, but within an environment which is characterised by dynamic interplay amongst a plethora of interconnected factors. Several tools and techniques have been used to enhancing understanding of organisation context, such as PESTLE (or STEEP) and SWOT analyses, to name a few. PESTLE analysis, a form of horizon scanning activity, explores a range of political, economic, social, technological, legal and environmental issues which might impact the business now and in the future. SWOT analysis systematically identifies internal factors as the strengths and weaknesses of the business, and external factors as opportunities for and threats to the business.

Analysing stakeholders and establishing their roles

Stakeholders hold the key to successful process, but are also a major source of uncertainty (Ward and Chapman 2008). This activity identifies stakeholders and clarifies their roles in the process. Stakeholders may be internal to the firm, but are not closely involved in the process. Nevertheless, they might exert a degree of influence at implementation of the strategy. The analysis of all possible stakeholders will enhance understanding of the context in which strategy is going to be enacted. It is also important to develop a reasonable awareness of those individuals and groups within organisation, who may have different (and may be competing) agendas (Ward and Chapman 2008). Their views will provide richness and diversity, which are essential to the identification of plausible futures.

Developing individual and group self-awareness

The intended aim of this activity is on developing reflective individuals and groups for improving corporate agility. Besides rational thinking, exploration of plausible futures and uncertainties utilises much of innate skills and tacit knowledge of individuals and groups within organisation. Creativity and intuition are encouraged and deemed as a vehicle to devise a breakthrough solution in the decision making. The caveat is that they can possibly lead to biases, if these skills are not appropriately understood and harnessed. For example, Hillson and Murray-Webster (2005) have demonstrated the application of emotional intelligence to enhance individual and group awareness of themselves. This self-reflection should reconsider corporate culture as it may explicitly and implicitly discourage creativity and intuition (Burke and Miller 1999).

Eliciting and communicating tacit knowledge

This activity concerns the articulation of the tacit knowledge by individuals and the interaction of articulated knowledge during strategic thinking. This involves bringing together the identified stakeholders in brainstorming workshops where future uncertainties and ideas are generated and discussed from the lower to higher levels of management. Communication is facilitated through the representation of this tacit knowledge or mental models of individuals involved. Cognitive mapping technique provides a framework to objectively exhibit these mental models in terms of constructs (e.g. events, issues), their interconnections and relations to goal(s) of an entity (e.g. individual, business, corporate). Soetanto *et al*. (2007) proposed an approach to connect the perceived future events in sequential manner, towards goal(s) at the end. Eden and Ackermann (1998) proposed a way of structuring the map according to a tear-drop/ pyramid shape, with the goal/ desired outcome at the top, the strategies/ key issues, and assertions, supporting facts and options at a lower level. What is critical here is the articulation and discussion of creative ideas, generated both consciously and unconsciously, and their relations to the stipulated goal(s). The interaction between stakeholders provides an opportunity to extent the sphere of collective thinking, by merging two (or more) individual cognitive maps. In sum, this activity stimulates individuals to utilise their rationality and intuition for thinking about the future, and amalgamate the other activities for developing strategic plan.

Conclusions

Exploration of plausible futures and identification of risks and opportunities are critical first steps in the strategic planning process. The task is complex and some might consider problematic due to inherent uncertainty of any future thinking. The process is often subjective, unstructured and characterised by both rational and irrational judgements of individuals and groups. A plethora of factors which may impact the formation of individual and group perception of the future, have been identified and discussed. This paper calls for a greater understanding of how these factors work in practice through a framework which appreciates interplay between these factors with other essential aspects of strategic thinking in a real organisational context. The framework encourages the recognition of intuitions and other irrational aspects, which are believed to enhance creativity, imagination and participation for devising possible breakthrough solutions. A comparison between common practice and the proposed framework is presented in Table 1. The framework has the potential to begin to induce a paradigm shift, because of the required fundamental change in process, content and thinking traditionally ingrained in the common practice. Successful implementation would require discipline and perseverance whilst at the same time maintaining flexibility and nurturing continuous organisation learning.

Table 1 Comparison between common practice and proposed framework

Common practice	Proposed framework
Top-down process	Bottom-up process
Responsibility of higher management	Allows participation from all levels
Attempt to simplify complexity with rational judgements	Embrace complexity by extending the sphere of thinking
Irrationality permeates the process, but little understood (in some cases, may be ignored or against for)	Irrationality recognised, understood and substantiated
Singular view about the future	Multiple views, allowing continuous learning about the future
Informal and unstructured process	Informal and flexible process, but requires greater commitment, guided and facilitated by the framework

Further research should concentrate on enhancing understanding of the interplay between rational and irrational factors in the identification of future risks and opportunities during the formulation of strategic plan. Importantly, the research should operationalise the proposed framework in real organisation settings, with a view to obtain a robust evidence of potential implementation, which ultimately will instigate the envisaged 'paradigm shift' in the construction sector. The benefits from this endeavour are revolved around the creation of sustainable 'future-proof' organisation.

References

Akintoye, A.S. and MacLeod, M.J. (1997) Risk analysis and management in construction. *International Journal of Project Management*, 15(1), 31-38.

Burke, L.A. and Miller, M.K. (1999) Taking the mystery out of intuitive decision making. *Academy of Management Executive*, 13(4), 91-99.

Chinowsky, P.S and Byrd, M.A. (2001) Strategic management in design firms. *Journal of Professional Issues in Engineering Education and Practice*, 127(1), 32-40.

Chinowsky, P.S. and Meredith, J.E. (2000) Strategic management in construction. *Journal of Construction Engineering and Management*, 126(1), 1-9.

Cooper, D.F., Grey, S., Raymond, G. and Walker, P. (2005) *Project risk management guidelines: managing risks in large projects and complex procurements*. John Wiley & Sons Ltd, Chichester.

Dake, K. (1991) Orienting dispositions in the perception of risk: an analysis of contemporary worldviews and cultural biases. Journal *of Cross-cultural Psychology*, 22(1), 61-82.

Dansoh, A. (2005) Strategic planning practice of construction firms in Ghana. *Construction Management and Economics*, 23, 163-168.

Eden, C and Ackermann, F (1998) *Making strategy: the journey of strategic management*. Sage Publications, London.

Elbanna, S. (2006) Strategic decision-making: process perspectives. *International Journal of Management Reviews*, 8(1), 1-20.

Green, S.D., Larsen, G.D. and Kao, C.C. (2008) Competitive strategy revisited: contested concepts and dynamic capabilities. *Construction Management and Economics*, 26, 63-78.

Henden, G. (2004) *Intuition and its role in strategic thinking*. Dr. Oecon dissertation, BI Norwegian School of Management, Sandvika.

Hillson, D. and Murray-Webster, R. (2005) *Understanding and managing risk attitude*. Gower Publishing Limited, Aldershot, England.

Hofstede, G. (1984) *Culture's consequences: international differences in work-related values*, abridge edition. Sage Publication Ltd, London.

Junnonen, J.M. (1998) Strategy formation in construction firms. *Engineering, Construction and Architectural Management*, 5(2), 107-114.

Mak, S.W. (1995) Risk analysis in construction: a paradigm shift from a hard to soft approach. *Construction Management and Economics*, 13, 385-392.

Maytorena, E., Winch, G.M., Freeman, J. and Kiely, T. (2007) The influence of experience and information search styles on project risk identification performance. *IEEE Transactions on Engineering Management*, 54(2), 315-326.

Miller, C.C. and Ireland, R.D. (2005) Intuition in strategic decision making: Fried or foe in the fast-paced 21st century? *Academy of Management Executive*, 19(1), 19-30.

Mintzberg, H. (1994) The fall and rise of strategic planning. *Harvard Business Review*, Jan-Feb, 107-114.

Price, A.D.F. (2003) The strategy process within large construction organisations. *Engineering, Construction and Architectural Management*, 10(4), 283-296.

Price, A.D.F. and Newson, E. (2003) Strategic management: Consideration of paradoxes, processes, and associated concepts as applied to construction. *Journal of Management in Engineering*, 19(4), 183-192.

Sadler-Smith, E. and Shefy, E. (2004) The intuitive executive: Understanding and applying 'gut feel' in decision making. *Academy of Management Executive*, 18(4), 76-91.

Slovic, P. (2000) *The perception of risk*. Earthscan Publications Ltd, London.

Soetanto, R., Goodier, C.I., Austin, S.A., Dainty, A.R.J. and Price, A.D.F. (2007) Enhancing strategic planning in the UK construction industry. *Proceedings of 3rd International Conference on Organizational Foresight, 'Learning the Future Faster'*, Burt, G. (ed.), University of Strathclyde, Glasgow, 16-18 August.

Tonn, B., Hemrick, A. and Conrad, F. (2006) Cognitive representations of the future: survey results. *Futures*, 38, 810-829.

Tversky, A. and Kahneman, D. (1974) Judgment under uncertainty: heuristics and biases. Science, 185, 1124-1131.

Venegas, P. and Alarcon, L.F. (1997) Selecting long-term strategies for construction firms. *Journal of Construction Engineering and Management*, 123(4), 388-398.

Ward, S. and Chapman, C. (2003) Transforming project risk management into project uncertainty management. *International Journal of Project Management*, 21, 97-105.

Ward, S. and Chapman, C. (2008) Stakeholders and uncertainty management in projects. *Construction Management and Economics*, 26, 563-577.

Warszawski, A. (1996) Strategic planning in construction companies. *Journal of Construction Engineering and Management*, 122(2), 133-140.

THE LAST DECADE ANALYSIS AND THE NEAR FUTURE TRENDS IN INTERNATIONAL CONSTRUCTION

Suat Gunhan[1], Ph.D., M.ASCE

ABSTRACT

The worldwide decrease of international construction activities starting from 1997 Asian crisis, started to gain momentum in 2002, and continues to grow parallel to world economic expansion. The paper analyzes the international construction sector within the 1997-2007 periods. It makes the world regional and the respective construction firms' analyses within the context of major trends such as firm acquisitions, facilities management, infrastructure projects, and public private partnership delivery systems. The paper suggests strategies and predicts the near future while highlighting the available threats and opportunities in international construction. Concluding remarks highlight that the most of the markets will continue to be attractive. China, Russia, Middle East and Eastern Europe are expected to be the leading markets although terrorist activity concerns exist in the Middle East. The trends such as the application of more innovative project delivery systems, increase in sustainability, and establishment of global professional and enterprise licensing are highlighted.

INTRODUCTION

The basic definition for international construction is where a company, resident in one country, performs work in another country. An international contractor is a contractor that works outside the country in which that company is registered (Seymour 1987). The activities of this type of firm constitute the scope of international construction. International work is unusual and challenging. The difficult tests are related to client communications, understanding a new culture, avoiding local politics, and supervising a diverse group of senior professionals (Kangari and Lucas 1997). Construction sector represents over 10% of the global economy. There are several reasons for international construction. Technological advances, political reform, the world-wide trends towards privatization and an

[1] Associate Professor, Department of Architecture, Izmir University of Economics, Sakarya Cad. No.156, Balcova, Izmir, Turkey, 35330; PH: +90(232)488 85 05; FAX: +90(232)279 26 26; e-mail: suat.gunhan@ieu.edu.tr

increasing recognition of economic interdependence, represent the primary forces of globalization which are embodied in the erosion of international trade boundaries (Hutton 1988; Kennedy 1991). Most economists agree that increasing openness and globalization brings all around benefits (Raftery et al. 1998). Significant market oriented economic reforms mainly in the areas of foreign trade and investments have resulted in a rapid increase in cross-border mergers and acquisitions, direct investment in infrastructure development, a greater need for consulting services, the international movement of labor and physical assets, and the development of emerging capitals (Ramcharran 1998). Seeking foreign contracts becomes obvious during periods of high interest rates, energy shortages, and stagnant domestic markets (Kangari and Lucas 1997). The growth of companies in truly global operations has been an important factor in the internationalization of construction. Agreements such as the Uruguay Round in the General Agreement on Tariffs and Trade (GATT) have fundamentally changed the structure of the construction industry. The resulting globalization of the construction markets is now allowing more local firms to compete internationally (Han and Diekmann 2001).

BACKGROUND

At the beginning of the twenty-first century, the United States, Japan, and the remainder of the G8 countries attracted the majority of the world's direct investment and dominated the world trade and commerce. The dispersion of the world-wide trade as shown in Figure 1 clearly indicates that the world's developed nations will continue the lead the world economy (Howes and Tah 2003). In the mean time in the leadership of China some of the developing regions of the world also become attractive. Mainly because of privatization, Eastern Europe, some Asian, South American and African nations started to offer opportunities. Due to energy shortages, oil and gas producing nations such as some Middle Eastern countries and Russia benefited from escalating energy prices and they obtained extreme wealth. They offer tremendous opportunities since they want to invest their accumulated cash. Although developed nations continue to be economically active, the developing nations also provide opportunities for higher profit margins.

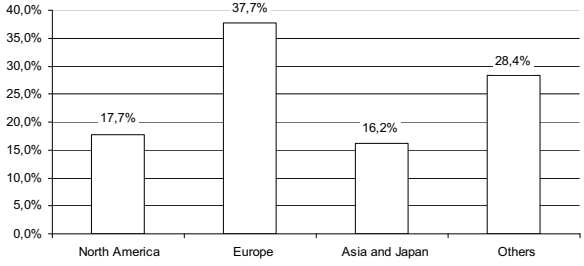


Figure 1. The dispersion of the world-wide trade in 2001 (Data Source: Howes, R. and Tah, J.H.M., 2003).

The worldwide decrease of international construction activities starting from 1997 Asian crisis, started to pick up in 2002, and continues to grow parallel to world economic expansion. The 1997 crisis affected the global economy. In 1999, European markets were in recession and many giant German contractors with accumulated cash were looking for different avenues in the global markets. The powerful U.S. construction market became an option for the German firms' difficult times in their domestic markets. By an acquisition of an overseas company, Germany's big three contractors prospered in the construction boom that followed the country's reunification in the early 1990's. Almost a decade later, domestic markets were in recession forcing Hochtief AG, Philip Holzmann AG and Bilinear + Berger Bau AG across the Atlantic and around the globe in search of growth or survival (ENR 2000). The largest U.S. building construction management firm Turner Construction became the wholly owned subsidiary of Hochtief AG in 1999. During 1999-2001 U.S. economy continued to prosper. It was a smart solution to acquire powerful local U.S. firms. In 2001 U.S. economy started to soften due to September 11. The European market was not doing well either and recession was still in place. One of the largest German contractors Philip Holzmann has filed bankruptcy in 2002. The overall international construction activities were affected due the collapse of the German giant (Figure 2).

In 2003, growing liquidity around the world boosted the international construction revenues as well. Euro and yen got stronger and this situation helped the revenues of European and Japanese firms increase. In the mean time U.S. firms also increased their revenues. Sixty six U.S. firms that are listed in ENR 225 increased their revenues by 41% (ENR 2003). The year 2003 became the year of acquisitions and mergers of construction firms. The continuing positive trend is still continuing.

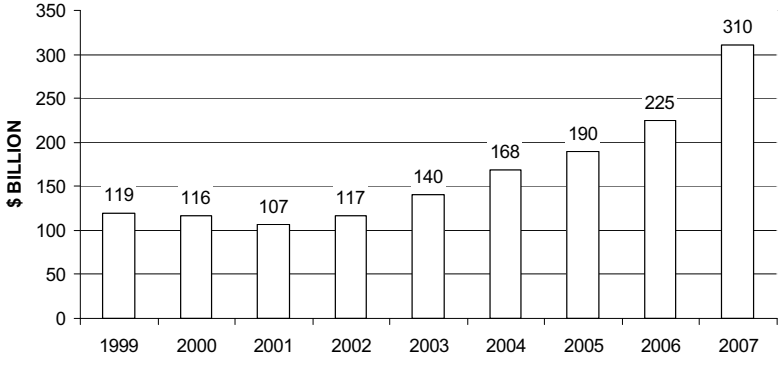


Figure 2. Total Revenues of International Contractors (Data Source: *Engineering News Record* 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008)

Between 1997 and 2007 there are certain trends that they can be called as the keywords of this period. They can be listed as firm acquisitions and mergers, facilities management especially airports, infrastructure, build operate transfer (BOT), and public private partnership (PPP). The major examples of firm acquisitions are the cases of European contractors. Hochtief acquired the U.S.' largest building construction firm (Turner) in 1999. In Spain ACS Actividades de Construccion y Servicios SA acquired Grupo Dragados SA in 2003. The acquisition created the world's biggest BOT contractors. Also, Dutch contractor Royal Bam Group acquired another Dutch firm HBG in 2003. Two big Japanese contractors, Sumitomo and Mitsui merged in 2003 and the new company is called Sumitomo Mitsui Construction Co. Ltd. (ENR 2003, 2004).

Both developing and developed countries offer opportunities in infrastructure projects that also include maintenance work. BOT projects were key to entry into some major markets due to the nature of infrastructure projects. Hochtief and Bilfinger Berger are active players in Australia's big BOT market (ENR 2004). Due to NATO and European Union enlargement the East European market also offers attractive BOT projects. Increasing demands by public clients have led international contractors to become not just entities that build the project, but ones that will develop, plan and finance it, as well (ENR 2005). This situation created financial/construction consortia and provided big advantage for financially strong firms. The PPP – the construction and upgrading of public-sector infrastructure facilities on the basis of private-enterprise financing – has developed in the past few years into a genuine procurement alternative for public authorities (Hochtief 2008). Due to the booming international market, international contractors became choosy and found themselves in PPPs which provide higher profit margins and steady cash flows (ENR 2007). Facilities management is a growing trend among large contracting firms. It may be seen as an alternative revenue generator and ultimately risk spreading strategy. As reported in ENR (2003), fifth of Hochtief's revenue came from facility management, airport operations and other services in 2002 and the firm was aiming to raise that ratio to 50% until 2006. The same report also mentioned that Bilfinger Berger Bau AG had the same goal and reached the 40% ratio in 2002.

REGIONAL ANALYSIS

China, with construction works growing up 8.5% a year is the third largest construction economy in the world. It is a tough market for international contractors since there are certain requirements in order to perform in the country such as licensing and joint venture requirements. Also, it is hard to compete with the low wages of Chinese workers. Some Japanese construction firms penetrated the market with the help of Japanese manufacturing firms doing investments in China (ENR 2004). In addition to above mentioned factors, language and cultural barriers and unique construction and design processes challenge international contractors (Lu and Morton 2007). According to Xu et al. (2005), cited in Lu and Morton (2007), within the four possible market entry strategies which are mergers and acquisitions, international joint ventures, project based collaborations and strategic alliances,

strategic alliance was identified as the preferred method of market entry. By working with local Chinese firms international AEC firms meet the local licensing and building code requirements (Lu and Morton 2007). Chinese firms are also active in Africa besides the mainland China with the help of the cost competitiveness derived from access to cheap capital, low-cost labor, and cheap building materials, as well as political support from Beijing channeled through frequent high-level missions and effective on-the-ground communication (Chen et al. 2007).

East European countries offer major opportunities in infrastructure. Poland, Czech Republic and Hungary are the most promising markets. The expansion of NATO and the European Union (EU) are the leading opportunity factors. One of the advantages of the EU expansion is that the funds are available for the newly joined countries to EU. The BOT is gaining popularity around the world so is in Eastern Europe. Major projects in the region are Hungary's M5 Motorway by French Bouygues and four-lane Romanian Highway (the biggest highway project in Europe) by American/Turkish Bechtel-ENKA joint venture. Czech Republic is attracting a lot of foreign direct investment (ENR 2003, 2004). Japanese manufacturers are shifting their manufacturing bases from Western Europe to Eastern Europe. Many manufacturing plants will be built across Eastern Europe. Japanese construction firms are expected to be active in this market in the near future. Some Western European firms are acquiring firms from Eastern Europe. One of the world's largest contracting firms Hochtief gets 85% of its revenue by international works and the firm is targeting the Central and Eastern Europe as its European strategy (ENR 2005).

Australian market offers many opportunities in BOT form in infrastructure projects. It is relatively a mature market compared to Asian markets and many European firms are attracted to BOT projects. Hochtief and Bilfinger Berger Bau AG are very active in this market by acquiring firms. Twenty five percent of Bilfinger Berger Bau AG's sales were generated from Australian infrastructure market. It is also noted that the two German firms own five subsidiaries in Australia and the total workload they have was counted for the 50% of major projects in Australia (ENR 2004, 2005).

There is no doubt that rising oil prices fueled investments in the Middle East region. The huge profits are reinvested in the region mainly in infrastructure. The booming market does not only offer opportunities in infrastructure works but also offers in housing, health, education and industry in Saudi Arabia, Qatar and the United Arab Emirates (ENR 2007). Refineries and petrochemical projects are still being built. Bilfinger Berger is building Barwa City residential project in Qatar. The first phase of the project consists of 6,000 luxury housing units. Turner International as a subsidiary of Hochtief is managing the construction of world's tallest building upon completion (Burj Dubai) (Turner 2008). The inflation of work in Dubai is escalating materials prices and the competition gets tougher. Turkish-Japanese consortium undercut a European bid for the $3.5 billion Dubai metro project by several hundred million dollars (ENR 2005). Besides the positive outlook, there are also concerns about the region. Iraq instability continues to cause security problems. The survey by London, U.K. based construction staffing firm EPCglobal released the results of the

survey that was conducted on over 2,128 international engineers over half of whom were working or have worked in the Middle East and North Africa (ENR 2006). Seventeen percent of the respondents reported that they would not work there, while 56% would, only if the financial rewards were sufficient and 60% reported that they would not work in Iraq. Although there are extensive rebuilding programs, Iraqi Government does not guarantee the security. Same conditions apply to Afghanistan projects. Deaths and kidnappings plagued Turkish firms. Engineers and workers of Kolin Construction were killed during the construction of 400-km of roads (ENR 2007). The authorities mention that the construction boom in the Middle East has not peaked yet; a lot more work is to come (ENR 2008).

By the early 2000's South American countries started to have economic stability and that helped boosting infrastructure investments. The ENR's (2006) Top 225 International Contractors Report stated a 44% increase in revenues in Latin America region which was actually the biggest regional increase in that year. Brazil, Argentina and Chile are the most active construction markets in Latin America. The growth of construction works in Argentina in 2005 was forty percent.

While German contractors' international revenues share is not less than 10% within the worldwide international contracting revenues, German market's activity is not parallel to its contractors' global activities. Germany has been Europe's weakest market for several years. United Kingdom (UK) is the most open market of Europe and is leading the region with its BOT projects. It is a competitive market with tight profit margins. There are opportunities in railroad projects which are considered specialty projects. U.S.' Bechtel secured dominance in that niche in the UK market after working on Channel Tunnel. French market was slow since 1998 depression but started to pick up in 2004 with privately financed public projects and residential projects (ENR 2003, 2004). French Bouygues' domestic business grew 35% in 2006 with large building projects and PPP's (ENR 2006).

The Russian market offers big opportunities in building and infrastructure projects and the market is also enjoying the boom in the petroleum market. According to ENR (2007) report, there are major opportunities from the development of new hydrocarbon fields and the new trunk pipelines in the Northwest, Eastern Siberia, and the Far East of Russia. There is not any slowing down in the horizon for the Russian market. Despite the constant growing market some large international construction firms are finding the market extremely difficult and they are not sure about what type of competitive edge they should have (ENR 2003). Skanska quit the market in 2006 (ENR 2007). The ENR (2007) report also adds that in the former Soviet Republics oil and gas continue to be the major markets. Despite being a rough market, Russia is expected to be the one of the biggest markets in the world for the next decade. For some firms, cultural similarities and long term relationships based on mutual trust played major role in establishing successful businesses in Russia. Most of the private sector jobs are negotiated. Turkey's ENKA became one of the biggest contractors in Russia.

Many contractors agree that the promising African market is in oil and gas businesses through private sector. The international contractors reported that they experience difficulties in getting paid while working with public owners (ENR 2004, 2005). The issues related to Chinese contractors constitute the top agenda in African construction industry. French contractors are still getting the major share in African market but Chinese contractors are following them closely. Chen et al. (2007) analyzed the African market shares of the top international contractors during the 2000-2005 period and they observed that American and Japanese firms are playing a decreasing role after reaching a peak in 2002 and 2003. Chinese contractors are growing rapidly and are expected to overtake their French firms to become the market leaders within the next few years. Sub Saharan part of the continent is dominated by Chinese contractors. The same research by Chen et al. (2007) also reports that Chinese contractors usually entered an African market in an ad hoc manner without a formal strategic plan or long term commitment, and the Chinese government plays an important role in facilitating their contractors' market entries. Their low prices create hard competition.

U.S. market is considered open and clean and according to Balfour Betty executive once it is understood in a greater depth with strong local and regional management the success will come (ENR 2004). U.S. has been a good market at hard times. The common entry method for U.S. market is "wholly owned subsidiary". Howes and Tah's (2003) suggestions confirm the global construction firms' strategy in U.S. Evidence from the case studies indicates that most global construction companies wish to provide their subsidiaries with as much autonomy and empowerment as possible to deal effectively with local conditions and circumstances. The U.S. market can be included in softening markets of the last two years but two of world's largest contractors Skanska and Hochtief reported good businesses in infrastructure projects for Skanska and in building projects for Hochtief through its wholly owned subsidiary Turner that is unaffected from falling residential market by having no exposure to residential sector (ENR 2008).

OPPORTUNITIES AND THREATS

In overall global construction markets are in good conditions. There is a cash flow through developing markets and this provides funding for infrastructure projects. The markets have been very good for many years and since 2006 international construction firms started to be selective. The boom in oil, gas, chemical and petrochemical markets will continue in the next few years. Resources become pricy due to oil price increase but in turn that increase also brings infrastructure investments.

Owners are more selective, they will prefer single source solutions for the delivery of their projects. Therefore, firms specializing in integrated delivery systems will gain competitive advantage. The key to integrated delivery system is being able to go beyond design and construction services and specialize in PPPs.

Despite the good conditions in the markets certain threats are also in place. Fast growing sector creates cost escalation of resources. Shortages of staffing, cost increase in fuel, steel and cement and also in some types of equipment, materials, logistical services and labor make international contractors worry (ENR 2008). The inflation of inexperienced and very low cost contractors especially from China creates concerns. Although rising oil and gas prices help oil producing countries to accumulate cash and invest, these countries are mainly in the Middle East, and the work conditions in this unstable region are very risky due to terrorist activities.

NEAR FUTURE TRENDS

The concerns about unqualified contractors especially in newly booming regions such as Africa and Asia will expedite the establishment of global professional and enterprise licensing, standards and practices. This is also noted by Moavenzadeh and Wolff (2006).

The owners will be in the search of design build companies that their service scope is beyond designing and building such as providing consulting in the areas of finance, facilities management, environment (sustainability), legal, social, economic, political and cultural issues. Sophisticated project delivery systems that include creative financing solutions in the form of public private partnership (PPP) will continue to be on the agenda of owners. The use of BOT, Design-Build-Operate-Own (DBOO), Design-Build-Operate-Own-Transfer (DBOOT), Design-Build-Finance-Operate (DBFO), Design-Build-Operate-Maintain (DBOM) types of delivery systems will be increasingly used.

Construction demand will be high in chemical, petrochemical, oil, and gas industries mainly in Russia, Middle East, Latin America and North Africa.

Sustainability will lead the AEC industry. Production of green buildings and recyclable materials industry will grow. The use of clean energy sources (wind, solar) is expected to be widespread in new buildings. According to ENR (2008), Johan Karlstrom, CEO of Sweden's Skanska reported that their all new investments in Nordic countries will be green building projects.

According to Howes and Tah (2003), the terrorist attacks, combined with the growing awareness of global warming and the apparent increasing regularity of natural disasters such as earthquakes, flooding, tornados and storm damage have made the world's population uneasy and less secure in their living environment. Therefore introduction of intelligent infrastructure and specific technologies such as strengthening foundations, building envelopes, improved fire resistance and barriers to contain damage will be improved.

CONCLUSIONS

The world has been enjoying the benefits of available liquidity that flows through emerging and developing nations since 2003. In addition to this, the profit made from rising oil and gas prices are reinvested in forms of infrastructure and building projects. It looks like the current trend will continue for the next decade. Another revenue boosting factor for international contractors is that the major currencies got stronger against the U.S. dollar.

According to the regional analysis, China, Russia, Middle East and Eastern Europe have been the leading construction markets and they are expected to be in the same position in years to come. Russia and Middle East will continue to generate profitable income from oil and gas.

The owners lean towards less complicated processes throughout the life cycle of a project. The expected scope of services go beyond the technical and managerial capabilities; from a one single source they would expect broader range of consulting services including financial, social, economic, political and cultural issues. This type of service is defined within a PPP type of delivery system. Sustainable projects will continue to be built with an increasing momentum. The inflation of projects creates concerns since unqualified firms come into the scene. In order to control this situation, it is expected that the global professional and enterprise licensing, standards and practices are established soon. The project inflation also causes the price escalations in resources and shortages in staffing. Building technologies are expected to improve due to growing concerns of global warming which causes other natural disasters such as flooding, tornados and storm damage that necessitate improved building envelope systems.

REFERENCES

Chen, C., Chiu, P., Orr, R. J. and Goldstein, A. (2007). "An Empirical Analysis of Chinese Construction Firms' Entry into Africa." *CRIOCM International Symposium on Advancement of construction Management and Real Estate,* Sydney, Australia.

ENR (2000). Global Wanderlust Helps Cushion German Firms' Problems at Home, *Engineering News Record*, 14 August, 44-47, McGraw-Hill, New York, NY.

ENR (2001). The Top 225 International Contractors *Engineering News Record,* 20 August, Vol. 247 Issue 8, p66, McGraw-Hill, New York, NY.

ENR (2002). The Top 225 International Contractors *Engineering News Record,* 26 August, Vol. 249 Issue 9, p26, McGraw-Hill, New York, NY.

ENR (2003). The Top 225 International Contractors *Engineering News Record,* 25 August, 28-40, McGraw-Hill, New York, NY.

ENR (2004). The Top 225 International Contractors *Engineering News Record,* 23 August, 34-40, McGraw-Hill, New York, NY.

ENR (2005). The Top 225 International Contractors *Engineering News Record,* 22-29 August, 40-45, McGraw-Hill, New York, NY.

ENR (2006). The Top 225 International Contractors *Engineering News Record,* 23 August, 28-40, McGraw-Hill, New York, NY.

ENR (2007). The Top 225 International Contractors *Engineering News Record,* 20 August, 30-36, McGraw-Hill, New York, NY.

ENR (2008). The Top 225 International Contractors *Engineering News Record,* 18 August, 32-37, McGraw-Hill, New York, NY.

Han, S. H. and Diekmann, J. E. (2001). Approaches for Making Risk-Based Go/No-Go Decision for International Projects, *Journal of Construction Engineering and Management,* ASCE, 127(4), 300-308.

Hochtief (2008). "Public-Private Partnership (PPP) Concessions Business at Hochtief"<http://www.hochtief.com/hochtief_en/data/pdf/ppp_positionpaper.pdf> (Aug. 5, 2008).

Howes, R. and Tah, J.H.M. (2003). *Strategic Management Applied to International Construction.* Thomas Telford, London.

Hutton, J. (1988). *TheWorld of the International Manager*. Phillip Allan, Oxford, UK.

Kangari, R. and Lucas, C. L. (1997). *Managing International Operations*. American Society of Civil Engineers. New York, N.Y.

Kennedy, C. R. (1991). *Managing the International Business Environment*. Prentice-Hall, Englewood Cliffs, NJ.

Lu, H. and Morton, D. L. (2007). "Opportunities and Challenges in China's Construction Industry towards Globalization: A Review." *ASCE Construction Research Congres*s, Grand Bahama Island, Bahamas.

Moavenzadeh, F. and Wolff, D. M. (2006). "Globalization of the Engineering and Construction Industry: A 20/20 Vision for the Future of the AEC Field" <http://stuff.mit.edu/afs/athena/course/1/1.463/www/session02.pdf> (Aug. 7, 2008).

Raftery, J. and Pasadilla, B. (1998). "Globalization and Construction Industry Development: Implications of Recent Developments in the Construction Sector in Asia." *Constr. Manage. Econom.,* 16(6), 729-737.

Ramcharran, H. (1998). "Obstacles and Opportunities in International Engineering Services", *Journal of Management in Engineering*, ASCE, 14(5), 38-47.

Seymour, H. (1987). *The Multinational Construction Industry*. Croom Helm Ltd., New York, NY.

Turner (2008). "Turner International Projects." <http://www.turnerconstruction.com/international /content.asp?d=3457&p=2372> (Aug. 7, 2008).

Xu, T., Bower, D. A., and Smith, N. J. (2005). "Types of Collaboration between Foreign Contractors and Their Chinese Partners." *Int. J. Proj. Manage.,* 23(1), 45-53.

BEYOND SUSTAINABILITY: THE CONTRACTOR'S ROLE IN REGENERATIVE SYSTEM DESIGN

Rebecca Mirsky[1] and Anthony D. Songer[2]

Abstract
Current business models employ the concept of the triple bottom line to integrate three aspects of sustainability into the organizational process: economic growth, environmental protection and social equity. This concept is evolving toward a regenerative design approach that promotes a triple "top" line, moving accountability to the beginning of the design process by assigning value to a variety of economic, environmental and social factors. There is an increasingly important need for proactive participation from the construction community in this new generation of sustainability efforts. Otherwise, there will be a widening gap between design and construction, in which the contractor role in sustainability is marginalized, relegated to merely minimizing end-of-project impacts rather than adding value and innovation throughout the project. This paper examines the triple top line in the context of construction projects and identifies opportunities for construction professionals to play a collaborative role in developing the next generation of regenerative facilities.

Sustainability and the triple bottom line
Business leaders today are beginning to incorporate the idea of sustainability into their corporate culture by measuring performance against three concerns: economic growth, environmental protection and social equity. These three concerns comprise what is referred to as the triple bottom line. In the realm of the built environment, the theme of the triple bottom line is expressed through a wide range of design and construction approaches, sometimes interchangeably referred to as sustainable, green, or high performance.

A design approach focused solely on the bottom line tends to emphasize resource efficiency measures or initiatives that meet the triple bottom line by minimizing the

[1] Associate Professor and Chair, Department of Construction Management, Boise State University, 1910 University Drive, Boise, ID 83725 RebeccaMirsky@boisestate.edu
[2] Associate Professor, Charles E. Via Jr., Department of Civil and Environmental Engineering, Virginia Tech, 200 Patton Hall, Blacksburg, VA 24061 adsonger@vt.edu

impacts of the project. This strategy for managing negative effects establishes an agenda for sustainability built on being "less bad" and is often a measure of the degree to which a company has minimized a liability (McDonough and Braungart 2002). To date, this has been the objective when design professionals encourage contractor involvement in sustainable building projects.

Previous studies identify a number of ways in which construction input during the design process assists in achieving sustainability goals for building processes, materials, and quality (Pulaski et al. 2006, Riley et al. 2003). Commonly identified areas of contractor expertise include estimating, procurement and constructability review services during preconstruction, and assisting with construction waste and indoor air quality management planning. Contractor participation on this level, while contributing to the sustainability goals for the project, does so using an economically focused, triple bottom line perspective aimed at maximizing efficiency by reducing field labor costs and material waste. The perceived challenge is to somehow manage the inefficiencies and additional expenses related to the iterative design process, higher construction standards, additional site precautions, and new materials requirements of sustainable building projects. Adherence to this approach can obscure opportunities to pursue innovation and create value in the design process.

Regenerative design and the triple top line

Current rating systems for high performance or green building projects award points for relative efficiency improvements in the use of energy, water and materials resources. From the standpoint of the end use of the project, the constructability review provides the greatest opportunity for the constructor to add value by identifying synergies and improvements to project performance and quality. Yet, all design improvements remain focused on the final product and the end user. As such, the construction process itself, which includes the human resource of construction labor crews, and the environmental and social impacts on the surrounding community during construction are largely unrecognized.

A new design perspective is to create a *triple top line* strategy: a project experience that enhances the well being of the end users, construction workers, and the surrounding community, while at the same time, generating economic value for all the contractual parties. This is in contrast to the manner in which many projects are managed when the focus is solely on the end user, failing to imagine or anticipate complaints from the community, a fine from the regulatory agency, or perhaps something more severe, such as the recent collapse of a pedestrian walkway next to a construction site in San Diego. The triple top line approach moves accountability for these impacts to the beginning of the design process by assigning value to a variety of economic, environmental and social factors. The goal is not to try to balance competing interests but to optimize and maximize value in all three areas through intelligent design.

Triple top line thinking shifts the design approach from compliance to commitment or sustainable to regenerative. Whereas the sustainable design approach only slows the

rate of destruction, design practices not only need to do no harm, they must initiate regenerative processes to replace the degeneration resulting from past practices. A regenerative system is one that goes beyond maintaining a certain level to actually produce more: more profit, a healthier environment, and a better quality of life for the people involved (Patelski and Poling 2008). Regenerative design is the proposed design approach that best reflects the thinking that will shape the next phase of development within the field of sustainable design (Mang 2001).

Within the context of construction projects, the concepts of regenerative design and the triple top line raise new questions that are seldom considered during the design process:

- Is the contractor positioned to provide a service rather than supply a commodity? (economic – social)
- Do the selected materials, tools and equipment employ a sustainable supply chain? (economic – social)
- Does each contractual relationship within the project organization support innovation and collaboration to achieve the project goals? (economic – social)
- Does the project/community interface provide a safe, secure and educational opportunity for the public to experience the building process? (social)
- Does the project value and contribute to the health and safety of the construction worker as well as the end user? (social-environmental)
- Does the timing of the project take advantage of optimum weather and site conditions? (environmental - social)
- Does the project mimic the functions of nature to preserve or restore ecologic processes? (environmental)
- Do the construction methods and selected equipment make efficient use of resources? (environmental – economic)
- Are there opportunities to provide incentives to subcontractors for meeting or exceeding sustainability goals? (economic – environmental)
- Is the concept of sustainability promoted throughout all branches and levels of the project organization? (all)

Typical construction practice would be to view these questions and immediately consider only how they are going to impact the project's bottom line. However, these questions should not be viewed as imposing costly restrictions, but as raising opportunities to identify economically viable ways to add social and environmental value. The parenthetical items for each question identify where in the regenerative model (discussed below) they occur.

Implementing the triple top line using the regenerative model

The key to discovering and realizing opportunities for adding value using a triple top line approach lies not only in early involvement by the constructor, but in alignment of the entire project team with triple top line values.

Pulaski et al (2006) make a compelling case for the urgent implementation of project management practices to strengthen integration between design and construction disciplines and manage sustainable design knowledge of green building projects.

Current management systems such as the balanced scorecard align well with triple bottom line models. The balanced scorecard is a strategic planning, management and communications system in which the work people do is aligned with an organization's or project's vision and strategy, in order to align strategic objectives with resources (Rohm 2008). The scorecard system includes a strategy map, to show how value is created for members (owner, A/E/C partners, end user, construction workers, community), strategic objectives to describe what needs to be accomplished to produce value, what performance measures will be used to measure progress against targets, and what strategic initiatives have been identified to make strategy actionable and operational.

The balanced scorecard, when applied to the triple bottom line, provides a framework for defining the strategy, matching it with resources, determining how it will be assessed, and communicating it to all stakeholders. It identifies who has accountability for implementation, and suggests ways to recognize and reward performance. However, the balance scorecard suggests a zero sum approach to limit liabilities of competing perspectives rather than maximizing value.

Implementing triple top line thinking also requires a champion and action by the management team. An adaptation of McDonough's fractal triangle provides an appropriate framework for shifting sustainable design-construction integration from a balancing (bottom line) to a maximizing (top line) approach. This approach provides a framework for regenerative design-construction planning.

When planning a project, the team moves around the triangle investigating the value creation potential for each category; economic, social, and environmental. The goal is to maximize value of the entire system instead of minimizing liabilities through tradeoff. As illustrated on the model, the boundaries between primary perspectives provide value adding opportunities generally not considered in triple bottom line approaches. Figure 1 illustrates the fractal triangle model.

Eisenberg and Reed (2003) describe regenerative design as being place-based. It requires an understanding of how activities need to be aligned with the characteristics of the place in which they are occurring. Connection to the place or project ultimately requires a sense of ownership by all parties and a cascade of the regenerative process to all individuals.

The potential impact of contractor involvement using the triple top line approach is illustrated in the following three examples: cost savings from construction waste management (economic growth), regenerative features for conveyance of stormwater runoff (environmental protection), and improving the availability of a skilled construction workforce (social equity).

Disposition of waste materials

At Greenbuild 2007, speakers presented a case study illustrating the savings realized from the reuse of concrete from demolition (Boecker et. al 2007). The Portola Valley Town Center project in northern California required disposition of 3,040 tons of demolished CMU block. After demolition, 2,470 tons of rubble was designated for

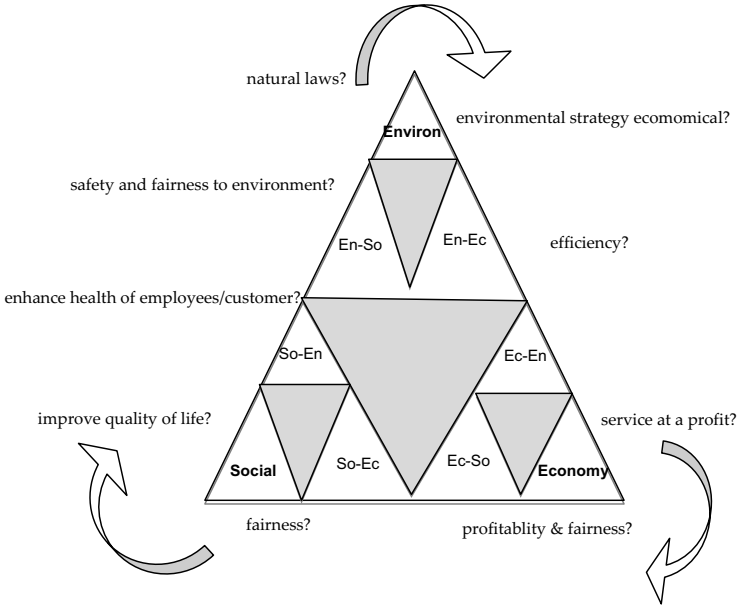


Figure 1. Fractal Triangle – Regenerative Model (adapted from McDonough and Braungart)

recycling and 570 tons was to be landfilled. The triple top line question was: Can the disposition of construction waste materials provide economic and environmental opportunity?

The project team decided to reuse the rubble onsite instead of importing base material for an area that was to be paved. The cost savings and reduced environmental impact realized went far beyond the savings associated with purchase of the base material. The project saved 1,049 gallons of diesel fuel that would have been used to truck the rubble to the recycling center and the landfill, and the base material to the site. Cost

savings and reduced environmental impact were also realized by reducing truck use time, truck driver labor, and base material costs.

Regenerative design for stormwater runoff

Two of the goals in sustainable project design are the reduction of the quantity of stormwater runoff from the site, and the improvement of the quality of the runoff. Achievement of these goals generally requires a reduction in the amount of impervious surface area on site, and incorporation of erosion control measures to reduce sediment load in the runoff. The triple top line question is: Does the project mimic the functions of nature to preserve or restore ecologic processes?

Berg and Underwood (2007) describe a regenerative design for constructing weirs and pools for non-erosive conveyance of stormwater runoff. Rather than adopting a traditional design utilizing pipes and concrete channels to convey runoff from impervious surfaces, the weir and pool system mimics the ecology of the local drainage area, contributes to local micro-habitat, and provides aesthetic value. To be economically viable, this approach requires close contractor involvement during the design phase because of the potential impact on jobsite layout and the site grading plan and sequence.

Regenerating a diminishing workforce

Skilled construction labor is a critical resource that is often taken for granted in facilities planning and design. Seldom are potential shortages in the skilled workforce considered during the design phase of a project, and yet those shortages can and do critically impact a project's schedule and thus its economic bottom line.

The current data underscore the importance of not just sustaining, but regenerating this human resource. According to the Bureau of Labor Statistics (BLS), there were 7,688,900 construction-related jobs in 2006, or 5.1% of the total U.S. employment (BLS 2007). Yet, the average craft professional is now 47 years old, largely because the construction industry is suffering from an image crisis. The labor issue can be even more critical in the sustainable building sector if workers are not available who have specialized training in building commissioning, construction waste management, materials storage and protection, photovoltaics, or other aspects of high performance building.

Construction work has the reputation of being dirty, physically demanding and unsafe. In their report for the National Center for Construction Education and Research (NCCER), Whyte and Greene (2008, p.1), write:

> *"Sons used to follow fathers into trades, yet today parents discourage their sons or daughters from pursuing career opportunities in the industry because of their perception of us."*

The relevant triple top line question is: Does the project value and contribute to the health and safety of the construction worker as well as the end user?

Construction Hazards Prevention through Design (CHPtD) is the process in which construction worker safety is explicitly considered during facility design (Toole and Gambatese 2008). In addition, constructor review during design can address whether design choices made to consider end user health and safety, actually transfer risk from the end user to the construction worker (Armenti 2004). For example, a change in materials or storage requirements may have a potential ergonomic impact associated with material handling. Only by addressing the health and safety of the construction worker when design decisions are made can the industry begin to change its image and not only attract new workers but extend the career length of the existing, skilled labor force. The triple top line approach poses the question about construction worker health and safety. The effect on the economic bottom line is a healthier, safer workforce that is more productive, and is attracted preferentially to a project with the worker's welfare designed in.

Conclusions

McDonough and Braungart make it clear that the triple top line does not obviate the need for triple bottom line accounting. A company cannot achieve sustainability unless it stays in business. But where the triple bottom line focuses on economic concerns, treating environmental and social factors as competing interests requiring compromise, the triple top line strategy recognizes that these factors provide previously unrecognized opportunities to create social and ecological as well as economic value. In this manner, the construction industry becomes a regenerative force in the built environment process.

References

Armenti, K. (2004). "Importance of including construction worker safety and health in green building: an integrated approach." *Proc. APHA 2005 132nd Annual Meeting on Public Health and the Environment*, Washington D.C.

Berg, J. and Underwood, K. (2004). "Constructed weirs and pools for safe, non-erosive conveyance of stormwater runoff: an example of regenerative design." *Proc ESA/SER Joint Meeting 2007*, San Jose, CA.

Boecker, J., Canseco, V., Malin, N, and Strain, L. (2007). "Green guideline specification: taking it public, making it real." *Proc Greenbuild 2007*, Chicago, IL.

Bureau of Labor Statistics (2007). *Monthly Labor Review*, November 2007. http://www.bls.gov/opub/mlr/2007/11/art4full.pdf

Eisenberg, D. and Reed, W. (2003). "Regenerative design: toward the re-integration of human systems with nature." *A contribution to the City of Boston's Mayor's Green Building Task Force - December 18, 2003*, http://www.cityofboston.gov/bra/gbtf/Documents/RegenerativeDesign-Reed03-12-18.PDF

Mang, P. (2001). "Regenerative design: sustainable design's coming revolution." *Design Intelligence*, July 2001, http://www.di.net/articles/archive/2043/.

McDonough, W. and Braungart, M. (2002). "Design for the triple top line: new tools for sustainable commerce." *Corporate Environ. Strategy*, 9(3), 251-258.

Patelski, J. R. and Poling, J. R. (2008). "Achieving a triple bottom line with sustainable design." *Urban Land*, June 2008, 125-127.

Pulaski, M., Horman, M. J., and Riley, D. R. (2006). "Constructability practices to manage sustainable building knowledge." J. Arch. Engr. 12(2), 83-92.

Riley, D., Pexton, K. and Drilling, J. (2003). "Defining the role of constructors on green building projects." *Proc., CIB 2003 Int. Conf. On Smart and Sustainable Built Environment*, Brisbane, Australia.

Rohm, H. (2008). "Using the balanced scorecard to align your organization." Balanced Scorecard Institute. January 2008. http://www.balancedscorecard.org/Portals/0/PDF/BalancedPerformance_Article1.pdf

Toole, T. M., and Gambatese, J. (2008). "The Trajectories of Prevention through Design in Construction."*J. Safety Research*, 39(2008) 225-230.

Whyte, D. and Greene, S. (2008). The skilled workforce crisis. National Center for Construction Education and Research. http://www.nccer.org/documents/Research/SkilledWorkforceCrisis.pdf

ACQUIRING LOCAL KNOWLEDGE FOR INTERNATIONAL PROJECTS

Amy Javernick-Will[1] and Raymond Levitt[2]

ABSTRACT

The construction market offers numerous opportunities for firms seeking to expand internationally. One can witness the amazing growth of "mega-cities" firsthand by observing skies filled with cranes in the Middle East, China, and other resource-rich developing countries. Projections for future demand in infrastructure and the built environment indicate that there will be increasing demands for firms to engage in projects around the world. There are tremendous opportunities for firms in the international construction market, but international construction projects also face numerous uncertainties and risks. These projects bring together teams working in unfamiliar environments with differing regulations, norms and cultural beliefs, which can lead to increased misunderstandings and costs. A key strategy that successful global firms adopt to reduce these costs is to increase their capabilities for acquiring and sharing information and knowledge about each local environment in which they have worked to use on their portfolio of international projects. This study compiles and analyzes data from 15 case studies of international firms engaged in global infrastructure development to identify the types of local and regional knowledge managers perceive to be most important to the success of their international projects. The firms covered in the case studies are of three types: real estate developers, contractors and engineers. These three firm types have different responsibilities and are involved in different phases of the project lifecycle. The paper concludes with the different kinds of knowledge that each firm type finds most critical to acquire and share in order to enhance the success of their global projects.

INTRODUCTION

Projections of increased population growth, urbanization and needed infrastructure around the world provide opportunities for firms within the AEC sector to expand internationally. For instance, demographers expect over a billion more inhabitants on earth in the next decade, particularly in emerging market countries (Sachs 2005). This growth will require increased spending on infrastructure and facilities to meet people's basic needs while allowing for economic growth and expansion. According

[1] PhD Candidate, Collaboratory for Research on Global Projects, Department of Civil Environmental Engineering, Stanford University, Stanford, CA, USA, ajwill@stanford.edu
[2] Professor, Department of Civil and Environmental Engineering, Senior Fellow, Woods Institute for the Environment, Stanford University, Stanford, CA, USA, ray.levitt@stanford.edu

to Morgan Stanley's predictions, emerging market countries will spend US$22 Trillion (present dollar values) on infrastructure in the next ten years alone (Economist 2008). Many firms are responding to these opportunities and seeing their revenues increase. The top 225 international firms revenues increased 18.5% from 2005 to 2006 for projects outside their home markets (Reina and Tulacz 2007).

As exciting as these predictions and opportunities appear, international projects also involve many uncertainties and risks not found on domestic construction projects. These projects engage participants from differing backgrounds and cultures who work together in unfamiliar locations, increasing risks and costs when doing business abroad (Flyvbjerg et al. 2003; Orr and Scott 2008). Firms entering foreign markets are therefore thought to be at a disadvantage due to their lack of familiarity with the local environment, which is often termed the 'liability of foreignness' (Zaheer 1995). Understanding these differences and nuances in different countries where they plan to work is therefore expected to reduce these risks, thereby increasing the success of global projects.

This study uses qualitative case studies with fifteen international firms to permit a wide view of the differences encountered on global infrastructure projects to answer two research questions: (1) What kinds of local knowledge do managers perceive to be most important on their global projects? (2) How does the importance of knowledge vary by company type? Future work related to this research will investigate: (3) How are firms acquiring this knowledge? (4) How do firms transfer this knowledge within the firm? (5) Can we develop a theoretical framework to explain and predict how this varies by firm type?

The paper first discusses the international business and project management literature, emphasizing the risks and differences encountered on international projects. The research methodology and firms studied are then presented. Finally, the paper presents the results regarding the types of knowledge managers perceive to be important by company type. This research contributes to the international project management literature by expanding focus on "normative" and "cultural-cognitive" (Scott 2001) risks in addition to "regulative" (political and legal) risks. And finally, it shows that not all kinds of firms are alike in the internationalization process by highlighting differences according to firm type.

POINTS OF DEPARTURE

The research focus on important types of knowledge for international projects and international business expansion naturally leads to prior international project literature that identified risks and differences. The prior work in this area is presented below.

International Project Risks

Most of the international business research has focused on the risks associated with conducting business abroad. For instance, Pennings (1994) found that differences in economic development, regulatory traditions, and political and social infrastructure all increase the risk involved in foreign expansion. The international project literature is no different—the majority of international project research in the Architecture-Engineering-Construction (AEC) literature focuses on risks that affect contractors engaged in international projects. Studies have identified critical risks in several categories of international work, including risks associated with China's BOT

projects (Shou Qing et al. 1999), international joint venture risks (Bing et al. 1999), risks affecting construction cost performance (Baloi and Price 2003), contractual issues (Chan and Tse 2003), opportunities and threats of international construction (Gunhan and Arditi 2005) and profit-influencing factors (Han et al. 2007).

The bulk of this work focuses on the political, economic and legal factors affecting contractors in international work. When cultural or social risks or differences are mentioned or analyzed, they are described in general terms. In addition, the research methods often rely on prior literature reviews and surveys to assess these risks. Recently, the work of Mahalingam and Levitt (2007) employed a single case study with a real estate developer to begin to compare and identify broader challenges encountered on global projects, including social and normative differences that can increase project risks. This research builds upon the important work of other scholars to expand and understand the various differences and risks involved on international projects. This research uses qualitative methods with open-ended questions to allow managers to describe any types of differences, risks and knowledge they perceive to be important, enabling naturally occurring phenomena to appear, and allowing the results to expand on the more normative and cultural factors. In addition, developers and engineers are studied with contractors to expand the research on international projects within the AEC sector and attend to variances between firm types.

RESEARCH METHODOLOGY

The research uses a case-based methodology because it provides a level of in-depth analysis that survey methods on larger samples cannot attain, and thus offers the prospect of rich, new insights (Eisenhardt 1989; Yin 2003) for this early stage of research in this area. In addition, we used semi-structured but open-ended questions that allowed informants to respond without constraints and provide additional detail. In addition, this method responds to the question of "How?" which focuses on the organizational and institutional processes that occur naturally.

We chose three types of companies to study within the AEC sector: engineers, contractors and real estate developers/owners. The company types defined the limits of population; in addition, varying firm type achieved theoretical replication, allowing the study to highlight differences and expand prior literature to include engineering consultants and developers. The study uses at least three companies of each type of firm to achieve literal replication and ensure that the findings were replicated within each company type. Please refer to Table 1 below for additional details of the case studies.

	Company (Coded*)	Primary location of interviews	# of Informants	# Countries with Offices
Real Estate Developers	Tottenham Court	UK	6	19
	Holborn	UK	4	16
	Goodge Street	USA	5	2
	Southgate	Norway	2	1
Contractors	St Pauls	Sweden / UK	7	25
	Leicester Square	India	12	18
	Charing Cross	Greece	9	32
	Oxford Circus	Japan	9	12
	St James Park	Japan	5	21
Engineering Consultants	Hyde Park	South Africa	27*	15
	Farringdon	USA	8	28
	Angel	UK/ USA	8	36
	Picadilly Circus	UK / USA	4	26
	Fulham Broadway	Finland	4	11
	Paddington	Finland / Thailand	3	29

Company names are disguised to protect confidentiality .

*** The five most substantive of these 27 interviews were coded for this anaylsis*

Table 1: Case Study Information

The first author conducted the case studies in company offices from September, 2007 through August of 2008. Subsequent phone interviews with informants in other office locations were also conducted during this time. The case studies primarily consisted of *interviews* with key informants and *collection of documents and secondary data* that was either available publically or provided by the informants. Using ethnographic interviewing techniques proposed by Spradley (1979), we asked descriptive, semi-structured but open-ended questions to informants within global firms. In total, 84 informants were interviewed (often more than once), who had past or current experience on global projects, were involved in the overall strategy of the firm, or were involved in a knowledge management initiative. By engaging informants and getting them to describe their projects, firms, and how they obtain knowledge on a daily basis for their international projects, rich, detailed and real-life scenarios were collected. The audiotapes were transcribed and imported along with collected documentation into a qualitative software coding program, QSR NVivo®. After importation, the study began a dynamic, multi-month process of topic and analytic coding to assign references within the transcripts and documentation to appropriate categories. The case analysis process followed a combination of qualitative data analysis strategies recommended by Miles and Huberman (1994), Eisenhardt (1989) and Yin (2003).

IMPORTANT TYPES OF KNOWLEDGE ON INTERNATIONAL PROJECTS

To answer the first question, "What types of knowledge are important for firms engaged in an international project?", specific knowledge was coded that: (a) the firm directly collects on their global projects, (b) the manager directly indicated was important, or (c) caused differences or difficulties on the project, indicating that the knowledge was retrospectively important. Ultimately, we ended up with the coding categories shown in Table 2. Out of all sources, the percentage of coding for each of these elements varied between four to nine percent, indicating that of the majority of companies faced these different elements, making each type of knowledge important to realize and collect on international work.

Important International Project Knowledge by Firm Type

Throughout our coding and analysis, we noted that although all types of knowledge listed are important to each kind of firm, different types of firm's perceived different types of knowledge to be more or less important for their role during international projects. From this insight, we compared the results of company types with knowledge types and will give examples of the top three knowledge types for each type of firm (see Table 2).

Real Estate Developers/Owners

For real estate developers and owners, important types of knowledge included Social Norms, Expectations and Local Preferences, Cultural Issues, and Approval Processes. These types of knowledge are rooted deeply in the local area and need to be taken into account when deciding on the type, location and plan of a development within a city, region or country. For owners and real estate developers, particularly of buildings, each development is completely unique, requiring adjustment and change. As one informant noted,

> *Real estate development is a local business. It is not like selling McDonalds, or opening up a Starbucks coffee. We needed the local know-how because we're creating something that can't be changed. Starbucks can change the taste of the coffee if they get it wrong- but if you get it wrong when you build a building, it is steel and concrete and will sit there without being leased. In real estate, without exception to be successful, you have to think and act locally.*

The category "Social Norms, Expectations and Local Preferences" includes everything from how you are expected to act in the local context- for example, at meetings and in introductions to people- to local preferences for office design and layout. Obviously, this can have a tremendous impact on the success of a development. If it is not accepted by the local population, the development will be a failure due to lack of interest and leasing opportunities. Informants talked about everything from typical floor plate adjustments (for instance, German employees have a right to natural light by law which will reduce the typical floor plate), to ceiling heights (European ceiling heights are often higher than in the US), to operable windows and mechanical system adjustments to toilet partition sizing.

> *Even though you may have built zillions of buildings…you will very quickly find out … that locally they don't want a 50 story building because they don't like height or they don't like big floors because, for instance in Europe every secretary… has be right next to a glass window on the outside. So, automatically, social mores start to create a design of a product. So even though you knew what to build in New York you have to adjust your product to fit what the market wants.*

		Important Knowledge by Firm Type		
	All Firms	Developer	Contractor	Engineer
Approval Processes	8%	11%	9%	9%
Climate & Conditions	4%	0%	7%	1%
Cultural	8%	13%	6%	12%
Design Const Standards	9%	10%	6%	11%
Industry Organization	6%	6%	7%	8%
Knowledge of Government	6%	8%	7%	3%
Language	4%	0%	2%	8%
Laws & Regulations	8%	8%	6%	5%
Logistics	7%	4%	11%	8%
Market Knowledge	4%	6%	1%	0%
Mtl and Labor	8%	5%	10%	10%
Operating Laws	8%	4%	13%	4%
Relationships	4%	5%	2%	0%
Social Norms & Local Preferences	8%	18%	5%	8%
Work Practices	8%	3%	9%	14%
		(N=40)	(N=92)	(N=72)

Table 2: Important Types of Knowledge for International Projects

The "Cultural" code includes everything from cultural beliefs to different concepts and meanings found in different areas to cultural disputes. For real estate developers, the main areas of importance reside within concepts and meanings and cultural beliefs. They have a real need to understand the minds of their customers, for instance with marketing campaigns and sales, as well as the people that they work with in the area. One informant talked about issues in setting apart buildings based on the lack of understanding of what is included in rentable square feet:

> *In the States, it's a very sophisticated formula, so when one building says you have 21,000 sq. ft. of usable space of our building by BOMA standards, you can go to any other building and ask them what their usable square footage on their floor is per BOMA and they'll tell you, and the numbers mean something, you can compare them. In India, that doesn't exist. In India, developers literally just tell you what you're renting, what your rentable area is and you have no idea what that relates to. There's no transparency as far as how they came up with that number, what the number relates to or what's included or not included in that number.*

Informants also frequently discussed the concept of time, which often became an issue with people they worked with or hired. One developer commented:

> *We've had serious arguments with our partners, and they… philosophically believe that Americans are nuts for worrying so much about the finish deadline—they think it's an emotional waste to worry about what month a project is going to be finished.*

Another indicated:

> *I've noticed [in India] that people's perception of time is definitely a lot more elastic than the Western perception of time. In the western culture two days means two days whereas in emerging markets, two days could mean*

two days plus or minus another two days…So, it's been an issue of risk perception and risk tolerance levels.

Approval processes fall between categories- requiring not only regulative knowledge, but also knowledge of the norms. For instance, the process of obtaining approvals is often not transparent and requires prior experience or intimate knowledge of the party granting approval. Some developers talked about the difficulties of developing in China in the late 1990's due to the fact that the "rule book" was still being written. This required almost 200 approvals, but changed on a day to day basis. Others talked about the challenge of acquiring clean land to build property and the unique land entitlements in different areas. For instance, in Prague, there were claims of land ownership prior to the Nazi invasion in World War II. One informant talked described a similar challenge in India:

In new developments, the biggest challenge has been finding land with clean title. This forced us to partner with locals who own land and who can prove that they have a clean title to a piece of land, have gone through the government approval process and who have been sanctioned for a specific buildable area. You need to ensure that the land that is truly clean and is sanctioned by the government as buildable area. This is something that we knew was difficult—but we had no idea how difficult!

Another informant described his frustration in attempting to figure out and deal with different approval processes—and even the meaning of receiving approval. In the example below, he talks about having permission from the planning commission, but still needing approvals from other city and regional departments. And even after getting the approvals, he would be responsible for ensuring upgrades to the city's infrastructure.

Sometimes this leads to frustration… clearly even if you've done some analysis when you are acquiring a site you may not be aware of the different hurdles or zoning requirements in that country and you can become stuck because it means that your development program could be delayed or face additional cost or create problems to deal with. No developer likes surprises.

Clearly, real estate developers and owners want to acquire knowledge related to their customer's expectations and beliefs as well as the meanings, norms and approval processes of the many people they need to work with in order to complete the development. Their general goal is to complete a building that will be accepted and leased in the marketplace to generate long term revenue, which has a long time horizon.

Contractors

Contractors were less uniform in the types of knowledge they needed for international projects; however, the top three categories included: Operating Laws; Material and Labor Quality, Availability and Cost; and Logistics; followed closely by Work Practices and Approval Processes. These types of knowledge tie intimately to the actual construction phase of the project with important knowledge relating to everyday working operations, finding necessary labor and equipment and ensuring timely delivery of products and materials to the site.

Operating laws included multiple daughter codes of labor laws, taxation, customs, company registration, tax laws, money repatriation, insurance policies, land laws and contractual differences. The most noted of these laws was labor laws, which focus on the requirements to hire local labor, the ability to mobilize international labor (which often addresses which nationalities are allowed to work there) and the availability of work permits. Contractors discussed everything from South Africa's Black Economic Empowerment (BEE) regulation, which requires subcontracting a portion of the work to Black South Africans, to immigration policies and local labor requirements:

> *The immigration policy [is also very important] for workers because construction is still quite people intensive…So we need to determine if they will allow people to come in and out freely or if they require that we use only locals. This makes a big difference. If they insist that you use only local people and the work culture is not conducive to using local labor, we are in trouble.*

Another contractor discussed the requirement for diverse labor pools, particularly in the Gulf, to ensure that contractors were not exploiting only the cheapest labor available in the world:

> *The problem of obtaining visas for workmen is the single biggest factor which will influence your progress… a work visa… especially in the UAE has a cap on the number of people that you can employ from one country. So, suppose I have 100 Koreans, 100 Filipinos, or 100 people from Bangladesh. Then I can't bring in the 101st guy unless I have at least 40 or 50 people from another nationality.*

The operating laws will influence the amount of labor and equipment required from the local area, and from this requirement comes the necessity to understand the cost, quality and availability of labor, materials and parts within an area. This can include available equipment, as this informant discussed:

> *I managed a pipeline project in Botswana in Africa. The market conditions were such that we couldn't mobilize our standard construction equipment and operate it efficiently due to a lack of spare parts. Even though all our construction equipment was made by Caterpillar of the USA, the equipment is made to different standards and the spare parts would not fit.*

This coding category also includes knowledge about productivity norms:

> *Productivity norms are very different. If you are used to American welders, you might know that an American welder can do [X] flanges of 6" pipes in half an hour. Well, in Azerbaijan, the same scope of work might take an hour and a half. So you have to be really careful and understand these differences in productivity norms…it affects all parts of your project.*

Logistics is also of utmost importance to contractors. They need to know how they will ship and transport resources, mobilize at the site location, work with currency and banks, ensure safety and security and set up camps for workers.

> *We need to find a place to live… we have to figure out how to set up a camp for people to come and start doing the work… We have to figure out deals with airlines because we'll have masses of people coming in (about the*

project can have 1000 or more expats)… we need to figure out how to bank and deal with money- opening bank accounts, paying labor, etc…..

Overall, the contractors were concerned primarily with operating laws and processes, availability of equipment and labor to complete their work, work practices and the logistics of constructing the project. In other words, they were concerned with completing the work contracted to them within the laws and norms of the area. This concern is highly location-specific and is limited to the scope and duration set forth in the contract.

Engineers

Engineers indicated the importance of, and differences encountered in Work Practices, Cultural Differences, and Design and Construction Standards and Permit Processes.

Design and Construction Standards and Permit Processes are important for engineers in order to adhere to specified standards and create a design that meets local requirements. There were some discussions of the differences and problems resulting from metric versus imperial units, but most discussions revolved around regional standard differences. One person talked about the different standards for concrete in the UK vs. Hong Kong:

The local tweaks on your technical stuff [are important to understand], you know the local Hong Kong office for instance… for some bizarre reason concrete shrinks more in Hong Kong than it does in UK. No, it doesn't! But they have within their local codes of practices and regulations a higher value for shrinkage of concrete than you do in the British standards.

Engineers also mentioned the importance of understanding capabilities and work practices within a local area in order to create a buildable design. One informant described an issue that occurred when working in a design-build contract with a French contractor on a project in Hong Kong:

[The contractor] was used to high quality precision machines in Paris for reinforcement bending so that you could optimize the use of reinforcement and wanted to do the same thing in Hong Kong. They contracted with the lowest priced subcontractor who said they could do it to that specification-- but the subcontractor couldn't do it to our specification so the reinforcement didn't fit inside the cage.

Cultural beliefs, conceptual meanings and misunderstandings were also important for engineers. Sometimes this was in contractual relationships with others, but at other times this became an issue for engineers within their own company. One informant discussed problems with value engineering due to cognitive cultural mental models:

In Korea …it's really face saving- they believe that once they put something on paper it's sacrosanct. So the concept of value engineering can't exist because nothing could be better than what is on the paper because it's sacrosanct. You can get kind of crazy trying to deal with face saving, particularly if something really won't work.

Another informant talked about how understanding a local area's culture was becoming more important as the emphasis on environmental and social sustainability increased:

> *In Australia, we tried to find an acceptable route for a new road through Aboriginal land—they spent a lot of time talking to the Aborigines to discover the meanings and ancient cultural importance of the land to determine a route alignment that avoids all the Aboriginal sites and it is therefore acceptable to the local people.*

Overall, engineers were interested in completing a design that was locally acceptable and buildable. Their contracts varied and thus affected the type of knowledge that was more or less important to them. Although the client would dictate the design and construction standards within the contract (which many participants noted is frequently based on international standards), the engineers still had to understand the codes and standards in order to complete the design. For the same reason, savvy engineers were interested in gathering information on local work practices to adjust their design accordingly. In addition, understanding culture was very important both within the company and also to meet new goals for sustainable projects. It should be noted that designers who supplied standard designs for specific equipment, such as boilers, did not worry about acquiring this knowledge.

CONCLUSIONS

Contributions to theory

AEC scholars have primarily concentrated on legal and regulatory aspects of institutional differences on international projects, broadly categorizing cultural differences. This research attempts to expand on these two kinds of differences to examine a broader range of cross-national differences —and, hence, needed knowledge— in international projects. Open-ended questions enabled managers engaged in international work to talk openly about what knowledge they perceive to be important, either through differences and difficulties encountered or knowledge they strategically collected. This enabled the research to learn about and expand upon the normative differences encountered on international projects in addition to the political, economic and cultural differences encountered. Finally, by studying three types of firms within the AEC sector, this research expands upon prior studies that focused only on contractors, enabling us to analyze important knowledge by company type.

Contributions to practice

Many companies agreed to participate in our study due to the impact the findings could have on their international projects. Several informants commented that they had many "Aha!" moments throughout the interviews, and almost everyone wanted to see the results, specifically requesting "lists" of important knowledge that they could use in their data gathering and knowledge collection to evaluate and mitigate the "liability of foreignness" on their international projects. Firms and managers can attend to these differences by focusing on the expanded and detailed knowledge and sources documented in our results. Our hope is that an understanding of these differences, and how to acquire and share knowledge about these differences, will enable firms to better align their projects to the local context, increasing the success rate of international work.

Limitations

The sample of firms was substantial for case study research of this type, but there were still limitations. The firms studied and participants interviewed had to agree to participate in the research. In addition, there can be some bias when relying on manager's perceptions of important knowledge. Specifically, informants may not have realized the importance of some kinds of tacit knowledge about the deeper cognitive cultural influences on global projects. There were also practical limitations—the time and resources to travel, interview, collect, transcribe and analyze the results—that restricted the number of firms in the study.

Future Research

The growth of international construction work, combined with the difficulties firms face when expanding internationally, dictates the need to attend to differences encountered and knowledge required. Understanding the knowledge that is important for international projects is therefore critical for project success. We are only beginning to understand and untangle the complex web of knowledge in these projects and many gaps remain to be filled by future research. Future research can attempt to validate and refine the findings and expand the number of companies interviewed. Additional work can also examine the sources and methods used to acquire this knowledge. Instead of only looking at company type, future work can analyzed important types of knowledge according to project scope and the project phase in which the knowledge is needed. And finally, additional work is needed on how this type of knowledge can be transferred within a single firm.

References

Baloi, D., and Price, A. D. F. (2003). "Modelling global risk factors affecting construction cost performance." *International Journal of Project Management*, 21(4), 261-269.

Bing, L., Tiong, R. L. K., Fan, W. W., and Chew, D. A. S. (1999). "Risk Management in International Construction Joint Ventures." *Journal of construction engineering and management*, 125(4), 277-284.

Chan, E. H. W., and Tse, R. Y. C. (2003). "Cultural Considerations in International Construction Contracts." *Journal of Construction, Engineering & Management*, 129(4), 375-381.

Economist, T. (2008). "Economics Focus: Builidng BRICs of Growth." The Economist, 88.

Eisenhardt, K. M. (1989). "Building Theories from Case Study Research." *The Academy of Management review*, 14(4), 532-550.

Flyvbjerg, B., Bruzelius, N., and Rothengatter, W. (2003). "Megaprojects and Risk: An Anatomy of Ambition." Cambridge University Press, Cambridge.

Gunhan, S., and Arditi, D. (2005). "Factors Affecting International Construction." *Journal of construction engineering and management*, 131, 273.

Han, S. H., Asce, M., Park, S. H., Kim, D. Y., Kim, H., and Kang, Y. W. (2007). "Causes of Bad Profit in Overseas Construction Projects." *Journal of construction engineering and management*, 133, 932.

Mahalingam, A. A., and Levitt, R. E. R. (2007). "Institutional Theory as a Framework for Analyzing Conflicts on Global Projects." *Journal of construction engineering and management*, 133(7), 517.

Miles, M. B., and Huberman, A. M. (1994). "Qualitative data analysis: an expanded sourcebook." Sage, Thousand Oaks, CA.

Orr, R. J., and Scott, W. R. (2008). "Institutional exceptions on global projects: a process model." *Journal of International Busienss Studies*, 39, 562-588.

Pennings, J. M. (1994). "Organizational Learning and Diversification." *Academy of Management journal*, 37(3), 608.

Reina, P., and Tulacz, G. (2007). "The Top 225 International Contractors: Firms are now more selective." *Engineering News Record*, 30-53.

Sachs, J. (2005). "The End of Poverty: Economic Possibilities for Our Time." The Penguin Press, New York.

Scott, W. R. (2001). "Institutions and Organizations." Sage, Thousand Oaks, CA.

Shou Qing, W., Robert, L. K. T., Seng Kiong, T., and David, A. (1999). "Political Risks: Analysis of Key Contract Clauses in China's BOT Project." *Journal of construction engineering and management*, 125(3), 190-197.

Spradley, J. P. (1979). *The ethnographic interview*, Holt, Rinehart and Winston, New York.

Yin, R. (2003). "Case Study Research: Design and Methods." Sage, New York.

Zaheer, S. (1995). "Overcoming the Liability of Foreignness." *Academy of Management journal*, 38, 341-341.

INVESTIGATION AND MODELING OF CRITICAL SUCCESS FACTORS IN CONSTRUCTION ORGANIZATIONS

Emad Elwakil[1], Mohammad Ammar[2], Tarek Zayed[3], Muhammad Mahmoud[4], Ahmed Eweda[1] and Ibarhim Mashhour[4]

[1] PhD Student, Concordia University, Department of Building, Civil & Environ. Eng., 1455 De Maisonneuve Blvd. West, Montreal, Quebec, Canada H3G 1M8.
[2] Associate Professor, Structural Engineering Dept., Faculty of Engineering, Tanta University, Tanta, Egypt. Presently: Visiting Scholar, BCEE Department, Concordia University, Montreal, Quebec, Canada. mamammr@yahoo.com.
[3] Associate Professor, Building, Civil, and Environmental Engineering Department, Concordia University, Montreal, Quebec, Canada, email: zayed@encs.concordia.ca
[4] M.A.Sc Student, Concordia University, Department of Building, Civil & Environ. Eng., 1455 De Maisonneuve Blvd. West, Montreal, Quebec, Canada H3G 1M8.

ABSTRACT

Profit and success are considered the main drivers of any organization. Achieving this success is based on many factors which have a direct effect on the performance of these organizations. Predicting construction organizations performance helps define the weak organization points in order to improve its performance and increase the profit. In construction organizations, it is more difficult to achieve or maintain a scientific strategy to measure their current success due to the diversity and complexity of construction organizations. Previous studies used questionnaires and interviews with technical and professional persons. However, most of these studies concentrated on the critical success factors on project level. The scope of this study is to investigate the most significant organizational success factors with focus on construction organizations. This paper aims at determining most significant (i.e. critical) success factors, and to develop a model to predict the company performance based on these critical success factors. The potential success factors were surveyed from the literature study. A questionnaire was prepared for evaluating the effect of those potential success factors on organizational performance. The data collected were analyzed using Artificial Neural Networks (ANNs). Neuro-Shell software was used to rank the potential success factors utilizing the data obtained from different construction organizations. The critical success factors were used in-turn to develop a NN prediction performance model of construction organizations. The model can be used to predict the performance of a construction organization based on estimated values of its success factors.

INTRODUCTION

Currently, the world is witnessing construction booming. Profit and success are considered the main drivers of any organization. Achieving success is usually based on many factors which have direct effect on the performance of organizations. In construction organizations, it is more difficult to achieve or maintain a scientific strategy to measure their current success due to the diversity and complexity of construction organizations (Abraham 2002). Predicting performance of construction organizations helps define weak points in order to improve its performance and increase the profit. Kaplan and Norton (1993) concluded that it is critical to measure and control new strategies after they have been put to work at the operational phase of construction organizations. In a research conducted to measure the performance on executive monitoring system, Holophan (1992) proved that critical success factors (CSFs) are the best methodology to develop an executive monitoring system to contain corporate-wide indicators of success.

Success is the main aim of any organization. Many research efforts have been done to determine the success factors but most of these studies have been done on the project level not on the organizational level. The determination of CSFs was approached via various methods. The most commonly used methods are questionnaires and interviews with technical and professionals. Most of the construction organizations CSFs are qualitative rather than quantitative. To reach construction organization success, it was found that there is a need to determine these factors and determine the critical ones at the organizational level. A model can be build to relate organization success with CSFs, which can then be used later to predict and improve organizational performance.

The scope of the present study is to investigate the most significant organizational success factors with focus on construction organizations. The main objective is to specify CSFs after prioritizing potential success factors and determining their impact on the performance of construction organizations. This study went through the following organization. Literature review of critical success factors and previous modeling work was carried-out. Extensive efforts were done to collect data from various construction organizations. Data analysis was performed using artificial neural network technique. The neural network technique was used to rank potential success factors covered in the questionnaire. A regression-based model to predict organizational performance was developed. The proposed model was verified and then validated using R^2 statistical measure.

LITERATURE REVIEW

Organization as a term has many different definitions. It is defined according to the American Heritage College Dictionary (1993) as: “An organization is a structure through which individuals cooperate systematically to conduct business.” Aldrich (1979) defined the organization as: “Goal directed boundary-maintaining activity systems.” The definition of success has been changed and more developed to include the quality of the project as an indication of success. The project success differs from one person to another and the success criteria are changing according to the project itself. However, success is mostly defined as the overall achievement of a project goals and expectations (Parfit and Sanvido 1993). Manufacturing, communication

and other industries used the revenue growth rate measurement over a period of time as a factor to determine success. The previous definitions of success are project oriented. Moreover, they are not easily measurable whether they are quantitative or qualitative factors.

CSFs as a concept and their applications to business are not new; it dates back to 1960s by Daniel (1961). CSFs appeared first in information system industry to identify executive information needs (Rockart 1979). Rockart (1981) approached and described the principles of success factors to make a systematic way of identifying the needed information for executives. Rockart (1982) defined CSFs as "the limited number of areas in which satisfactory results will ensure successive competitive performance of the organization." Rockart and Bullen (1981) differentiated between the goals and CSFs through the traditional strategic planning and management, where the goal and objectives are fairly well known but the CSFs definition is much less clear. However, the organization goals are defined to be the targets that are established to achieve the organization's mission. They are very specific, known what and when to be achieved, by whom and should have a quantitative measurable elements (Richard 2004).

Rockart (1979) identified four prime sources of CSFs for any organization working in any industry, which are:

1. Structure of the industry: has its own set of CSFs which are dependent on its characteristics.
2. Competitive strategy, industry position and geographic location: Each organization has its own strategies and strategic plan due to the nature of the industry in which it operates.
3. Environmental factors: the effects of the environment upon the organization behavior are essential to understand the CSFs.
4. Temporal factors: CSFs change with the change of the organization priorities, where the areas of activity for success changes and some activities become more critical and other become less critical.

Ahmed and Dye (1994) addressed the common essential attributes of business organizations throughout an extensive literature. These attributes should be taken into consideration while analyzing organization performance. These organizational performance criteria and their sub-factors are summarized in Table 1. Camp (1995) gave a list of the most important internal business processes that might be considered when evaluating firm's performance against other competitors. The list includes: Market Management, Product Design and Engineering, Product Operations, Customer Engagement, Logistics and Inventory Management, Product Maintenance, Business Management, Information and Technology Management, Financial Management, and Human Resource Management. The first six factors are considered operational business processes, while the rest are support business processes.

In furniture industry, Buxey (2000) described the various strategies of Australian companies, in which the main strategies' attributes are product innovation and quality, brand image, excellent customer support, outsourcing, relocation to off-shore sites to lower cost, and tariff protection. Quesada and Gazo (2007) modeled a prioritization tool for ranking CSFs and key performance measures and internal business processes in furniture organizations. As a result of Quesada and Gazo (2007)

study, it was concluded that the most critical internal business processes for the office furniture companies were customer engagement and product operations.

Table 1: Performance Criteria and Factors (Adopted from Caballero and Dye 1999)

Business Experience	Personnel	Financial
Number of years in business	Number of full time employees	Annual Revenues
Number of Contracts completed, previous 3 years	Average length of time employed	Liquid Quick Assets
Largest contract completed in last 3 years	Ratio of supervisors to tradesmen	Dollar value of lines of credit
References	Level of training of supervisors	Dunn and Bradstreet rating
Type of License	Workers Compensation	Aging of receivables
	Modification factor	
	Established full-time office	

Past studies on CSFs in the IT industry used semi-structured or structured interviews for data collection; through which the organization's key factors could be known. These efforts provided a standardized set of CSFs that can be used in different types of IT organizations. Pollais and Frieze (1993) also proposed a list of CSFs for IT organizations which was developed using strategic management concepts, specifically competitive advantage and strategic planning.

CONSTRUCTION ORGANIZATIONS SUCCESS FACTORS

Abraham (2002) adopted the approach of Pollais and Frieze (1993) for combining the latest strategic management theory; the seven guiding principles of strategic management for civil engineering (Chinowsky and Meredith 2000), with the latest CSFs methodology theory for IT organizations (Rochart et al. 1996). Abraham (2002) added a third dimension and incorporated information from organizational behavior theory, specifically the characteristics of an organization, with the two knowledge domains. A fuzzy-based expert system model was developed by Caballero and Dye (1999) to help individuals, agencies, or general contractors to rank and classify the capability of competing construction organizations to perform a certain project. According to Jaselskis el al. (1996), safety was considered as a performance success factor and to achieve excellence in construction. Furthermore, construction industry combined injury and illness which were rated to be the most after agriculture.

According to Abraham (2002), a proposed list of CSFs for construction organizations can be developed from the characteristics of organizations, organizational behavior theory, and the seven guiding principles of strategic management utilizing the Pollais and Frieze (1993) approach for the IT organizations. The methodology followed by Pollais and Frieze (1993) was quantitative (survey-based research) while Rockart et al. (1996) and Martin (1997) used a qualitative (interviews with top executives in the industry) methodology. The quantitative methodology goal was to isolate categories before the study undertaken as precisely as possible, while the qualitative one expects the nature and the definition of categories to change in the course of a project

(McCracken 1988). Then, Abraham (2002) combined the two methodologies together in order to benefit and capture the advantages of both.
Abraham (2002) developed the CSFs from Rockart et al. (1996) identification of eight imperatives for IT organizations and Chinowsky's (2001) identification of seven guiding principles of strategic management for civil engineering industry. The list is not inclusive in all construction organizations, but organizations should take into consideration the updates to CSFs methodology as the CSFs can be changed by time according to environmental issues, transformation of industry, and variations in competitive strategy. Abraham (2002) revealed eleven CSFs for construction organizations. These factors are: Competitive Strategy, Market Conditions, Political Environment, Organizational Structure, Technical Applications, Employee Enhancements, Process Benchmarking, Feedback and Evaluation, Inter Organizational Relationships, Environmental Factors, and Management Skills and Relationships. Chinowsky (2001) comprises seven areas according to the results of interviews with civil engineering, construction, and public agency executives; which are Vision, Mission, and Goals, Core Competencies, Knowledge Resources, Education, Finance, Markets, and Competition. Based on the literature review and focusing on construction organizations, the most potential CSFs are given in Table 2. These factors will be considered in the present study.

Table 2: Potential Success Factors Choosing for the Present Study

No.	Success Factor	No.	Success Factor
1	Clear Vision, Mission and Goals	10	Usage of International Aspects (ISO)
2	Competition Strategy	11	Availability of Knowledge
3	Organizational Structure	12	Usage of IT
4	Political Conditions	13	Business Experience (no. of years)
5	No. of Full Time Employees	14	Product Maintenance
6	Employee Culture Environment	15	Quick Liquid Assets
7	Employee Compensation and Motivation	16	Feedback Evaluation
8	Applying Total Quality Management	17	Research and Development
9	Training	18	Market Conditions/Customer Engagement

RESEARCH OBJECTIVES AND METHODOLOGY

The primary objectives of the present study can be summarized as follows:

1. Determine critical success factors for construction organizations.
2. Develop an organizational performance prediction model based on the determined critical success factors.

To achieve the previous objectives, data regarding CSFs and organization performance are collected from various construction companies. The collected data is then classified and normalized to be ready for input to Artificial Neural Networks (ANNs). ANNs are used to test the significance of CSFs. After specifying the critical success factors, a NN organization performance model is developed and then validated. Sensitivity analysis is performed to show the effect of each critical success factor on organization performance.

NEURAL NETWORKS: MODELING TOOL

Artificial Neural Networks (ANNs) attempt to model the brain learning, thinking, storage, and retrieval of information, as well as associative recognition. ANNs are introduced as hardware or software systems analogous to biological neural systems both in structure and in functionality (Moselhi et al. 1991). In the general form of a neural network, the unit analogous to biological neuron is referred to as processing element. A processing element (artificial neuron) performs summation ($\sum$) and transfer function (F) to determine the value of its output. The network consists of many of those elements usually organized into a sequence of layers with full or partial connections between successive layers specifically designated (Moselhi et al. 1991). Figure 1 shows simple three-layer network architecture.

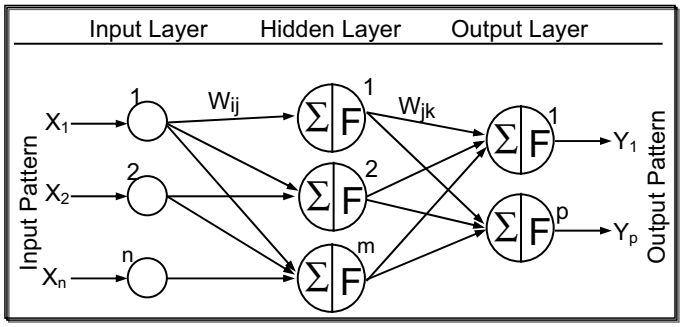


Figure 1: Typical Example of Simple NN Architecture

Similar to human thinking and decision making, an ANN takes previously trained problems to build a system of neurons that makes new decisions, classifications and forecasts. NNs learn patterns that are being presented during the training or learning phase. During the course of training, ANNs develop the ability to generalize, thereby becoming able to correctly classify new patterns or to make forecasts and predictions. Back Propagation Neural Networks (BPNNs) are one of the most common ANN structures, as they are simple and effective, and have found home in a wide assortment of machine learning applications. BPNNs start as a network of nodes arranged in three layers; the input, hidden, and output layers. The input and output layers serve as nodes to buffer input and output for the model, respectively, while the hidden layer serves to provide a means for input relations to be represented in the output. Before any data has been run through the network, the weights for the nodes are generated randomly. BPNNs support a contribution factor module which produces a number for each input parameter called a contribution factor that is a rough measure of the importance of that variable in predicting the network's output, relative to the other input parameters in the same network. The higher the number, the more the variable is contributing to the prediction or classification.

DATA COLLECTION

After identifying the potential success factors that may affect the organization performance, a questionnaire was prepared to assess the effect of each factor on organization performance. Sixty three questionnaires were sent to several construction organizations to be filled across Canada (21), Egypt (31) and other countries (11). Decision makers in these organizations are invited to fill-in questionnaires reflecting their experience. A scale from 1 to 5 is used to to rate the effect of each factor on organization performance. In addition, a percentage is used to reflect the decision-maker openion regarding overall organization success. Sample of the raw data of two responses obtained from the questionnaire is given in Table 3.

ORGANIZATION PERFORMANCE MODEL DEVELOPMENT

There are several methods to assess the significance of independent factors affecting the performance of a dependent criterion. In the present research, ANNs and regression analysis are used to assess the most significant success factors and hence evaluate the performance for construction organizations. The collected data points-out different construction organizations worldwide that are used to extract an organization performance model based on the CSFs.

Table 3. Sample of the Collected Raw Data

Category	Success Factor	Responses (1~5)	
		#1	#2
Administrative and Legal	Clear Vision, Mission and Goals	5	5
	Competition Strategy	3	5
	Organizational Structure	5	5
	Political Conditions	4	4
	Number of Full Time Employees	5	5
Technical	Usage of International Aspects (ISO)	3	4
	Availability of Knowledge	4	4
	Usage of IT	5	5
	Business Experience (no. of years)	4	4
	Product Maintenance	2	3
Management	Employee Culture Environment	5	4
	Employee Compensation and Motivation	5	4
	Applying Total Quality Management	3	4
	Training	3	4
Market and Finance	Quick Liquid Assets	3	4
	Feedback Evaluation	4	4
	Research and Development	5	5
	Market Conditions/Customer Engagement	5	5
Overall Company Performance (%)		70	80

Neural Network Training

Before an ANN is trained, training criteria must be specified in advance. These include: the maximum and minimum absolute errors and number of training cycles without improvements. The data space is divided into three sets: training set, test set, and production set. The training set is used to train the network, where the error with respect to the training cycles will be calculated. The test set is used to test the network during development/training and to continuously correct it by adjusting the weights of network links in order to reduce the error. The production set is the part of data which is not shown and used to validate the model.

Ranking of Input variables

The purpose of establishing ranks of the input variables is to determine the relative importance of the variables and those mostly affect organizational performance. In this study, quantitative estimates of the contribution of all the 18 input (independent) variables are done. The contribution percentages are derived from an analysis of the weights of the trained neural network. The higher the number, the more that variable is contributing to the classification and/or prediction. Obviously, if a certain variable is highly correlated, the variable will have a high contribution percentage. In Table 4, the contribution percentage (relative significance) of the 18 success factors are given. The success factors are ranked according to their contribution percentages. The differences in contribution percentage between each two successive success factors are also given in Table 4. The difference in contribution percent between success factors No. 9 and 10 is 0.794 which is about seven times the immediate preceding difference in contribution percent (0.117). Therefore, only the first nine factors can be considered more significant (i.e. critical) factors. These nine critical success factors will be used to perform NN training and sensitivity analysis.

Organization Performance Model

The data of the critical success factors specified previously are used only again to train NN in order to obtain an organization performance model. The same training criteria are used (maximum and minimum absolute errors and number of training cycles without improvements). The data space is divided here into two sets: training set (80%, i.e. 48) and validation set (20%, i.e. 12). The training set is used to train the network, where the validation set is used to calculate validation parameters. After the NN is trained, it can be recalled to predict the organization performance for any given values of the critical success factors.

CONCLUSIONS

Construction is a highly competitive industry nowadays. Achieving success is based on many factors which have direct effect on the performance of construction organizations. In construction organizations, it is difficult to measure performance due to the diversity and complexity of construction organizations. Most of previous studies concentrated on determining critical success factors at the project level. In this paper, a regression model has been developed to predict construction organizations performance. A multi dimensional study on construction organizations performance has been conducted using 63 surveys obtained from various construction

organizations in Canada, Egypt, France, Greece, Germany, USA, Saudi Arabia and Dubai. The obtained data was analyzed using back propagation model of artificial neural networks, which was used to determine the relative significance of various success factors. After specifying the critical success factor, a NN organization performance model was developed. The model can be used to predict organization performance of construction companies based on estimated values of its CSFs.

Table 4: Ranking and Relative Significance of Success Factors

Rank	Success Factor	Contribution (%)	Difference in Contribution (%)
1*	Availability of Knowledge	7.13	---
2*	Clear Vision, Mission and Goals	7.02	0.114
3*	Organizational Structures	6.73	0.282
4*	Feedback Evaluations	6.63	0.101
5*	Business Experience	6.55	0.082
6*	Political Conditions	6.48	0.070
7*	Research and Development	6.45	0.029
8*	Employee Culture Environments	6.25	0.199
9*	Competition Strategy	6.14	0.117
10	Market Conditions/Customer Engagement	5.34	**0.794**
11	Training	5.12	0.225
12	Number of Full Time Employees	5.01	0.105
13	Product Maintenance	4.82	0.193
14	Usage of IT	4.75	0.070
15	Quick Liquid Assets	4.37	0.378
16	Applying TQM	4.06	0.308
17	Usage of International Aspects (ISO)	3.99	0.070
18	Employee Compensation and Motivation	2.79	1.199
	SUM	**99.65**	

***** Critical Success Factors

REFERENCES:

Abraham G. (2002). "Identification of Critical Success Factors for Construction Organizations in the Architectural/Engineering/Construction (A/E/C) Industry," Ph.D. Thesis, Georgia Institute of Technology, Atlanta, GA, USA.

Ahmad, I. and Dye, J. (1994). "Development of a Database of MBE/DBE Firms and Decision Model to Determine their Capacity for the Florida Construction Industry," Technical Report No. 120, Department of Construction Management, Florida International University.

Al-Barqawi, H. and Zayed, T. (2006) "Condition Rating Model for Underground Infrastructure Sustainable Water Mains," J. of Performance of Constructed Facilities, ASCE, 20(2), 126-135.

Aldrich, H. (1979). "Organizations and Environments," Organization Studies, Englewood Cliffs, NEW Jersey, 9(1), 18-25.

American Heritage College Dictionary (1993). Houghton Miffin Org., 3rd ed., Boston.
Buxey, G. (2000). "Strategies in an Era of Global Competition," International Journal of Operations and Production Management, 20(9), 997-1016.
Caballero A. and Dye J. (1999). "Comparison of Construction Firms Based on Fuzzy Sets," Journal of Construction Education, 4(3), 313-320.
Camp, R. (1995). "Business Process Benchmarking: Finding and Implementing Best Practices," ASQC Quality Press. Milwaukee, WI.
Chinowsky, P. and Meredith, J. (2000). "Strategic Corporate Management for Engineering," Oxford University Press, New York.
Chinowsky, P. (2001). "Strategic Management in Engineering Organizations," Journal of Management in Engineering, ASCE, 17(2), 60-68
Daniel, D. (1961). "Management Information Crisis," Harvard Business Review, 39(5), 111-116.
Holophan, J. (1992). "Use of Executive Information System in Measuring Business Performance," Journal of Information Technology, 7(3), 177-86.
Jaselskis E., Anderson, S. and Russell, J. (1996). "Strategies for Achieving Excellence in Construction Safety Performance," J. of Construction Eng. and Mgmt, ASCE, 122(1), 61-70.
Kaplan, R. and Norton, D. (1993). "Putting the Balanced Scoreboard to Work," Harvard Business Review, 71(5), 34-40.
Martin, R. (1997). "Do We Practice Quality Principles in the Performance Measurement of Critical Success Factors?" Total Quality Mgmt, 8(6), 428-439.
McCracken, G. (1988). "The Long Interview," Qualitative Research Methods Series, Volume 13, Newbury Park, Sage Publications.
Moselhi, O., Hegazy, T. and Fazio, P. (1991). "Neural Networks as Tools in Construction," Journal of Construction Engineering and Management, ASCE, 117(4), 606-625.
Parfit, M. and Sanvido, V. (1993). "Checklist on Critical Success Factors for Building Projects," Journal of Management in Engineering, ASCE, 9(3), 243-249.
Pollalis, Y. and Frieze, I. (1993). "A New Look at Critical Success Factors in IT," Information Strategy, The Executive's Journal, 10 (1), 24-35.
Quesada, H. and Gazo, R. (2007). "Methodology for Determining Key Internal Business Processes Based on Critical Success Factors," Inter. J. of Physical Distribution and Logistics Management, 13(1), 5-20.
Richard, A. (2004). "Critical Success Factor Method: Establishing a Foundation for Enterprise Security Mgmt," Tech. Report, Carnegie Mellon Software Eng. Institute.
Rockart, J. (1979). "Chief Executives Define their Own Data Needs," Harvard Business Review, 38(1) 43-55.
Rockart, J. and Bullen, C. (1981). "A Primer on Critical Success Factors," Center for Information Systems Research, Massachusetts Institute of Technology,.
Rockart, J. (1982). "The Changing Role of Information System Executive: A Critical Success Factors Perspective," Sloan Management Review, 24(1), 3-13.
Rockart, J., Earl, M. and Ross, J. (1996). "Eight Imperatives for the New IT Organization," Sloan Management Review, 38(1), 43-55.

USE OF A3 REPORTS TO FOCUS DESIGN AND CONSTRUCTION CONVERSATIONS

Kristen Parrish[1], Iris D. Tommelein[2], and Glenn Ballard[3]

ABSTRACT

This paper describes a project team's use of A3 reports to focus their conversations and direct their decision-making process throughout the design phase of a hospital project. A3s are named after the size of the paper they are presented on (approximately 11" x 17") and provide a concise description of options and tradeoffs associated with a given problem or decision. A3s are widely used at Toyota as conversation pieces and to document steps of the Plan-Do-Check-Act (PDCA) cycle that supports their continuous improvement process. A3s combined with use of an integrated form of agreement (IFOA) promote the creation of shared understanding of various design options and associated design impacts, and thus support set-based design. This paper presents the development and use of an A3 report related to selection of a landscape architecture consultant. Research on this case study indicates A3 report detailing must advance in parallel to design development; otherwise, insufficient detail is available to facilitate 'real time' decision making.

INTRODUCTION

Lean project production theory describes projects as "networks of commitments" (Macomber 2005) and design as a social process (Bucciarelli 2003). These views purport that effective communication is required for successful project management. An A3 report is a tool to support effective communication, synthesizing information necessary for teams to develop a shared understanding of the project (Shook 2008; Sobek II and Smalley 2008). A3s can guide so-called 'priority conversations' (e.g., Mikati et al. 2007), explaining breakdowns or current situations as appropriate. A3s show discussion topics brought to the fore in design conversations; they are not a substitute for these conversations.

[1] PhD Candidate, Civil and Environmental Engineering Department, University of California, Berkeley, CA, kristen_parrish@berkeley.edu

[2] Director, Project Production Systems Laboratory http://p2sl.berkeley.edu/ and Professor, Civil and Environmental Engineering Department, 215-A McLaughlin Hall, University of California, Berkeley, CA 94720-1712, Phone +1 510/643-8678, FAX +1 510/643-8919, tommelein@ce.berkeley.edu

[3] Research Director, Project Production Systems Laboratory and Adjunct Associate Professor, University of California, Berkeley, ballard@ce.berkeley.edu

This paper describes the process of generating and reviewing an A3 report for a hospital project in the San Francisco Bay Area. Specifically, this A3 addresses the project team's need to select a landscape architecture consultant who is to provide expertise about the use of a green roof (Grant 2007) on the project. Project-level decisions, such as the hiring decision presented, are made by the Core Group, a group of project stakeholders contractually responsible for the functioning and operation of the project. The Core Group requires the project team to submit information for all project-level decisions in A3s. A3s are also submitted for decisions affecting operation and decisions requiring user group input.

CASE STUDY BACKGROUND

The California Pacific Medical Center's (CPMC) Cathedral Hill Hospital (CHH) project is a new 555-bed hospital in San Francisco, California, budgeted at $1.7 billion. The hospital is 93,000 m^2 (1,000,000 ft^2) with 555 parking stalls for a total of 15 above- and below-grade stories. The project is sited on sloping terrain, 11 km (6.8 mi) from the nearest active earthquake fault. Design of this hospital began in 2005 and the project is expected to complete in 2013 (Parrish et al. 2008).

CPMC is an affiliate of Sutter Health, a major healthcare provider in Northern California. Sutter Health has shown a commitment to lean practices in its hospital design and delivery processes and has experience in lean projects (e.g., Lichtig 2005b; Mikati et al. 2007). Sutter Health implements lean using a relational contract called the Integrated Form of Agreement (IFOA) (Lichtig 2005a; 2005b; 2006) that fosters an innovative and collaborative project environment.

The CHH Integrated Project Delivery team includes CPMC (owner), SmithGroup (architect), Degenkolb Engineers (structural engineer), Herrick (steel fabricator), Dowco (steel detailer), Dynamic Isolation Systems (supplier of viscous damping walls), Pankow Builders (concrete subcontractor), HerreroBoldt (construction manager and lean process integrator), and other trade partners (Parrish et al. 2008).

RELATED WORK

A3s pertain to several concepts in design theory. Viewing design as a social process, the A3 promotes communication that allows the team to build shared understanding of a comprehensive design and commit to performing specific actions to realize that design. The steps involved in creating and using an A3 are in sync with the 4 steps of the Plan-Do-Check-Act cycle (aka. the Deming cycle). In the Lean Project Delivery System™ (Ballard 2000), A3s articulate user and provider needs for each step.

DESIGN AS A SOCIAL PROCESS

Bucciarelli (2003) postulates that no single team member has a "God's eye view" of a project's design, and thus, specialists (including designers, contractors, and others) should team up and collaborate in order to effectively design and construct a project. He further explains that no single team member has enough information about the project or the current state of every industry to single-handedly develop all possible design options. Finally, he concludes these facts eliminate the possibility of decoupling design into a series of smaller, independent tasks. Thus, design teams should communicate and collaborate in order to provide a comprehensive design.

The language/action perspective (Flores and Ludlow 1980; Howell et al. 2004; Macomber and Howell 2003) describes projects as "networks of commitments." Specifically, language/action describes a commitment cycle, where a customer makes a request; a provider understands that request and commits to fulfilling it, if able; the provider declares completion, and finally, the customer confirms satisfaction with the fulfillment of that request. This commitment cycle is known as 'reliable promising,' which has become a key element of lean project delivery. Breakdowns in this commitment cycle can lead to project delays and rework, so teams must make efforts to truly understand what is being requested and whether or not they are capable of meeting those requests. Customers and providers alike must strive for clarity in describing their needs and capabilities in order to deliver their project in a lean way.

PLAN-DO-CHECK-ACT (PDCA) CYCLE

The Plan-Do-Check-Act (PDCA) cycle (Figure 1), credited to Shewhart (1939), can be used to improve any stage of a process. Deming (1986) explains that effective improvements can be made only when root causes of variation are understood. The 4 steps in the cycle determine causes of variation, and define and test possible remediation of these causes (Deming 2000).

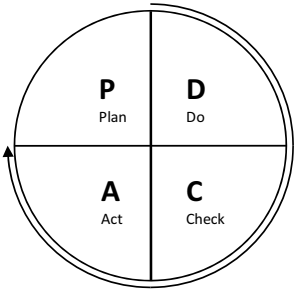


Figure 1. Plan-Do-Check-Act Cycle

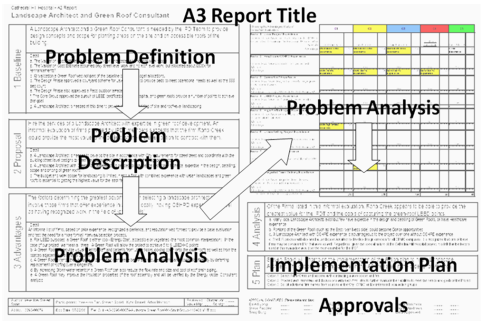


Figure 2. A3 Flow (Koga 2008)

Sobek II and Smalley (2008) define the PDCA cycle as "a high-level methodology to raise both individual and organizational consciousness about what is known and what is not known in order to resolve the problems currently faced and to prevent future recurrence… The PDCA cycle simply follows the steps of the scientific method: Plan is developing a hypothesis and experimental design; Do is conducting the experiment; Check is collecting measurements; and Act is interpreting the results and taking appropriate action." Deming (1986) explains, "planning requires prediction." Thus, planning may be re-visited multiple times due to predictions becoming more accurate after the 'check' step or testing is necessary in another set of environmental conditions.

The PDCA cycle can be used in the architecture-engineering-construction (AEC) industry on its own or, e.g., as a part of a first run study (Ballard et al. 1996) to

analyze a process. A3s can highlight the measures taken in each phase of the PDCA cycle. Sobek II (2008) enumerates the steps of the problem-solving A3 process: (1) Identify a problem or need, (2) Conduct research to understand the current situation, (3) Conduct root cause analysis, (4) Devise countermeasures to address root causes, (5) Develop a target state, (6) Create an implementation plan, (7) Develop a follow-up plan with predicted outcomes, (8) Discuss plans with all affected parties, (9) Obtain approval for implementation, (10) Implement plans, and (11) Evaluate the results. Besides being used in the course of problem solving, A3s are used for many other purposes and at many organizational levels within Toyota (Morgan and Liker 2006). At Toyota, developing an A3 report is a discipline. Its purpose is not merely to produce a piece of paper that documents a PDCA cycle; more importantly, it is to support people within an organization as the explore options and develop arguments for discussion. A3 documents establish "a concrete structure to implement PDCA management" (Shook 2008; Sobek II and Smalley 2008, p. 11).

A3 DOCUMENTS

Figure 2 illustrates the basic flow of an A3 report. A3 Report Title introduces the contents of the report. Problem Definition and Problem Description present "pertinent… information… essential for understanding the extent and importance of the problem" (Sobek II 2008). Problem Analysis describes the current condition, giving an overview of the current state, highlighting problems or opportunities for improvement, and identifying these opportunities quantitatively where possible (Sobek II and Smalley 2008). Problem Analysis also illustrates causes of the current condition and shows why these conditions can be or need to be improved. This section may include a target condition that sets out countermeasures to the causes of the major issues, and measurable objectives to determine the success of these countermeasures. Toyota engineers use the term 'countermeasures' (as opposed to, e.g., 'problem solutions') to amplify that they anticipate challenges and proactively work to preempt problems. One example of such proactive engagement is their practice of 'poka yoke' or 'mistake-proofing' (Tommelein 2008). Implementation Plan addresses who will address, when and where, and what questions that are associated with the countermeasures suggested in Problem Analysis. It also states how and when effects of countermeasures will be recorded. The Approvals section, consisting of supervisor signatures, confirms the A3 report has been discussed and the Implementation Plan approved (Sobek II and Smalley 2008, p. 83).

CHOOSING BY ADVANTAGES (CBA) DECISION-MAKING SYSTEM

Suhr (1999) developed the Choosing By Advantages decision-making system, CBA, to enable sound decision-making. This system focuses on comparing advantages of alternatives to make a decision. CBA defines an 'alternative' as a possible decision (e.g., choose alternative 1 or alternative 2), an 'attribute' as "a characteristic, quality, or consequence of one alternative," and an 'advantage' as a beneficial difference between two and only two attributes. Only advantages are expressed in the CBA system, a disadvantage of one alternative is listed as an advantage of another to ensure advantages are not double counted. CBA defines a criterion as a decision rule

or guideline established by the decision-maker, and a factor as a container for information and data (Suhr 1999).

LEAN PROJECT DELIVERY SYSTEM

The Lean Project Delivery System™ (LPDS™) exemplifies a 'project-based production system.' The LPDS™ requires "downstream stakeholders [be] involved in front end planning and design through cross functional teams" Ballard (2000, p. 2), highlighting the need for effective communication in the design process. In each phase of the LPDS™, A3s can be used to articulate user needs and reflect how to best meet those needs. Collaborative work to develop A3s and the ensuing discussion reveals opportunities for adding value to a project. The A3 report itself does not spur innovation; rather, innovation results from conversations about issues the A3 reveals.

EXAMPLE: CALIFORNIA HOSPITAL CASE STUDY

USE OF A3S ON THE CHH PROJECT

In order to streamline the decision-making process and make it more transparent, project-level decisions are made by the Core Group, as mandated by the IFOA. This group consists of David Long (Sutter Health), Geoffrey Nelson (Operations Advisory Committee representative with CPMC), Ralph Marchese (Marchese Co.), Steve Peppler (SmithGroup), Paul Reiser (HerreroBoldt), Lonnie Andrews (Pankow Builders), and Tony Burg (Sutter Health).

The Cathedral Hill Hospital (CHH) team is experimenting with the development and use of A3s to improve their project's delivery. Managing with A3s represents a major cultural change for the team, so they have tailored Toyota's process to their own organization's need and they are making adjustments to it as they hone their skills. At CHH, Integrated Project Delivery (IPD) team members write A3s to provide information for decision-making to the Core Group. Value Analysis techniques are often employed by the team during the A3 effort. A3s are reviewed by HerreroBoldt's Value Manager, John Koga, and are then either revised or passed on to the Core Group for review in their meeting. As the A3 process evolves, the team is changing their A3 review process. At the time of this writing, the Core Group is phasing in discussions with the A3 author during their meetings as part of the A3 process. A3s may be revised after first Core Group review to capture new information, re-define the problem or countermeasures, or both.

LANDSCAPE ARCHITECT AND GREEN ROOF CONSULTANT A3 REPORT

The Landscape Architect and Green Roof Consultant A3 report used on CHH (Figure 2) is shown in detail in Figures 3 through 8. The detailed figures have been modified, however, to reflect the new purpose of this A3 (i.e., to serve as an example for this paper) and the A3 standards implemented at CHH at the time of this writing. Figure 3 shows the Baseline section, which explains the need for a landscape architect and green roof consultant (defines the basic problem). The Detail subsection expands on reasons why the services of such a consultant are necessary for the project (explanation of problem context). It also quantitatively describes the problem,

explaining budget allocations for landscaping and the need for a landscape architect's expertise to design the landscaping and estimating the costs of these designs.

1 Baseline	A Landscape Architect and a Green Roof Consultant is needed by the IPD Team to provide design concepts and scope for planting areas on the site and on accessible roofs of the building.
	Detail: a. The Validation Cost Estimate allocated $837k for landscape and irrigation work scope. b. The Validation Cost Estimate assumed only street level work and no roof level work, but allocated about $500k for enhancements. c. At Validation a Green Roof was not part of the baseline design or budget allocations. d. The Design Phase approved a courtyard scheme for Levels 5 and 6 to provide beds to meet operational needs as well as the 555 bed count. e. The Design Phase also approved a Peds outdoor terrace at Level 7. f. The Core Group approved the pursuit of LEED certification for the hospital, and green roofs provide a number of points to achieve that goal. g. A Landscape Architect is needed at this time to provide designs for pricing of site and roof-level landscaping.

Figure 3. Landscape Architect and Green Roof Consultant A3: Baseline

Figure 4 shows the Proposal section, which follows the same format as the Baseline section. The suggestion to hire a landscape architect with expertise in green roof development is supported by an explanation of the value this specialist's expertise would bring to the IPD team and the project. Specifically, this specialist can provide a landscaping plan to meet the city of San Francisco's requirements for trees lining the street, and provide detailed designs and cost estimates for green roofs.

2 Proposal	Hire the services of a Landscape Architect with expertise in green roof development. An informal evaluation of firms provided by IPDT members suggests that the firm C1 would provide the most value to the project, so the preferred option is to contract with them.
	Detail: a. A Landscape Architect is needed to develop the site in accordance with City requirements for street trees end coordinate with the building street level designs to meet the approvals of the City as well as the neighborhoods. b. A Landscape Architect with Green Root experience is needed to provide the necessary technical expertise in the design, detailing/scope and pricing of green roofs. c. The budget and work scope for landscaping is limited, hiring a firm with combined experience with urban landscapes and green roofs is essential to get the highest value for the least fees.

Figure 4. Landscape Architect and Green Roof Consultant A3: Proposal

Figure 5 shows the Advantages section of the A3 report, which states the plan to evaluate multiple landscape architects as project consultants and then lists why a green roof is important to the project. Specifically, green roofs provide as many as 8 LEED® certification points (U.S. Green Building Council 2008), a pleasant visual for hospital patients and staff, and a mechanism for capturing and reusing storm water. The Advantages section also underscores the importance of a green roof to the project, reinforcing the need to hire a landscape architect with green roof expertise.

3 Advantages	
	The factors determining the greatest advantages for selecting a landscape architect primarily involve those firms that offer experience in working locally, having OSHPD experience, as well as having recognized work in the field of "green roofs".
	Detail: An informal list of firms, based on prior experience, recognized experience, and reputation was formed to provide a base evaluation and test the need for a more formal interview/selection process. See Consultant Evaluation Chart. a. For LEED purposes, a Green Roof means is either cool (Energy Star), accessible or vegetated (the most common interpretation). In the case of our project, we mean all 3. A Green Roof will allow the project to achieve 6 to 8 LEED-HC points. b. A Green Roof will provide visual relief for staff and patients from upper floors looking down onto the lower roofs as well as from the spaces adjacent to the Level 5 courtyard. c. A Green Roof extends the useful life of the roofing membrane below and reduces maintenance costs significantly by deferring replacement of roofing over a longer life. d. By increasing Storm-water retention a Green Roof can also reduce the flow rate and size and cost of roof drain piping. e. A Green Roof may improve the insulation properties of the roof assembly and will be verified by the Energy Model Consultant analysis.

Figure 5. Landscape Architect and Green Roof Consultant A3: Advantages

Figure 6 shows the Consultant Evaluation CBA Table. Landscape architects are ranked according to their experience with local (San Francisco Bay Area) projects, healthcare projects (specifically with the Office of Statewide Health Planning and Development (OSHPD), California's hospital design regulatory agency), green roofs, LEED®, high-profile projects, urban settings, CPMC, and IPD teams. Ranked according to these criteria, C1 is preferred. Figure 7 shows the A3 Analysis section and expands on the rationale for this choice.

Figure 8 shows the Action Plan. It outlines how a specific person from the IPD team will proceed in hiring a landscape architecture consultant, first attempting to negotiate a contract with C1 and if that fails, interviewing the other consultants to determine their ability to integrate with the IPD team. If neither of these results in a hiring, the IPD team will try to find additional consultants to interview.

The Core Group considered the information shown in the A3. They discussed whether or not all information necessary to make a decision about hiring a landscape architecture consultant had been presented. When confident they had all they needed to make a decision, they discussed the suggested Action Plan to make sure it aligned with the project goals and budget. They then approved the Action Plan, by initializing the bottom right corner of the A3 (Figure 2), and subsequently moved to the 'Do' portion of the PDCA cycle.

Choosing By Advantages Study of: Consultant Evaluation										
	C1		C2		C3		C4		C5	
Factor 1: Local Project Experience										
Criterion: Min: 2 local projects >$1 M in scope since 1998 in the Bay Area. More is better										
Attribute:	San Francisco		San Francisco		San Francisco		Southern CA		Palo Alto	
Advantage:	**Much more close exper.**	100	**Much more close exper.**	100	**Much more close exper.**	100	!	0	**Close Exper.**	85
Factor 2: Healthcare OSHPD Experience										
Criterion: Must have successful involvement with OSHPD projects.										
Attribute:	Yes		Yes		Yes		Yes		No	
Advantage:	**More OSHPD**	90	**More OSHPD**	90	**More OSHPD**	90	**More OSHPD**	90	!	0
Factor 3: Green Roof Experience										
Criterion: Must have designed successful large green roofs in recent years.										
Attribute:	Yes		Yes		Yes		Yes		Yes	
Advantage:	!	0	!	0	!	0	!	0	!	0
Factor 4: LEED Project Experience										
Criterion: Must have min 5 years experience with LEED.										
Attribute:	Yes		Yes		Yes		Yes		Yes	
Advantage:	!	0	!	0	!	0	!	0	!	0
Factor 5: High Profile Project Experience										
Criterion: Should have several high profile projects that occurred at a local level										
Attribute:	Yes		No		No		No		No	
Advantage:	**More**	60	!	0	!	0	!	0	!	0
Factor 6: Urban Setting Project Experience										
Criterion: Must have min 2 project experiences in an urban setting										
Attribute:	Yes		Yes		Yes		Yes		Yes	
Advantage:	!	0	!	0	!	0	!	0	!	0
Factor 7: CPMC Project Experience										
Criterion: Should have worked successfully with CPMC in the past										
Attribute:	No		Yes		No		No		No	
Advantage:	!	0	**More CPMC**	40	!	0	!	0	!	0
Factor 8: Integrated Team Delivery Experience (LEAN)										
Criterion: Have IPD team delivery experience. If not, should be interested in participating.										
Attribute:	No		No		No		No		No	
Advantage:	!	0	!	0	!	0	!	0	!	0
TOTAL IMPORTANCE OF ADVANTAGES										
	250		**230**		**190**		**90**		**85**	

Figure 6. Landscape Architect and Green Roof Consultant A3: CBA Table

4 Analysis	Of the Firms listed in this Informal evaluation, C1 appears to be able to provide the greatest value for the IPDT and the goals of capturing the green-roof LEED points for the Project.
	Detail: a. Many local Landscape Architects exist but few have expertise in the design and detailing of Green Roofs, or have Healthcare experience. b. Portions of the Green Roof (such as the East/Van Ness side) could become Donor opportunities. c. A Landscape Architect with OSHPD experience is advantageous to the project over one without it d. The EIR process will also need a Landscape Architect to develop design direction for all CPMC campuses It is recognized that one of these firms may be considered for that work as well. Regardless, given the special nature of the Cathedral Hill Hospital project, it is felt that the factors used in this evaluation would be the most desirable for the IPDT.

Figure 7. Landscape Architect and Green Roof Consultant A3: Analysis

5 Plan	Steven Spaid will champion the implementation of the Action plan to hire a Landscape Architect. The options for taking action on this A3 are listed in the order of preference.
	Option 1: Select C1 and proceed with contracting a work scope and fee.
	Option 2: Proceed with interviews and discussions with each firm listed to further evaluate their abilities to meet the needs and goals of the Project.
	Option 3: Solicit add'l. firm names from sources at City, CPMC and/or interested local action groups.

Figure 8. Landscape Architect and Green Roof Consultant A3: Action Plan

CONCLUSIONS

Conversations and collaboration between project team members are essential for successful project delivery. A3s can provide a basis for these conversations. Collaboration across disciplines and the Lean Project Delivery System™ is necessary to generate A3s and determine an appropriate course of action given the information they present. Problem-solving A3s document the Plan step of the PDCA cycle, and guide conversations about how to Do (implement), Check, and subsequently Act to continuously improve processes or tasks needed for project delivery. A3s support the development of shared understanding of a process or task amongst team members.

The Core Group of the Cathedral Hill Hospital project is committed to the use of A3s. Their requirement that all submissions to the Core Group be in the form of A3s has supported collaboration amongst the IPD team and has fostered consistency in communication and a learning environment on the project. The use of A3s on this project can be studied further to illustrate their effectiveness in supporting decision-making strategies and in making Core Group actions more transparent.

ACKNOWLEDGMENTS

We thank David Long of Sutter Health, John Koga and Paul Reiser of HerreroBoldt, and Lonnie Andrews of Pankow Builders for their support in researching the use of A3s on CHH. We also thank our research team partners Prof. Bozidar Stojadinovic and John-Michael Wong for their thoughtful review and input. This research is funded by grant CMS-0511044 from the National Science Foundation (NSF) and by gifts made to the Project Production Systems Laboratory (P^2SL)(http://p2sl.berkeley.edu). All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the writers and do not necessarily reflect the views of the NSF or P^2SL members.

REFERENCES

Ballard, G. (2000). "Lean Project Delivery System." LCI White Paper 8, Lean Construction Institute. September 23. Available at www.leanconstruction.org.

Ballard, G., Casten, M., and Howell, G. A. (1996). "PARC: A Case Study." *Proc. 4th Ann. Conf. Intl. Group for Lean Construction*, Birmingham, UK, 14 pp.

Bucciarelli, L. L. (2003). "Designing and Learning: A Disjunction in Contexts." *Design Studies*, 24(3), 295-311.

Deming, W. E. (1986). *Out of Crisis*, Massachusetts Institute of Technology, Center for Advanced Engineering Study, Cambridge, MA, 507 pp.

Deming, W. E. (2000). *The New Economics,* Massachusetts Institute of Technology, Center for Advanced Educational Services, Cambridge, MA, 247 pp.

Flores, F., and Ludlow, J. (1980). "Doing and Speaking in the Office." In G. Fick and H. Sprague Jr. (Eds.) (1980). *Decision Support Systems: Issues and Challenges: Proc. Intl. Task Force Meeting,* 23-25 June, 95-118.

Grant, E. (2007). "A Decision-Making Framework for Vegetated Roofing System Selection," PhD Diss., Virginia Polytechnic Inst. & State Univ., Blacksburg, VA.

Howell, G. A., Macomber, H., Koskela, L., and Draper, J. (2004). "Leadership and Project Management: Time for a Shift from Fayol to Flores." *Proc. 12th Ann. Conf. Intl. Group for Lean Constr.*, Copenhagen, Denmark, 8 pp.

Koga, J. (2008). Pers. comm., "A3s at Cathedral Hill." HerreroBoldt. SF, CA. July 1

Lichtig, W. (2005a). "Sutter Health: Developing a Contracting Model to Support Lean Project Delivery." *Lean Construction Journal*, 2(1), 105-112.

Lichtig, W. (2005b). "Ten Key Decisions to a Successful Construction Project." *Proc. Amer. Bar Assoc. Forum Constr. Ind.*, 29-30 Sept., Toronto, Canada, 27 pp.

Lichtig, W. (2006). "The Integrated Agreement for Lean Project Delivery." *Construction Lawyer*, 26(3), 8 pp.

Macomber, H. (2005). "LCI 7th Congress Keynote Address." Reforming Project Management, http://www.reformingprojectmanagement.com/2005/09/21/513/.

Macomber, H., and Howell, G. A. (2003). "Linguistic Action: Contributing to the Theory of Lean Construction." In C. Formoso and J. C. Martinez (Eds.) (2003). *Proc. 11th Ann. Conf. Intl. Group for Lean Constr.*, 22-24 July, Blacksburg, VA.

Mikati, S. O., Roller, T. G., Tommelein, I., and Khanzode, A. (2007). "Priority Conversations: A Case Study on Priority Walls." In C. Pasquire and P. Tzortzopoulos (Eds.)(2007). *Proc. 15th Ann. Conf. Intl. Group for Lean Constr.*, 18-20 July, East Lansing, MI, 431 - 441.

Morgan, J. M., and Liker, J. K. (2006). *The Toyota Product Development System: Integrating People, Process, and Technology*, Prod. Press, NY, NY, 377 pp.

Parrish, K., Wong, J.-M., Tommelein, I., and Stojadinovic, B. (2008). "Set-Based Design: A Case Study on Innovative Hospital Design." In P. Tzortzopoulos and M. Kagioglou (Eds.)(2008). *Proc. 16th Ann. Conf. Intl. Group for Lean Constr.*, 16-18 July, Manchester, UK.

Shewhart, W. A. (1939). *Statistical Method from the Viewpoint of Quality Control*, Washington, The Graduate School, Seattle, WA, 155 pp.

Shook, J. (2008). *Managing to Learn: Using the A3 Management Process to Solve Problems, Gain Agreement, Mentor, & Lead*, Lean Ent. Ins., Camb., MA, 138 pp.

Sobek II, D. K. (2008). "Steps of the A3 Process." Available at http://www.coe.montana.edu/IE/faculty/sobek/A3/steps.htm. Accessed 08/30/08.

Sobek II, D. K., and Smalley, A. (2008). *Understanding A3 Thinking: A Critical Component of Toyota's PDCA Management System*, Taylor & Francis Group, LLC, New York, NY, 186 pp.

Suhr, J. (1999). *The Choosing By Advantages Decisionmaking System*, Quorum, Westport, CT, 293 pp.

Tommelein, I. (2008). "'Poka Yoke' or Quality by Mistake Proofing Design and Construction Systems." In Tzortzopoulos & Kagioglou (Eds.)(2008). *Proc. 16th Ann. Conf. Intl. Group for Lean Constr.*, 16-18 July, Manchester, UK, 195-205.

U.S. Green Building Council (2008). "LEED." Available at http://www.usgbc.org/DisplayPage.aspx?CMSPageID=220. Accessed 08/31/08.

CREATING ORGANIZATIONAL CHANGE: MINIMIZING CLIENT GENERATED CONSTRUCTION INEFFICIENCIES AT THE US ARMY MEDICAL COMMAND

Jacob S. Kashiwagi[1], Neha Malhotra[1], Eduardo Luna[1], Dean T. Kashiwagi[2], and Kenneth T. Sullivan[3]

[1]Graduate Student, Del E. Webb School of Construction, Arizona State University, PO Box 870204, Tempe, AZ 85287-0204; PH (480) 965-8196.
[2]Professor, Del E. Webb School of Construction, Arizona State University, PO Box 870204, Tempe, AZ 85287-0204; PH (480) 965-8196; dean.kashiwagi@asu.edu.
[3]Assistant Professor, Del E. Webb School of Construction, Arizona State University, PO Box 870204, Tempe, AZ 85287-0204; PH (480) 965-8196; kenneth.sullivan@asu.edu.

1. Abstract

The United States Army Corps of Engineers (COE) and Army Medical Command (MEDCOM) work in tandem to meet the hospital construction requirements for military bases located across the country. Over the past three years, MEDCOM has partnered with the authors to increase the efficiency of their construction delivery system through the research and testing of a new performance information environment. The objective of the research is to create an organizational structure and performance reporting platform that minimizes the need for decision making by the Director of MEDCOM. If the performance information environment can generate clear, timely, accurate, and dominant information, the need for decisions will be reduced, as the data will drive organizational operations and become self-regulatory. To date, the information has allowed an increase of contract performance from an average of 25% on-time and on-budget, to a current average of 40% on-time and 67% on-budget. This paper documents the hurdles and impacts, based upon a three year research effort, of implementing an automated technology for collecting and tabulating performance metrics, to create and sustain an information environment. Past literature has also shown that some 80% of organization change fails, the key finding of this paper is that performance information can be used to drive organization change and culture adjustment to create a sustained efficiency improvement in a large bureaucratic entity.

2. Introduction

Hospital renovation projects are complicated due to numerous external factors that impact construction. On account of the critical nature of the function of the building, it is the objective of hospital construction and facility management groups to keep facilities maintained and operational during renovations, with minimal impact to the patients and visitors. The ability to deliver a finished product on schedule and within budget plays an essential role in the stability and continuance of the building's operation. Despite these realities, the historical performance of hospital construction has been very poor, with over 40 percent of recently completed projects exceeding their original schedule and budget goals (Carpenter 2008). These performance problems are not isolated to hospital construction, but are a reflection of the entire industry (Egan 1998, Post 1998, PSC 2003, CIB 2003).

The United States Army Medical Command (MEDCOM) is a hospital construction organization that identified with the poor performance of the industry. MEDCOM is responsible for the construction, maintenance, and repair/renewal of over 26 medical facilities in the United States, servicing over 5 million soldiers (active, retired, and their relatives) and civilian employees (U.S. Army Medical Department 2008). MEDCOM prioritizes Medical Major Repair and Renovation facility project requirements and facilitates the execution of approximately 250 projects with a scope of $300M each fiscal year. To support this workload, the MEDCOM works in conjunction with the U. S. Army Corps of Engineers (COE) to administer and manage design and repair/renovation contracts.

Due to current global events and initiatives, MEDCOM anticipated an increase in construction requirements. The Director proposed that in order to increase the output, performance, and efficiency of the organization with fixed resources, MEDCOM could not continue following the current behaviors, but required a completely different operating model. The Director attended a research seminar that introduced an organizational structure that achieved optimization by naturally aligning individual functions through the use of a performance information environment. From this seminar, the authors proposed to the Director that an information environment could be established at MEDCOM through a gradual transformation, using performance information as the stimulant for increasing adoption.

This paper will discuss the details of MEDCOM's adaptation of a performance information-based organizational structure, including: the initial steps taken, the implementation and organizational problems encountered, lessons learned during the three year research test, the steps that have enabled MEDCOM to sustain the transition over the three year period, and the plans for the future. Furthermore, the results of the transition are presented and the prospects for future research analyzed. Only a brief theoretical background of the structure is discussed in this paper, but additional information can be found in supplementary publications (Kashiwagi et al. 2008, Pauli et al. 2007).

3. Information Environment

Within MEDCOM, the authors sought to implement an organizational structure that was founded on the measurement and application of performance information (Deming 1982, Bourne et al. 2000). Central to the structure is a reporting arrangement that quantifies, compiles, and compares the real time results of all individuals related to MEDCOM projects. The objective of the structure is to provide impartial data that minimizes the need for extrapolation or decision making within the organization (Chowdhury 2001). If the performance information-based structure, or environment, can generate clear, timely, accurate, and dominant information, the need for an individual to substitute subjective experience will be reduced. Initiatives and changes are made based on actual rather than perceived circumstances. The data can then drive organizational operations and in effect, become self-regulatory. The primary tools created to support the reporting system are the Weekly Risk Report and the Director's Overview.

3.1 Weekly Risk Report

Within a project, three main organizations are working together, MEDCOM (with a Project Integrator who requests the project and a Quality Assurance Engineer who oversees the design and quality of the project), the COE (the entity handling the contracting portion of the project and the project management functions), and the IDIQ contractor (the vendor performing the design and construction). The IDIQ contractor is at risk to complete the project, as design and construction is their expertise. MEDCOM and the COE provide information and owner requirements that are necessary for the contractor to perform their work. The Weekly Risk Report is a contractor generated document that is submitted at the end of every work week from the commencement of a project to its conclusion. It records any risk issues that have developed that will affect the project's performance (budget, schedule, customer satisfaction), the risk's impact to the project, the person responsible for the risk, and what is being done to minimize the risk. The document is cumulative and serves as a record detailing the project problems from their inception to resolution. This report is distributed to all individuals involved on the project as well as the MEDCOM Director.

The Weekly Risk Report clearly identifies the reason a project is behind schedule or over budget and the entity that is responsible for the issue. The report is distributed directly from the contractor to all individuals involved, regardless of rank. This eliminates the manipulation of information, pinpoints the source of the problem, and places immediate attention on that individual and the action that is required for the resolution of the issue. As a result of the dominant information being passed, minimal external management is needed.

3.2 Director's Overview

The Director's Overview allows the Director to compile the 250+ project risk reports that are received weekly to gain a definitive overview of MEDCOM. The performance of MEDCOM is presented in terms of current budget, the number of change orders involved, the total number of current projects, the percent of projects

on time and on schedule, the average number of risks per project, and the average customer's satisfaction on each project. The report then ranks or prioritizes all of the projects according to their degree of risk (percent over budget, percent over schedule, and owner satisfaction, scaled based upon the size of the project's budget). The report also compares the performance of the individuals within a specific role, in order to recognize the relative performance ranking of each person (Project Integrator, Project Manager, Quality Assurance Engineer, COE, or Contractor). For example, all project managers are compared against one another based on the performance of the job(s) for which they are responsible (the performance of their jobs is defining via the metrics outlined above). Lastly, the report compares the performance measurements of the various areas or Regional Offices. These reports are distributed by the Director to the appropriate parties. For instance, the contractors are able to see their performance numbers compared to the other contractors, the percent of MEDCOM's projects they were responsible for, and the percent of change orders they were responsible for.

The Director's Overview allows the Director to easily identify where problems are occurring in the organization. Instead of trying to address all the problems within the organization, the Director is able to isolate the projects with the highest risk impact and devote primary attention to them. The information distributed from the overview allows the Director to pass information to each individual regarding their current status in relationship to the whole. This provides an automated system that allows everyone in the organization to understand the strengths, weaknesses, and areas of improvement in the organization. Thus the research has found that the weekly risk report and director's overview tools minimize internal decisions and management resources requirements on a weekly basis.

4. Initial Process Implementation

Due to the breadth and magnitude of the MEDCOM organization, the initial implementation of the information environment tools extended over two years. The tools were applied to 30 new projects during the first year, and later expanded to cover all new and in-progress contracts (280 projects to date). The early problems encountered had very little to do with the actual process, and were related more to the general issues involved in change (Rogers 2003): Defining the initial conditions, measuring the change, and educating the employees.

4.1 Defining Initial Conditions

First, the organization had a difficult time defining the initial structure and functions of MEDCOM. There was no official handbook that was referred to in defining MEDCOM's current processes, separation of job functions, or individual responsibilities. After interviewing several key components, it became clear that there were several different perceptions of the original system. Projects were being handled differently depending on their regional location in the United States and the MEDCOM personnel assigned to the project. The job functions of the various components (Facility Manager, Project Manager, Quality Assurance Engineer, COE, and Contractor) seemed to meld together until it was difficult to distinguish the different roles. The instability of the system made it very difficult to introduce

changes into MEDCOM. Much of the initial efforts included establishing a basic sense of conformity in defining the roles, processes, and system.

Another cultural hurdle with which MEDCOM was dealing was reliance upon relationships. Information regarding the actual occurrences on a project was "screened" by the personnel onsite prior to it reaching the knowledge of the Director. The Project Integrator, Project Manager, Quality Assurance Engineer, COE, and Contractor, were working closely together. Reporting the poor performance of one component could breed bad feelings that would affect the actions of the component in the future, on that project and others. The information each individual reported to their superiors was constrained by their perception of how this would affect their current and future work in terms of favor trades between contractors and other personnel as well as the concealment of problems in exchange for the suppression of others.

4.2 Measuring the Change

Secondly, there was a lack of existing measurements within the MEDCOM organization. The Director and authors were required to establish the measurements that were important to the performance and results of MEDCOM. The Weekly Report and Director's Overview went through several iterations during the first year as the measurements were adjusted according to emerging information and the organization's needs. Additionally, the lack of benchmarking measurements did not provide the organization with a motivation for change. It was impossible to quantify the current performance of the group, as statistics involving the number of open projects, the status of the projects, and even the current budget were not readily available. While individuals expressed an intuitive feeling of inefficiency and dissatisfaction with the original structure, there was no evidence to support a critical need for change. Furthermore, momentum for change became difficult, as the impact or change brought about by the information environment could not be immediately quantified.

4.3 Educating the Employees

Lastly, because of the number of integrated roles involved in the MEDCOM projects, the extensive distance between locations, and the involvement of individuals not hired directly by MEDCOM, system-wide education of the information environment was difficult to accomplish. At the outset, MEDCOM attempted to educate the eight Project Integrators, who would then in turn educate the other components (Project Manager, Quality Assurance Engineer, COE, and Contractor). However, the following misunderstandings resulted, slowing the adoption of the tools:

1. The COE did not understand the contract requirements (Weekly Report and Director's Overview).
2. The COE interpreted the new MEDCOM requirements as conflicting with their internal processes.
3. Individuals were educated to different degrees.
4. Individuals interpreted the education they received differently, resulting in conflicting perceptions. This resulted in many disagreements and inconsistencies in the process.

Despite the difficulties of integrating the Weekly Report and Director's Overview into the MEDCOM processes, through the persistence of the MEDCOM Director and continuing education from the authors, all projects were being tracked and measured after the second year of research testing.

5. Organizational Change

According to documented statistics, 50-80 percent of change initiatives of various sizes fail for Fortune 1000 companies. However, the numbers are lower for larger sustainable changes or the actualization of organizational strategic plans, where only 10 to 30 percent are successfully implemented (Boyne et al. 2007). The implementation of the information environment tools was only the first step in MEDCOM's change. It did not guarantee the success of the larger impact of organizational change. The authors were aware of the high probability of failure in implementing measurements into an organization's structure, and especially in a government entity with a large scope of requirements. Unsuccessful attempts in government agencies, both inside and outside of construction, had been well documented (Bourne et al. 2000, Newell 2008a, Newell 2008b, Dalrymple et al. 2006, Friel 2008). The majority of efforts did not fail because of difficult or complex tools; but because of an inability to change the organization's deep rooted culture. Although MEDCOM is still in the process of internal change, the preliminary cultural problems encountered are presented below.

From the performance information collected, the largest paradigm shift that the data required of MEDCOM was the realization that the majority of project issues and change orders were attributed to their internal processes and communications, and not to the contractor (as was previously believed). The organization had maintained this position for so long, that inefficient behavior attempting to retain risk from the contractor had been adopted, substantially increasing the MEDCOM management function and cost. This unsubstantiated belief had altered the focus of the MEDCOM role to encompass the contractor's management responsibilities, adding redundancy to the processes and confusing lines of accountability. It had also blinded the organization to their internal inefficiencies and process problems. It was only after performance information had been obtained from the Weekly Reports verifying that the source of project problems stemmed from internal mistakes (See Table 1) that MEDCOM began to understand and accept that the majority of the change would have to be made from within.

In Table 1, it shows that of the 9691 days of delay on tracked MEDCOM projects, only 5% of the delay was attributable to the contractors, with the vast majority stemming from MEDCOM's facility managers (FM) and the Corps of Engineers (COE) contracting and project management functions. Likewise, Table 1 also shows that the majority of cost impacts stem from incomplete contract requirements and internal client project management, as generated from the COE.

Table 1: MEDCOM's source of increase to cost and duration

Entity	Days	%	Entity	$$	%
Contractor	438	5%	Contractor	$ 1,051,992	4%
FM	4271	44%	FM	$ 4,425,692	16%
COE	3742	39%	COE	$ 21,149,101	77%
Unforeseen	1240	13%	Unforeseen	$ 939,076	3%
Totals	**9691**		**Totals**	**$ 27,565,861**	

From this information, the Weekly Risk Report served as a training tool for MEDCOM components to convert from behaving as the construction expert who managed the vendor, to the supporting role of allowing the vendor to control the project, providing the necessary components inherent to the owner. This shift made both the MEDCOM and Contractor personnel uneasy. The IDIQ Contractors had grown comfortable working in an environment where they were not expected to solve problems, but took direction from the owner representatives. The owner representatives had begun to feel like resolving problems and project issues was part of their responsibility, and that the contractor could not be trusted to act in the best interest of the owner. Though, upon learning that the majority of project delays and cost impacts were caused by MEDCOM personnel, the owner representatives became more receptive to transferring control to the vendors.

With the Weekly Risk Reports, the Contractors were held responsible for all delays and change orders that occurred. All risks to the project must be reported on the report, stating who was responsible, what must be done to minimize the risk, and the resulting impact (in time and money) to the project. This motivated the contractor to become proactive in their approach to project issues, as it was not in their best interest to have a project report with a large amount of risks (especially since the contractors would be compared to their competitors). Issues listed on the report were more apt to have a speedy resolution, as the responsible party was clearly identified. The culture change was tracked over time, as illustrated in Table 2 (which shows the first three years of implementation and testing), as the number of risks needing to be listed on the report diminished with the number of days it took to resolve each risk. The Weekly Risk Report also assisted the MEDCOM personnel. Their function in the Weekly Risk Report was limited to validating the report (checking the accuracy) and rating the contractor's performance in handling the risks. If there was a risk not identified on the report, they could request it to be added, but the contractor was the entity that would have to create the plan to resolve the risk. The information reporting system and the simple requirements has served as an instrument in changing the organization's traditions regarding the interaction of functions and the focus of each role.

The heavily relationship based mentality that constrained unfavorable information from reaching directors also began to transition, as the reporting system eliminated the choice of whether to advance information forward or not. It prioritized the passing of unadulterated information over relationships, allowing the people identified as risks to act as the checks and balances of the system.

Table 2: MEDCOM risks and risk durations over time

No.	Number of Projects	Time Period	Ave. No. of Risks Per Project	Ave. No. of Days to Resolve a Risk
1	30 projects	July 1 – Dec. 31, 2005	2.5	109
2	120 projects	Jan. 1 – Dec. 31, 2006	1.1	64
3	200 projects	Jan. 1 - June 30, 2007	0.9	43
4	All projects (280+)	July 1, 2007 – Dec. 31, 2007	0.5	51
5	All projects (280+)	Jan.1, 2008 - June 30, 2008	0.7	37

6. Transformation Efforts into a Data Driven Organization

The functional goals of the research effort and MEDCOM have, over the past three years, coalesced into a singular objective of creating an organization structure that is operated via performance information, with the elimination of decision making requirements of the Director. Optimally, the Director's function will only be to set goals and vision for the MEDCOM organization, with the performance information environment tracking and sharing the pertinent metrics within the identified vision. The transformation of MEDCOM into a data driven organization have required the use of performance information to generate a culture of accountability. Through identifying and sharing performance results, the MEDCOM group has seen an increase of performance from an approximate 25 percent of projects delivered on time and 25 percent of projects deliver on budget, to a current performance mark of 40 percent on time and 67 percent on budget.

In addition to the implementation and use of performance information to drive accountability, education has been identified as a critical requirement for the sustained usage of the developed tools. To date, much of the educational efforts have been haphazard, with the authors hosting training sessions as the various project locations and regional elements allowed. With the initial three years of testing results indicating substantial efficiency improvements, the research effort has become more of a "new way of business" and is seen by organizational participants as permanent and not as a "fad" of upper management. Furthermore, the necessity of providing continuing education for the MEDCOM leaders (Director of MEDCOM, Director of Facilities for Health Affairs, TriCare Management, and the COE), on the theory behind an information environment and the importance of implementing information into their roles has also been realized. The support of the Director of MEDCOM and his senior staff has been crucial to the new educational efforts and changes that will be required and formalized as the research moves forward. Previous literature has also supported this finding that the actual support of upper management to sustaining change initiatives is critical (Kelman 2005, Cowley et al. 2007).

As accountability and education are proliferated throughout the MEDCOM organization, the research is moving forward and has begun measurement of cost and value for each organizational entity. This includes Project Integrators, Quality Assurance Engineers, Project Managers, Facility Managers, Contracting Districts, etc. As an example, each Quality Assurance Engineer will be tracked for costs incurred

versus projects performance and productivity. Over time, the Quality Assurance Engineers will be compared based upon performance, with future funding decisions being dictated purely based upon cost and value data points. Those with higher performance will see an increase in funding and responsibility. Those with lower performance will see a decrease in funding and responsibility. It is expected that over time the system will normalize, aligning each individual with the proper workload and funding. This same process will be applied to all MEDCOM organizational entities. The data driven organization will operate from the continuous feedback loop of performance information, requiring the Directors to have minimal involvement in the day-to-day functions.

7. Conclusions

This research effort has confirmed much of what has been defined in previous literature regarding organization change:

1. Establishing of initial conditions, implementing change, and measuring the difference are critical to success (Denton 2002)
2. Sustained education is critical to success (Rogers 2003)
3. The support of upper management is critical to success (Kelman 2005, Cowley et al. 2007)
4. Change requires effort and resources (Conner 1992)

In the specific case of MEDCOM, the authors have attempted to outline the confirmation and relevance of each of the above findings in the first three years of research testing. However, past literature has also shown that the overwhelming majority of change fails due to the inability of an organization to change its internal culture (Kotter 1996, Rogers 2003). The new contribution of this research is that the implementation and use of performance information at MEDCOM was able to drive and bring about culture change. Change is difficult unless a reason for change is readily apparent. In the current research effort, identification, sharing, and accountability of inefficiencies at both the project level and organization structure level have proven to increase performance and begin changing culture. Further research within different organizations is required to fully validate the hypotheses. The authors propose for future research that the high levels of organization change failure can be reduced through the use of performance information. The types, methods, and processes for identification, collection, and use of the performance metrics will need to be developed for specific organization types and application circumstances.

8. References

Bourne, M., Neely, A., Platts, K., and Mills, J. (2000). "The success and failure of performance measurement initiatives." International Journal of Operations & Production Management Year. 2002, Vol. 22, Issue 11 Pg. 1288-1310.

Boyne, G.A., Meier, K.J., O'Toole, L.J. and Walker, R.M. (2007). "Leading Organizational Change." Wharton Executive Education, University of Pennsylvania.

CIB-Programme Committee (2003). *Re-Valuing Construction.* CIB 2003 – International Council for Research and Innovation in Building and Construction,

Manchester, UK. Accessed on 5 August 2003. Url: http://www.revaluing-construction.com/

Carpenter, D. (2008). "No End in Sight." Health Facilities Management Magazine, February 2008 Issue.

Chowdhury Subir (2001). *The Power of Six Sigma.* Chicago, IL: Dearborn Financial Publishing.

Conner, D. (1992). *Managing at the speed of change*. New York: Villard Books.

Cowley, B. and Lilly, E. (2007) "Why Change Succeeds: An Organizational Self-Assessment." *Organization Development Journal*; Summer 2007, 25(1), 25.

Dalrymple, J. (2006). "Feasibility Study Linking Best-Value Procurement Assessment to Outcome Performance Indicators." *CRC Construction Innovation,* Accessed on November 1, 2006 at www.construction-innovation.info.

Deming, E.W. (1982). *Out of the Crisis*. Massachusetts: Massachusetts Institute of Technology.

Denton, D. K. (2002). "Learning how to keep score." Industrial Management, Mar/Apr 2002, 44, 2, 28.

Egan, S.J. (1998), Rethinking Construction: The Report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction. *The Department of Trade and Industry.*

Friel, B. (2008). "Management Matters." *Government Executive News,* Accessed on March 15, 2008 at http://www.goveexec.com/dailyfed/0308/030508mm.htm.

Kashiwagi, J., Sullivan, M., Sullivan, K., and Kashiwagi, D. (2008). "Transforming an Organization by Using a New Project Management Approach." *4th Scientific Conference on Project Management (SCPM),* Greece, 198-203 (May 29, 2008).

Kelman, S. (2005). *Unleashing Change: A Study of Organizational Renewal in Government.* Washington, DC: Brookings.

Kotter, J.P. (1996). *Leading Change.* Boston, MA: Harvard Business School Press.

Newell, E. (2008a). "GAO: Homeland Security lacks adequate workforce for performance-based acquisitions." Government Executive News, Accessed on May 12, 2008 at Governmentexecutive.com.

Newell, E. (2008b). "House Panel Weighs Contracting Reform Legislation." Government Executive News, Accessed on February 27, 2008 at Governmentexecutive.com

Pauli, M., Sullivan, K., and Kashiwagi, D. (2007). "Utilization of Risk Management to Show Value and Increase Competitiveness." *Cobra 2007 Conference,* Georgia Tech Global Learning Center, Atlanta, GA, CD Track 59 (September 5, 2007).

Post, N.M. (1998). "Building Teams Get High Marks." Engineering News Record, Vol 240, No. 19, 32-39.

PSC (2003). PSC Working Paper Best Value Procurement for Professional and Technical Services: Where We Stand. Accessed on Jan 1, 2004 at www.pscouncil.org/westand/Best_value.htm.

Rogers, E.M. (2003). *Diffusion of Innovations, Fifth Edition*. New York, NY: Free Press.

U.S. Army Medical Department (2008). Introduction to the U.S. Army Medical Department. Retrieved March 6, 2008, from Army Medical Department Web site: http://www.armymedicine.army.mil/about/introduction.html#structure.

HOW TO DETERMINE CONSTRUCTION PROJECT RAIN DELAY TIMES USING LOCAL RAINFALL DATABASES IN ASHEVILLE, NC

Dr. George Ford, P.E.[1], Dr. John Patterson[2] and Dr. Bradford Sims[3]

ABSTRACT

Rain delays can prove costly to construction contractors and significantly affect long-term profitability if not carefully considered during the planning stages of a project. This paper includes a short literature review of technology related to predicting construction project rain delays and an analysis of rainfall event probabilities for the Asheville, North Carolina region. An analysis methodology is provided in a step-by-step discussion which illustrates how to determine statistical probabilities of significant rainfall events to forecast construction project delays. Local rainfall data for Asheville, NC is analyzed to determine rainfall frequency to provide an example of the forecasting methodology for the reader.

INTRODUCTION

Construction project delays often pose serious financial and character threats to a contractor, but contracts are often silent on the subject (Xi, Balaji & Molenaar, 2005). There are seemingly an infinite number of ways a project may be delayed such as labor disputes, materials delivery and weather (Holman & Parks, 2001). Some construction delay issues may be avoided by sufficient planning. Poor contract management is often cited as the primary factor responsible for project delays (Frimpong, Oluwoye, and Crawford, 2003), but nobody can control the weather. Historical weather data is readily available for most geographic areas within the United States. A simplistic statistical approach to predicting weather related work disruptions may prove helpful to construction project managers during the planning,

[1] Western Carolina University, Department of Construction Management, Cullowhee, NC 28723: (828) 227-2519; FAX (828) 227-7138; email: gford@wcu.edu
[2] Western Carolina University, Department of Construction Management, Cullowhee, NC 28723: (828) 227-2438; FAX (828) 227-7138; email: jpatterson@wcu.edu
[3] Western Carolina University, Department of Construction Management, Cullowhee, NC 28723: (828) 227-2175; FAX (828) 227-7138; email: bsims@wcu.edu

estimating, and proposal stages of a project to supplement contract management functions.

The discussion which follows provides a straightforward approach for construction project managers in the Asheville, North Carolina region to determine potentially work-disruptive rainfall patterns. The methodology presented may also be applied to other geographic regions in the United States, but other weather effects besides rainfall, such as temperature, are not fully considered in this discussion in order to maintain simplicity in the methodology. A short literature review of weather related construction delays is also provided. Emphasis is placed upon predicting delays in highway construction projects, but the principles present are intended for general project applications.

REVIEW OF LITERATURE

There are several articles that discuss weather issues which trigger construction delays and lost productivity (Xi, et al, 2005; Kenner, Johnson, Matt, Miller, & Salmen, 1998; Guo, 2000; Lee, Ryu, Yu and Kim, 2005; and Lee, Woods, Jue & Speed, 2007). The South Dakota Department of Transportation (SDDOT) found that "significant time and effort are spent on settling disputes between what the contractor and the Department consider to be a reasonable number of weather related non-working days" (Kenner, et al, 1998, p iii). Kenner, et al (1998) developed weather charts for highway construction contractors to use to estimate an expected number of adverse weather delays for each calendar month of the year for six weather zones within South Dakota. They examined different highway construction project tasks and weather data including, rainfall and temperature, from a total of 103 climate stations within the state with at least 30 years of continuous data. They considered a single daily precipitation threshold of 0.30 inches per day, a daily maximum temperature threshold of 32 degrees Fahrenheit, and a combination of the two conditions as work stopping scenarios. The regional weather charts they generated could be used by construction contractors to request time extensions for their projects, one day for 0.30 inches of rainfall, two days for 0.75 inches of rainfall, and one day for maximum daily temperatures of 32 degrees Fahrenheit and below.

Guo (2000, p 67) wrote, "in practice scheduling uncertainties are usually estimated by experience and judgment". He presented a model to estimate project duration which considered the impact of rainfall. He recognized that rainfall varies due to geographic location and season of the year and also identified partial workday losses due to precipitation in his model. Lee, Ryu, et al (2005) focused on methods to estimate declines in work productivity affecting project delays, like Guo (2000) considering partial day delays. They defined productivity in terms "of work produced per man hour, equipment hour, or crew hour" (p. 1148).

Lee, Woods, et al (2008) developed a regression equation to predict construction non-working days. They analyzed precipitation, wind speed and temperature over a two year period to generate their regression model. They used the same threshold values for precipitation and temperature as Kenner, et al (1998) and Xi, et al (2005).

Holman and Parks (2001) provided a brief legal analysis of claims for construction weather delays. They defined liquidated damages as "per diem rate of damages that a contractor is obligated to pay in the event its work is not substantially complete by the required date under the contract" (p. 5). They also discussed procedures which contractors should use to document delays to avoid paying liquid damages due to weather delays.

Xi, et al (2005) wrote an extensive analysis of the effects of weather and related construction delays in an effort to assist contractors in reducing disputes and claims. They estimated that weather delays cost approximately $40 billion per year in the United States. They discussed contract language, construction operation types, precipitation, temperature, wind velocity, soil temperature and critical path scheduling methodology in their study. They also surveyed 38 state departments of transportation to obtain relevant information about contracts and related weather provisions.

METHODOLOGY

Daily rainfall data for Asheville, North Carolina was obtained from the State Climate Office of North Carolina for a 30-year period, from 1977 to 2006. This data was tabulated by year and day of the year. February 29th on the leap years was deleted from the data set to simplify data manipulation. The average annual rainfall for the 30-year period for Asheville, N.C. was found to be 37.25 inches, ranging from a low annual rainfall amount of 23.05 inches to a high of 51.68 inches. There tended to be more rainfall in the summer months with the lowest monthly rainfall generally occurring in October each year.

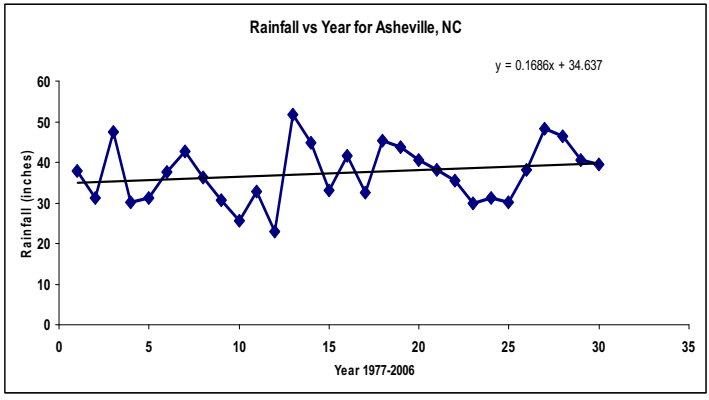


Figure 1: Annual Rainfall for Asheville, NC, 1977-2006.

The number of days with rainfall greater than 0.30 inches was counted for each year (30 years X 365 days of data points). Per previous highway construction studies, more than 0.30 inches was assumed to provide one day of estimated construction delay. In a similar fashion, the number of days with rainfall greater than 0.75 inches was counted for each year and taken to cause two days of construction delays, (one additional day above the 0.30 inch count). The results of this count found that on average, in Asheville, NC, there would be a construction delay 14% of the time or about one in seven days. In 365 days, one would expect about 51 days of rain delays. The range for the 30-year dataset of annual days of delay was found to be from 30 to 77 days per year. The trend line also shows a slight upward trend in the number of non-workday occurrences per year from 46 to 53 from 1977 to 2006 possibly due to the effects of global warming, see Figure 2 below.

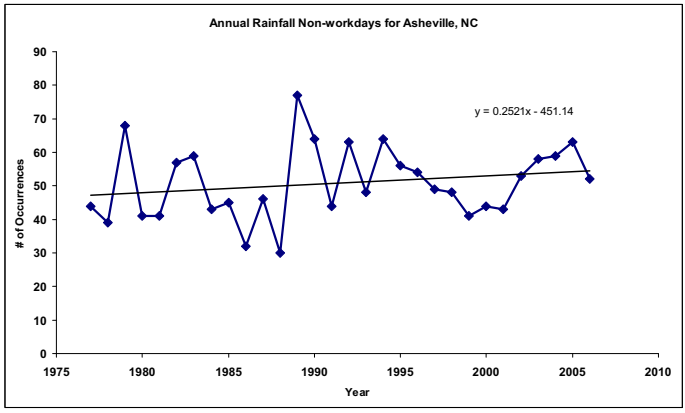


Figure 2: Annual Rainfall Non-workdays for Asheville, NC, 1977-2006

DISCUSSION

The primary finding of this study was that the weather is very unpredictable, but statistical data may help a project manager to understand when remarkable weather conditions have occurred. Contract documents must be inspected carefully early in the job to ensure that clear remedies are provided for the project manager to address loss of productivity or workday delays due to weather related causes.

The basic methodology presented here is:

1. Obtain daily rainfall data for the region where a construction project is located. The data should cover a 30 year period.
2. Tabulate the data in an EXCEL spreadsheet to simplify analysis.

3. Delete February 29th days in leap years to further simplify the data.
4. Determine the total amount of rainfall each year and graph 30 years of data to look for trends.
5. Determine the number of days in each year with daily rainfalls above 0.30 inches using EXCEL formula such as =COUNTIF(B7:AE7,">.30").
6. Determine the number of days in each year with daily rainfalls above 0.75 inches using EXCEL formula such as =COUNTIF(B7:AE7,">.75")..
7. Add the days from step 6 and 7 together to get a total number of days.
8. Graph the number of non-workdays for each of the 30 years of the period considered. Look for trends.
9. Estimate the number of non-workdays for the project due to rainfall by finding the average number of rain-delay days for each of the 30 years in the dataset and multiplying this percentage by the days of duration of the applicable project.
10. Estimate the number of non-workdays due to other related events applicable to the region in which the project is located with the best information available such as temperature.
11. Integrate the estimated productivity losses into the project proposal as applicable.

The literature review provided a litany of material applicable to forecasting weather related project delays during construction projects. The simple statistical methodology presented in this discussion provides additional information for project managers to use during the early stages of a project to minimize liability due to unanticipated weather delays so that professional reputations and financial well-being may be preserved. If precipitation induced delays are easily addressed during a project, construction managers may be able to address other unforeseen issues adequately.

CONCLUSIONS

Construction project managers may obtain a dataset of daily rainfall amounts for the geographic location of their project during the proposal stage of the project, and estimate potential delays as outlined in this paper, to determine if the project timeline provided by the customer is realistic. This may prove infeasible for smaller jobs, but once an analysis is done for a specific geographic region, then it may be re-used. In Asheville, NC, a project manager may expect about one day of lost work for every seven workdays due to rainfall alone.

REFERENCES

Frimpong, Y., Oluwoye, J., and Crawford, L. (2003). Causes of delay and cost overruns in construction of groundwater projects in developing countries: Ghana

as a case study. *International Journal of Project Management,* 21(2003), p 321-326.

Guo, S. (2000). Computer-aided project duration forecasting subjected to the impact of rain. *Computer-Aided Civil and Infrastructure Engineering,* 15(2000), p67-74.

Holman, M., and Parks, G. (2001). Snow & rain & hail & sleet: Making the claim for weather delays. *Ohio Construction Law.* August, 2001.

Kenner, S.,Johnson, L., Matt, A., Miller, R., and Salmen, A. (1998). Development of working day weather chart for transportation construction in South Dakota. Retrieved July 7, 2008 from http://ntl.bts.gov/lib/9000/9000/9083/SD97-07final.pdf.

Lee, H., Ryu, H., Yu, J., and Kim, J. (2005). Method for calculating schedule delay considering lost productivity. *Journal of Construction Engineering and Management*, 131(11), p 1147-1154.

Lee, W, Woods, P., Jue, W., and Speed, M. (2008). Predicting non-working days due to adverse weather conditions for highway construction projects in Brazos County, Texas using 2nd order linear regression. Proceedings of the Associated General Contractors Association, April, 2008.

Xi,Y., Balaji,R., and Molenaar, K. (2005). Quantify Construction Delays Due to Weather, *Federal Highway Administration, Central Federal Land Highway Division,*Research Report, Oct. 2003 to Mar. 2005. University of Colorado. Retrieved on July 9, 2008 from http://forecast.colorado.edu/~apipatta/delay/.

INTEGRATED MODULE FOR MOBILE CRANE DYNAMIC INSTABILITY ANALYSIS AND SUPPORTING SYSTEM DESIGN

Shafiul Hasan [1], Mohamed Al-Hussein [2], U. H. Hermann [3], Hassan Safouhi [4]

[1] Research Assistant, Construction Engineering and Management, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta,T6G 2G7,Canada. PH (780) 492-0370; e-mail: mdshafiv@ualberta.ca

[2] Associate Professor, Construction Engineering and Management, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, T6G-2G7, Canada. PH (780) 492-0599; e-mail: malhussein@ualberta.ca

[3] Senior Construction Engineer, PCL Industrial Constructors Inc., 5402–99 St., Edmonton, AB, Canada T6E 3N7. PH (780) 733-5514; e-mail: Rhhermann@pcl.ca

[4] Professor, Campus Saint-Jean, University of Alberta, Edmonton, Alberta, T6C 4G9, Canada. PH (780) 485-8631; e-mail: hassan.safouhi@ualberta.ca

KEY WORDS: Truck Crane; Crawler Crane; Stability, D-Crane; Outrigger Reaction; Track Pressure; Timber; Steel Plate.

ABSTRACT

Stability is an important safety issues related to the use of mobile cranes. Dynamic loading related to crane motion and load are the key factors associated with the failure to maintain stability. In this regard, the dynamic nature of mobile crane operations entails a variety of outrigger reaction values for truck cranes and track pressure values for crawler cranes. Crane supporting reaction or pressure is a function of the lifting configuration, crane geometry, and the crane component's weight; in most situations, such information is not readily available. Moreover, this paper presents an algorithm which is designed to assist practitioners in evaluating the elements required for calculating the reaction forces for both types of mobile cranes—truck cranes on outriggers and crawler cranes on tracks—and checking the stability of the crane. The developed algorithm integrates a reaction influence chart, which accounts for the dynamic relationship between the reaction of the outriggers or pressure of the crawler tracks and the boom's horizontal swinging and vertical angles. The developed algorithm is also integrated with a previously developed crane selection system and a database. Finally, a case example is described in order to demonstrate the use of the presented algorithm. The proposed system has proven to be effective in reducing the time and cost associated with the preparation of lift studies.

1. Introduction

Cranes are involved in many different tasks, and are one of the most heavily used and shared resources on construction sites (Liu 1995). In particular, efficient crane operations can have a significant impact on the overall scheduling, cost, and safety of a construction project. According to a website tracking and documenting crane accidents (www.craneaccidents.com), 347 accidents occurred worldwide in 2007 alone. Braam (2002) has noted that a significant share of crane accidents have been caused by instability during crane operations. Instability accidents for mobile cranes have generally resulted either in the crane tipping or the load falling off the hook or slings. More broadly, the cause has been improper design, lack of a proper crane support system, or a faulty decision to carry a load which exceeds the lifting capacity of the crane. As such, it has become increasingly necessary to build a methodology which can assist in the design of the supporting system for mobile cranes as well as check the operations against tipping failure and capacity constraints.

At present, planning for mobile crane operations is mostly performed intuitively and informally (Shapira and Glascock 1996). Knowledge-based expert systems have been used in construction for several years, although primarily for the purposes of equipment selection and site layout optimization and scheduling of construction activities. Today, however, lift planning and crane selection are receiving considerable attention from practitioners and academics who wish to ensure safety and economy within the workplace. Relational database management systems (DBMSs) are being widely used to model data using a simple table-type structure without having to predefine the inter-data-relations. Al-Hussein et al. (2000) have developed a database designed to house information related to cranes, including their geometric lifting configuration specifications and their lifting capacities, based on the information provided by manufacturers in crane lifting capacity charts. Computer modules for planning heavy and critical lifts have also been made available using integer programming and optimization techniques (Lin and Haas 1996).

The dynamic stability of a truck crane can be compromised for specified geometrical and load conditions (Sochacki 2007). Jerman (2006) has proposed a mathematical model for investigating the dynamic loading of a slewing crane, and obtained the dynamic forces which act on the crane's steel structure during load transport. Researchers have also observed that not only do the structures of the crane and external loads determine the dynamic behavior of mobile cranes, but the body motion and drive system of the crane are also responsible for dynamic stability (Sun and Kleeberger 2003). Moreover, in order to reduce the dynamic effect on crane operations, the swing operation must be effectively controlled. In this regard, Klosinski (2005) has developed a mathematical model of mobile crane operations in order to ensure minimization of crane swings. Also, Maczynski and Wojciech (2003) have developed an optimization algorithm of drive functions for mobile crane slewing. In practice, mobile cranes may become unstable as a result of rapid penetration of the outriggers into the ground (Tamate et al. 2005). Crane support design is commonly carried out by the rental company, the general contractors, or a third party; they use rules of thumb or manual equations to calculate outrigger

reaction and support design. Some geo-technical engineers use the traditional soil bearing capacity calculation for building foundation to design the crane mat. However, the duration of loading for a crane is relatively short and the allowable settlements for cranes are higher than for the building foundation (Liu 2005).

This research presents a newly developed automated system designed to aid practitioners in the process of preparing lift studies with the crane stability analysis and designs for a mobile crane supporting system. The methodology has been built based upon the principles of limit state structural design and in accordance with the research of Shapiro et al. (1999) in order to calculate the support reaction values for truck cranes and crawler cranes. In addition, a reaction influence chart has been produced to show the dynamic relationship between a truck crane's outrigger reaction or a crawler crane's track pressure and the boom's horizontal swinging angles and vertical boom angles to the ground. The integrated system has been developed using MS-Visual Basic™. The units of the developed system are metric; however, the user may use imperial units as the system also includes self contained unit changes.

2. Proposed Methodology

This system is comprised of the following five components: (1) crane selection, (2) crane operation details; (3) support reaction calculation; (4) stability check; and (5) support design and considers two scenarios depends on the crane operation condition: (1) static condition; and (2) dynamic condition as shown in Figure 1.

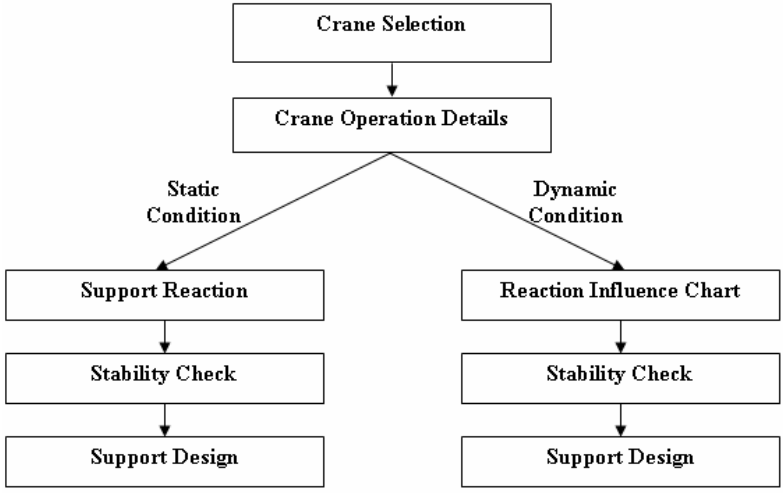


Figure 1. System Design Process

The crane selection module, which has been designed by Al-Hussein et al. (2005) to assist practitioners in selecting optimum crane configurations for a given project, is

used here to provide the geometric input for the type and size of the crane to be used in the analysis. The crane operation details module allow users to input the operation configurations and edit the crane geometric information. The geometric configurations needed to perform the calculations are not ordinarily given in the crane manufacturer's literature. Unfortunately, manufacturers supply information about their cranes in inconsistent and paper-based formats. To address this deficiency, researchers have developed a database to replace and store the existing paper-based crane load charts and geometric information in a standardized computer-based format. In this research, the "D-Crane" database (Al-Hussein et al. 2000) has been used to store information pertaining to the crane's geometry. Based on the type of the given crane under study, the geometric configuration module interacts with the crane database to retrieve the information. The user must provide the crane geometry and lifting configuration inputs if the crane dimension is not available in the database. After providing the crane configuration the rest of the design can be carried out either at a static condition or at the dynamic condition of the crane depends on the operation configuration.

Scenario 1: Static Condition

For a static condition, the reactions have been calculated for a specific boom angle (θ) and swing angle (α) (see Figure 2) as well as for a specific load. The reaction calculation module assists in determining the reaction under the crane's four outriggers, two fronts P_{fb}, P_{fc} and two rears P_{rb}, $P_{rc,}$ in the case of the truck crane (see Figure 3) and the pressure under the front and rear of each track (P_{fb}, P_{rb} and $P_{fc,}$ $P_{rc)}$ in the case of crawler crane. The crane stability analysis is based upon the following criteria: (1) material allowable stress for the material selected for the support system design; (2) soil allowable stress; and (3) crane stability against tipping failure.

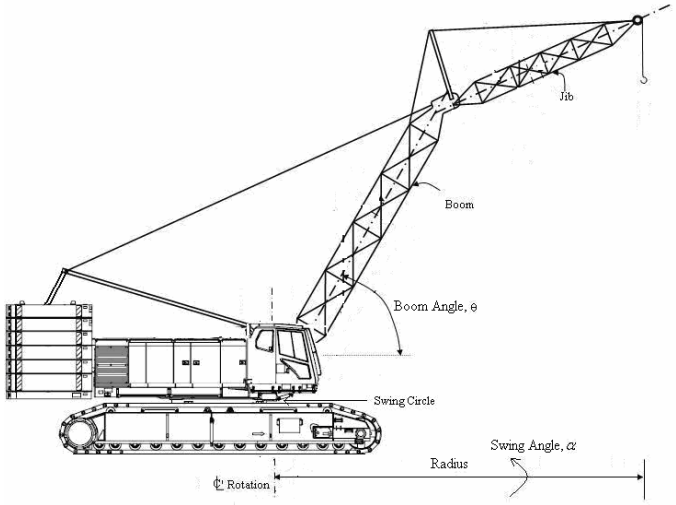


Figure 2. Mobile Crane and its basic parameters

The reaction calculation module evaluates the crane stability against tipping by highlighting the reaction with negative values (i.e., the probability that tipping will occur) as shown in Figure 3. The support design module has been described elsewhere (Hasan et al. 2008), but is also briefly described here in order to provide continuity. This module assists in designing the support foundation using either steel plates or timber for truck crane and using a timber mat approach in the case of the crawler crane, and the design is performed based on the maximum values of forces for all outrigger reactions or track pressures.

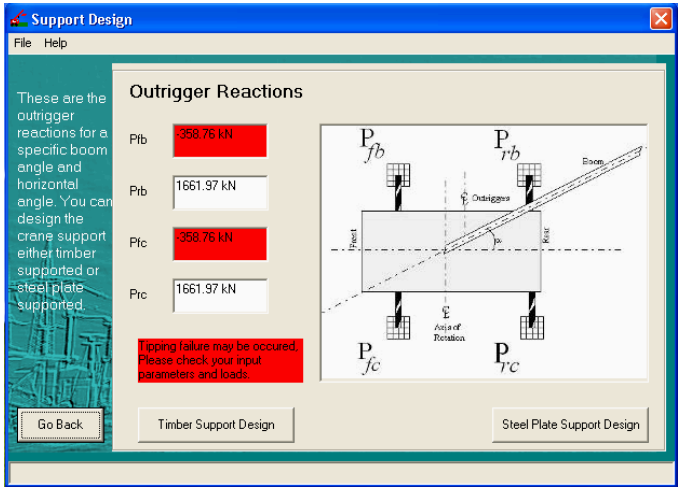


Figure 3. Instability Warning along with Outrigger Reaction Values

Scenario 2: Dynamic Condition

For dynamic condition, the reactions have been calculated for loaded and unloaded scenarios and for both changing boom angles θ and changing swing angles α. The user is given the option to specify the start and end swing angles α and the required increments of change for these angles; the user can also change the angle of the crane boom to the ground θ, specifying the minimum and maximum boom angles to be at the ground and the required increments of change of these angles as shown in Figure 4. A reaction influence chart for a 360° field of swing angles α in increments predetermined by the user has been integrated into the system in order to illustrate the variability in the outrigger's reaction with respect to a change in swing angle α over 360° for each boom angle to the ground θ and for either loaded or unloaded condition (see Figure 4). The reaction influence chart will change with either a change in boom angle (horizontal and vertical) or a change between loaded and unloaded condition. The chart shown in Figure 4 is an extension of the outrigger reaction calculations, and provides the user with the following information: (1) a global view of the pattern of reaction values for 0° to 360° swings; (2) the horizontal boom position associated with a particular potential for tipping failure; and (3) the maximum values for an

outrigger's reaction with respect to the boom's horizontal position (swing angle), boom angle to the ground, and loaded versus unloaded condition. These charts are generated automatically based on either the default values or the user inputs. In addition to being displayed in the chart, this information is also shown in the tabulated format which the user can view using a standard spreadsheet; the maximum values from that table are highlighted, available for reference by the user, below the influence chart as shown in Figure 4. The user can also view the maximum reaction value for each outrigger or track with respect to all swing angles and boom angles to the ground for loaded and unloaded condition. Again, the user can view the load distribution in each outrigger or crawler track as shown in Figure 5 for any swing angle by selecting any of the swing angles in the table.

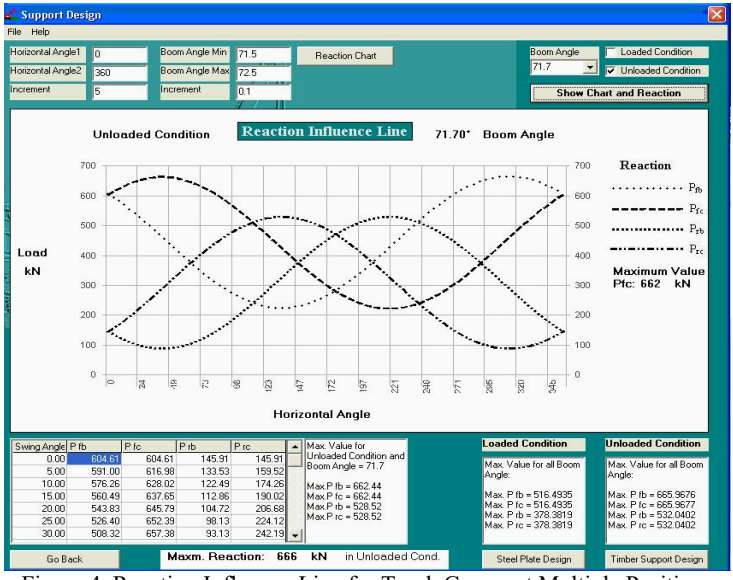


Figure 4. Reaction Influence Line for Truck Cranes at Multiple Positions

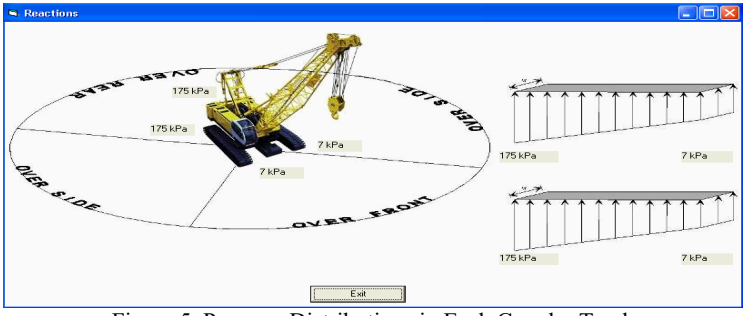


Figure 5. Pressure Distributions in Each Crawler Track

The crane stability analysis in dynamic condition can be carried out by checking the reaction values of each outrigger or crawler track in the reaction influence chart along with the spreadsheet (see Figure 4). The area of unsafe rotation is highlighted in that spreadsheet for any case in which the outrigger reaction becomes negative. The support design is performed in dynamic condition based on the maximum reaction values for all the boom angles and swing angles and for loaded and unloaded conditions as addressed in the reaction calculation step, and can be designed using the same methods as described in static condition of the crane.

The output of the crane instability analysis and supporting system design includes the following components: (1) type and model of the crane to be used; (2) crane support reactions, which is determined by calculating the values of the outrigger reaction for the truck crane as well as track pressure for the crawler crane; (3) the proposed design for the support system (steel plate or timber); and (4) the reaction influence chart for dynamic condition only, which accounts for the relationship between outrigger reaction or track pressure and horizontal swing angle of the boom in cases where the operator is required to safely swing the crane. This research considers dynamic loading condition, but all the equations used to calculate the support reaction and to check the crane stability are queasy static.

3. Case Example

This case describes the construction of the Light Rail Transit (LRT) extension on the south side of the city of Edmonton, Canada, which requires the moving of many different kinds of construction materials. The particular operation under discussion involves the lifting of a maximum load of 11,000 kg., then swinging it 360° with a constant boom angle to the ground θ and radius R (see Figure 6). The lifting radius R should be not less than 15 m. and the boom angle to the ground θ must be greater than 50°, as shown in Figure 6. The solution requires the selection of a crane that can perform this lift, as well as checking of the operation against tipping failure and calculation of the outrigger reactions for 360° of swing in order to properly design the crane support system.

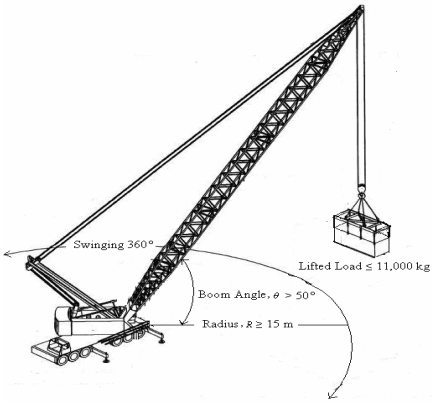


Figure 6. Crane Operation Requirements for LRT Construction

Step1: This step is carried out in order to select an appropriate crane by which to perform these lifts. By performing these configurations in Selectomatic Software (Al-Hussein et al. 2005), a list of all technically feasible cranes can be generated. The GROVE TM1400, with a counterweight of 7112 kg, is the best choice to perform the lift with this particular configuration and was thus selected for the operation.

Step2: In this step, the operation details module interacts with the "D-Crane" database and "Selectomatic" software in terms of (1) the crane's dimensions; (2) the geometric location of the respective centers of gravity of the crane's components; and (3) the respective weights of the crane's various components, which in turn are used in the algorithm to calculate the outrigger's reactions. Once the crane configuration has been added, the user need to select the support design for multiple positions of the crane as this case is dynamic condition.

Step 3: The purpose of this step is to calculate the maximum reactions in the outrigger pad. In this case the crane must be able to swing 360° in both loaded and unloaded condition with no need to alter its vertical boom angle to the ground. The output represents the outrigger reaction values for all these swing angles (over 360°) with a fixed 55.79° boom angle to the ground for loaded and unloaded conditions, along with the maximum values shown in Figure 7 and the maximum outrigger reaction value is an acceptable 530 KN.

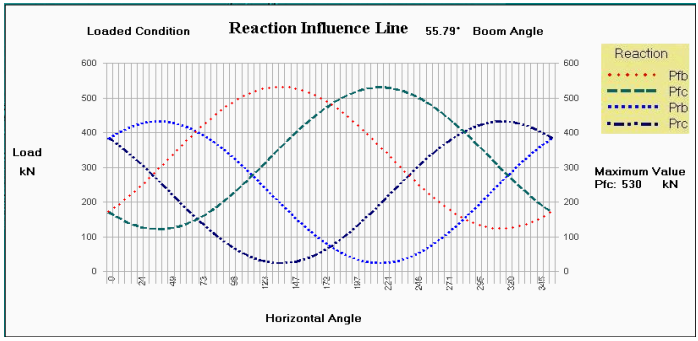


Figure 7. Reaction Influence Chart for GROVE TM1400

Step 4: In this step the crane's stability has been checked. The given crane operation can be deemed to be safe as Figure 7 has illustrated that all the outrigger reaction values are positive. GROVE TM1400 can safely rotate to 360° with the maximum load of 11,000 kg and with the given configuration. User can now design the crane supporting system using either timber or steel plate.

Step 5: The support system can be determined based on the calculated maximum outrigger reaction value from Step 3. User need to select the design option, either timber or steel, and need to provide the soil bearing capacity of the supported soil which can be determined from the geotechnical report of the soil. For the maximum

outrigger reaction 530 KN the timber design output of this system has been shown in Figure 8.

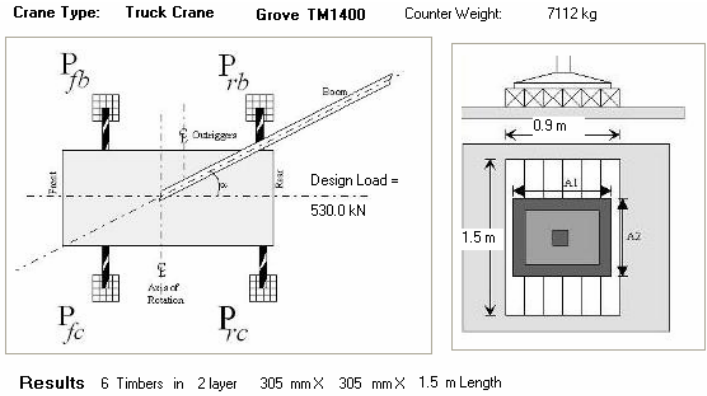


Figure 8. Crane Support Design Results

4. Conclusions

In current practice, design of the crane support system has been carried out manually based on a number of rules of thumb without calculating the proper reaction of the outrigger or crawler track. Accordingly, this research has been motivated by the large number of cranes used in the construction industry and the consequent need to design crane supporting systems more accurately. This research has also been motivated by the need to prevent crane accidents caused by poor design practice on construction sites. This paper has described the development of an automated system for the analysis and design of a crane support system; the primary focus has been on the methodology used to support planners in executing lift studies for mobile cranes. The developed automated system provides its users with additional graphics in the form of 2D reaction influence charts supporting the visualization of the forces being exerted upon the outriggers or crawler tracks for the planned lift. Furthermore, the developed support system integrates a previously developed set of selection modules as well as a crane database. To these ends, the developed methodology for this research can assist with the accurate and economical design of a crane support system as well as with preventing crane accidents caused by instability and tipping failure due to poor design practice.

References

Al-Hussein, M., Alkass, S., and Moselhi, O. (2005). "Optimization algorithm for selection and on-site location of mobile cranes." *Journal of Construction Engineering and Management*, ASCE, 131(5), 579-590.

Al-Hussein, M., Alkass, S., and Moselhi, O. (2000). "D-CRANE: Database system for utilization of cranes." *Canadian Journal of Civil Engineering*, 27, 1130-1138.

Braam, A. C. (2002). "Crane accidents evaluating the risk and feasibility of potential practices to eliminate/reduce future occurrences," Technical Report, North Carolina Department of Transportation, July.

Hasan, S., Al-Hussein, M., Hermann, U. H., Safouhi, H. (2008). "Interactive and Dynamic Integrated Module for Mobile Cranes Supporting System Design." Submitted for the publication in a journal.

Jerman, B. (2006). "An enhanced mathematical model for investigating the dynamic loading of a slewing crane." Published in the proceedings of the Institution of Mechanical Engineers, Part C, *Journal of Mechanical Engineering Science*, 220(4): 421-433.

Klosinski, J. (2005). "Swing-free stop control of the slewing motion of a mobile crane." *Control Engineering Practice*, 13(4): 451-460.

Lin, K. L. and Haas, C. T. (1996). "Multiple heavy lifts optimization." *Journal of Construction Engineering and Management*, ASCE, 22(4), 354-361.

Liu, L.Y. (1995). "Construction crane operation simulation." Published in the proceedings of Second Congress in Computing in Civil Engineering, 2, 1420-1426, Atlanta, June 5-8, 1995

Liu, X. (2005). "Soil bearing capacity for crawler cranes." MSc thesis, Department of Civil and Environmental Engineering, University of Alberta, Edmonton.

Maczynski, A. and Wojciech, S. (2003). "Dynamics of a mobile crane and optimisation of the slewing motion of its upper structure." *Nonlinear Dynamics*, 32(3), 259-290.

Shapira, A. and Glascock, J. (1996). "Culture of using mobile cranes for building construction." *Journal of Construction Engineering and Management*, 122(4), 298-307.

Shapiro, H. I., Shapiro, Shapiro, J. P., and Shapiro, L. K. (1999). *Cranes & Derricks*. McGraw-Hill, NewYork, N.Y

Sochacki, W. (2007). "The dynamic stability of a laboratory model of a truck crane." *Thin-Walled Structures*, 45(10-11), 927-930.

Sun, G. F. and Kleeberger, M. (2003). "Dynamic responses of hydraulic mobile crane with consideration of the drive system." *Mechanism and Machine Theory*, 38(12), 1489-1508

Tamate, S., Suemasa, N., and Katada, T. (2004). "Analyses of Instability in Mobile Cranes due to Ground Penetration by Otriggers." *Journal of Construction Engineering and Management*, ASCE, 131(6), 689-704.

THE REALITIES OF BUILDING INFORMATION MODELING FOR COLLABORATION IN THE AEC INDUSTRY

Carrie S. Dossick[1], Gina Neff[2] and Hoda Homayouni[3]

ABSTRACT

In this paper, we will report on how the introduction of a new technology, Building Information Models (BIM), is in the process of changing collaboration among architects, engineers, and builders. Using a multi-method study of comparative case studies and triangulation interviews, we have observed two building projects over an eight-month period, interviewed architects, engineers, general contractors and subcontractors, and we are able to create generalizable grounded theory about technology-supported collaboration. This rich ethnographic data enables the analysis of the ramifications of the existing frameworks of standards of practice and occupational boundaries for collaboration, and allowed us to identify the potential of new technology to change these frameworks.

Technology is always embedded in a social context, and its successful adoption depends upon that context. Some in the building design and construction industry are pushing for new technological advancements along side collaborative delivery methods, but there remain a number of organizational questions that must be addressed, particularly in how to engage second and third tier consultants, suppliers and subcontractors who are not part of the primary architect-owner-contractor agreements. Where delivery methods alone will not address the inter-organizational challenges, strategies such as co-location support a stronger team orientation to the project through informal communication.

[1] Assistant Professor, Department of Construction Management, University of Washington, Box 351610, Seattle, WA 98195 USA; (206) 221-4894; cdossick@u.washington.edu.

[2] Assistant Professor, Department of Communication, University of Washington, Seattle, WA 98195 USA; gneff@u.washington.edu.

[3]Ph.D. Candidate, Department of Construction Management, University of Washington, Seattle WA 98195 USA; hoda@u.washington.edu

Introduction

Buildings "have a complex social and material manifestation whose organized production is reliant on shared frames of reference" (Beamish and Biggart 2006), such as standards of practice, legal arrangements, and industry norms. Building Information Models have the potential to change these frames of reference in that jurisdictions between occupations and organizations are often tightly tied to the technologies in use and that power struggles among these groups can emerge when new technologies are introduced (Barley 1986; Bechky 2003).

Construction has been characterized as inter-organizational collaboration with bounded (internal to an organization or entity) and unbounded (across multiple organizations) modes of innovation (Harty 2005). Efforts to increase performance in the AEC industry have primarily been driven by technology adoption and are often at the trade level (Katsanis 2006). Building Information Modeling has the potential to improve inter-organizational collaboration (American Institute of Architects 2006; CURT 2004), but that the fragmented nature of the industry acts as inhibitor to the adoption of innovation in work process (Katsanis 2006).

Industry leaders have developed a number of reports that outline collaborative delivery methods, such as design-build, that address organizational collaboration between the first tier players—owner, architect and general contractor (American Institute of Architects 2006). However, research on these contracting strategies does not address the second–and third-tier players, such as subcontractors and fabricators who generate and share much of the BIM data.

Related Work

Innovation in information technology in the AEC industry is driven by competitive advantage, process problems, technological opportunity, and institutional requirements (Mitropoulos and Tatum 2000). Personal attitudes towards new technology adoption are shaped by the risks involved in using unproven means and methods; by the difficulty in implementing technology in particular settings; by financial risks involved, by the perception of other workers' attitudes towards new technologies, and by how an individual perceives the introduction of the technology (Bill 1997). Individual attitudes, skills, and learning are often seen as the keys to successful collaboration in order to manage processes and improve performance (Morton et al. 2006). Katsanis (Katsanis 2006) argues that there is higher potential for productivity gains through organizational process innovation. Taylor found that with relationships that bridge the intersection of design and construction companies the teams found more novel solutions to project problems from which both parties benefit (Taylor 2007). However, in the inter-organizational adaptation of technologies, like BIM, unforeseen repercussions beyond the implementers' sphere of influence can be present (Harty 2005).

Specific to unbounded inter-organizational innovation, researchers studying web-based project management tools for collaboration and communication across

organizational boundaries have found that: team member's attitudes towards the technology, corporate culture, relationships between companies, characteristics of the specific projects (Nithamyong and Skibniewski 2006), industry wide issues of legal precedents, communication density (described as "yet another channel"), organizational barriers, and individual's resistance to change (O'Brien 2000) impact innovation, adaptation and adoption. Researchers have found that companies resist technological change on the basis of legal risks associated with standards of practice, concerns over intellectual property, financial risks associated with capital investments in hardware and software, and the investment needed to train and maintain technologically-skilled staff (Allen et al. 2005).

In their evaluation of construction detailing teams, Listen et al. found that teams using digital tools for MEP coordination were more likely to be satisfied with the meeting process and spent less time digressing from the issue at hand compared to paper-based coordination. It seems that the digital model itself can function as a coordinating artifact to encourage conversations about the organization chart, work process and work flow, and clarification of work (Liston et al. 2007). Harty (2005) analyzes inter-organizational issues of 3D CAD adoption in the Heathrow Airport Terminal 5 project and found that since the real benefit of using 3D modeling and BIM is achieved once all the parties involved in the project are using BIM, part of the adoption process is encouraging smaller parties to adopt the technology as well. Hence, the successful adoption of the technology necessitates more transactional compensation models to allocate financial benefits to those who take more risks and do more work (Holzer 2007).

Even when companies commit the resources needed for technological change, project participants do not necessarily participate equally (Cuff 1991). For instance, in design collaboration, different styles can emerge such as Mutual Collaboration (working with the other); Exclusive Collaboration (working on separate parts of the problem); and Dictator Collaboration (designating a leader) (Maher et al. 1998). The most common approaches for facilitating collaboration involve some combination of risk sharing, obtaining access to new technologies and markets, co-location and pooling complementary skills (Eisenhardt and Schoonhoven 1996; Hagedoorn 1993; Harty 2005; Kleinknecht and Reijnen 1992; Kogut 1989; Mowery and Teece 1993).

Scholars of organization and communication are still divided about how technological change can support effective collaboration. People often use new tools to reassert professional status and difference, to "restructure" organizational forms, and to revisit previous distinctions (Barley 1986; Bechky 2003; Orlikowski 2000). New technologies do have the power to change organizational structure but scholars still do not fully understand what organizational forces need to be in place for effective collaboration to occur.

Within construction, organizational and cultural divisions between designers and builders and between contractors and subcontractors may stifle collaborative work and joint problem-solving, even as the expertise needed for buildings becomes increasing complex and professionally differentiated. Using ethnographic studies

empowered us to explore the organizational complexity as experienced by these individual actors in the natural settings of their work environment (Sommerville et al. 1993).

Setting and Methodology

Hill and Valley are pseudonyms for two urban commercial construction projects in the same city that we studied in 2007–2008. Hill is a 450,000 sq. ft. (41,806 sq. m.) mid-rise complex commercial office building. Valley is a 300-unit high-rise mixed-use residential building with retail and parking. For each project, we observed the series of MEP coordination meetings among the detailers from subcontractors for sheet metal ductwork, piping, plumbing, fire protection, and electrical systems. For both projects the design coordination and clash detection process was complex and lasted 12 to 18 months and entailed weekly meetings of 8 to 10 people. The meetings were led by representatives from the General Contractor (GC), which was the same firm in both projects. Between July 2007 and June 2008, we observed MEP coordination meetings for 12 months on the Hill project and for seven on the Valley project. A research team of one faculty researcher and one graduate student were primarily responsible for attending each meeting and writing detailed field notes as soon as possible after the meeting.

In both of the construction projects we studied, Building Information Modeling was used by subcontractors in the MEP coordination process. Subcontractors are hired to create shop drawings, fabricate and install MEP systems. After they create 3D shop drawings that outline the specific details of what will be manufactured, purchased and installed, these shop drawings are approved by the architect and design engineers. In order to create shop drawings, the detailers must coordinate their systems such that they all fit into the available space, and meet building code requirements. During weekly meetings, detailers from the subcontractors involved in MEP coordination would meet to examine the combined individual efforts of their digital detailing. From this "consolidated model," conflicts between the systems, or "clashes" were automatically and manually observed for reconciliation during the meeting. The joint model functioned to highlight potential conflicts and to help the project participants solve them, well before actual field installation began.

Concurrent with the site observations, the same team of researchers conducted 77 triangulation interviews with architects, engineers and builders in Seattle, Chicago, New York, San Francisco and Los Angeles. Respondents were invited to be interviewed based on a snowball sampling technique. Each interview was 45–90 minutes long and covered the culture and communication with the AEC industry as well as their experiences with BIM. Interviews were fully transcribed before being analyzed using qualitative analysis software (Atlas.ti).

The method of analysis in this study was based on established methods of "grounded theory" development (Glaser and Strauss 1967). The qualitative techniques of analyzing data helped us better ascertain how people use tools in practice, the ways in

which tool adoption changes power within the workplace, and how new organizational structures emerge when new tools are introduced. The research team analyzed field notes and interview data with an emergent, iterative coding schema, eventually building larger thematic categories to explain differences and similarities between the industry articles and interviews and the two cases. This paper presents a preliminary review of one of those main emergent themes, inter-organizational collaboration and the ways in which second– and third-tier participants feel disenfranchised from power and decision making processes that affect their day-to-day work.

Findings

BIM has been touted as the technological solution to collaboration, communication and information exchange in the AEC industry. Our observations and interviews reveal that although digital exchange is possible, organizational and cultural barriers inhibit collaboration and communication within AEC teams: namely, construction professionals and design professionals continue to work in silos with formal lines of communication between them, even as BIM holds the promise for increased collaboration across these divisions. The division of labor in commercial construction dictates that distinct scopes of work are defined, before the contractor "deals them out through our procurement to our fabricators and subcontractors." (interview B071107)

In Figure 1, arrows represent the channels of communication that we observed in the two construction projects we studied. Dotted lines represent the channels that respondents in our interviews wanted to have opened during projects.

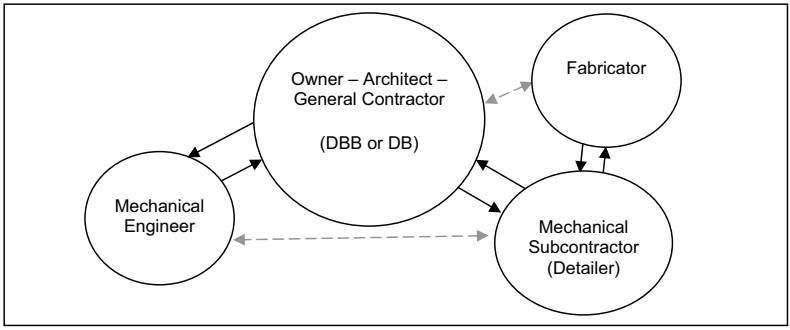


Figure 1. Organizational structure of second and third tier companies

Organizationally, fabricators and subcontractors are often isolated from the design team's second tier consultants. Although the technology allows for digital integration of information, we found that the organization of commercial construction projects inhibits collaboration across the design process, even when new technologies are implemented. While it is true that BIM tools improve the communication between

builders, designers and owners, we have found that new work processes and organizational strategies must be in place to improve collaboration.

Inter-organizational Collaboration

As with any technological change, the legacy of work processes, traditions, and cultures frame both the initial adoption and how the use of technology matures in an industry. What we have found is that people within the AEC industry are adapting the new technology to existing work processes. It was previously shown (Dossick and Neff 2008) that each project participant works within a context of conflicting obligations between their own scope of work, their company and the project (see Table 1). To optimize for the project, the conflicting obligations to scope and company need to be resolved. Table 1 outlines these conflicts from the perspective of the subcontractor (who has a specific scope as shown on the left column), the detailer's company shown on the right column, and the project (represented by the general contractor who tried to pull the team together for the detailing coordination and construction effort) in the middle column.

Table 1. Comparison of Conflicting Obligations in MEP Coordination (Dossick and Neff 2008)

	Scope	**Project**	**Subcontractor's Company**
Who	Detailers	General Contractor	Management
Level	Individual	Temporary Team	Firm
Mission	Produce Documents	Produce Building	Balance Projects
Tasks	Translate	Manage Team	Act in Market
Actions & Values	Advocate for Scope	Negotiate among Scopes and Conflicting Obligations	Optimize with respect to Time & Money
Relationship to other Obligations	Project Dictates Constraints	Scopes Intersect in Unanticipated Ways	Decision on Staffing, Work Practices & Exchange Affect Others
Approach to Collaboration	Exchange Information	Solve Problems	Avoid Exposure

Conflicting obligations to scope, project, and company shape the actions of people working on AEC teams. Some in the industry have recognized this conflict of obligations, and to address these issues they have worked on formal contractual agreements, compensation and incentive schemes to align individual and company interests with that of the project. For example, on the Camino project, the subcontractors had Guaranteed Maximum Price (GMP) contracts, which were complemented by a project culture that fostered increased "relatedness" of project participants, collaboration, and project optimization (Mikati, 2007). Organizational strategies are needed to support what we would call *authentic* collaboration on a project, particularly at the second and third tiers of project participants.

Beyond Delivery Methods

Collaborative delivery methods take on several names: Design/Build, DBOM, Design assist, Integrated Project Delivery. Many in the industry have focused on these kinds of delivery methods to unlock the full potential of BIM and to solve the problem of conflicting organizational obligations; however, in our research and as illustrated by the Camino project described above, delivery methods alone are not enough to achieve the collaborative vision of BIM and Integrated Practice. Delivery methods often reshuffle distribution of project risk, but they place the individual actors in the same positions where they face conflicting obligations of personal work scope, project and company.

As the industry explores collaboration strategies, questions remain as to when to bring different project participants together? What are the roles of designers and builders? How do we foster buy in from second and third tier subconsultants and subcontractors? We have observed that if a culture of mutual respect is cultivated on a project, where the project participant's expertise is used in the decision making, individuals feel compelled to act in the best interest of the project. However, if they become disenfranchised from the decision making and confined to their scope of work, they become increasingly protective of their own scope and their own time — the things over which they have control. The authors acknowledge that there are several organizational and cultural strategies to overcome conflicting obligations, and many designers and builders who work under stratified and hierarchical chains of command use leadership to navigate through the organizational structure and cultivate a positive project-oriented culture (Dossick and Neff 2008). However, a strategy that has come out of our interview data as well as the literature is co-location or what is been coined a 'big room' to encourage detailers and subcontractors to work more closely with designers (Mikati, 2007). Co-location allows for informal communication that crosses the formal divisions of project organizational hierarchies and builds a sense of teamwork, where designers, detailers and builders are working side by side for a specific duration, or in frequent periodic work sessions.

An example of this comes from our interview data. One interview subject excitedly discussed a "pretty good co-location that went hand in hand with co-developing a model", and explained how the architect, key consultants, general contractor and key subcontractors worked through the detailed design. While it was difficult initially to get some of the engineers and subcontractors to spend much time at the co-located office, once the momentum and culture was established for the collaboration, the project participants wanted to be there, finding that their work was more efficient and effective if they worked together as a group. The builder explains: "We didn't have that one magic model that everybody logged into every day, although that would be nice, but we did have a lot of concurrent data being developed and everybody was there to answer questions at any time." (interview B071012)

Co-location enabled intense informal communication to occur across organizational boundaries. This co-location example is in a striking contrast to the experience of the

subcontractors in our case study projects. Although they were using BIM, they were still following a traditional detailing process; as the detailers came across questions or issues in the design documents, they are asked by the general contractor and the designers to write Requests for Information (RFIs). This formal communication hindered the progress of the detailers work, making them wait for the paperwork to be processed before they get the answers necessary to complete their detailing. In our case study observations, the engineer and architects would ask for formal RFIs—even when they attended the detailers' coordination meeting—before they would provide answers to detailers' questions. These questions could be left unanswered for several weeks and in several cases, many months.

The impact of co-location on productivity can be significant. The same builder compared the co-located project to another: "The architect was working on another project simultaneously, very similar scope, similar schedule, just similar in almost every respect, same owner, actually, working with a different builder who is not relying on BIM, not collocating, they were in a 10 month design development phase, our design development phase was 10 weeks. And we started behind them with less data, less kind of certainty about the schematic design and ended up at the end of DD [detailed design]developing, I would say we were almost 50% CD [construction documents]'s from the effort. We had very little to do in CD afterward, and we did it in record time. And that was in part due to the emphasis on 3D, but more, by and large, to do with the co-location, but the two go hand in hand." (interview B071012)

Many questions remain in terms of how and when collocation should be put into practice. Who should be in the room and for what duration? Can we achieve the benefits of co-location from remote workstations over the internet? Perhaps there are other strategies that are equality effective in creating a sense of team and project-orientation with a temporary team of experts. Perhaps we as an industry need co-location as an extreme example to change our industry culture where everyone expects intense collaboration across disciplines as they come to a project. The authors have found that as the industry becomes more technically tightly-coupled and vertically integrated with design software that drives manufacturing machines, our project organizations will need to accommodate more integration and collaboration vertically and horizontally across the project process.

Conclusions

While collaborative delivery methods address many of the conflicting obligations of company, such as *Optimize with respect to Time & Money*, and *Avoid Exposure* shown in Table 1, collaboration strategies are needed to address the conflicting obligations of scope and project. One type of collaboration strategy we identified and explored in this paper is co-location. Therein, the project participants broke out of the old ways of working – where design information is exchanged between the parties one iteration at a time. In the co-located environment, the informal communication allowed project participants to more fully participate in the decision making process and drew them into the team and a project orientation. In contrast, the formal and

separated nature of the case studies' detailing teams, with formal lines of communication from subcontractors through general contractor to architect, drove the detailers to focus more on their own scopes of work.

Where the BIM tools appear to be an enabler of informal collaboration, they do not appear to be a driver for organizational change. The industry is using BIM in traditional formal ways of working as well as innovative ways of working. While some advantages are seen in easy communication between builders and designer, the potential for BIM to revolutionize the industry has not yet come common. Many of the people we interviewed are advocates for BIM internal to their firm and in the industry. As they introduce these technologies to their colleagues and business partners, they are often confined to work within existing work processes and frames of reference that limit the potential for BIM to enable collaborative environments.

Acknowledgements

This research was supported by the University of Washington's Royalty Research Foundation, College of Architecture and Urban Planning Dean's Development Award, the Department of Communication.

References

Allen, R. K., Becerik, B., Pollalis, S. N., and Schwegler, B. R. (2005). "Promise and Barriers to Technology Enabled and Open Project Team Collaboration." *Journal of Professional Issues in Engineering Education & Practice*, 131(4), 301-311.

American Institute of Architects, C. o. I. P. (2006). "Report on Integrated Practice." American Institute of Architects, Washington, D.C.

Barley, S. R. (1986). "Technology as an Occasion for Structuring: Evidence from Observations of CT Scanners and the Social Order of Radiology Departments." *Administrative Science Quarterly*, 31(1), 78–108.

Beamish, T. D., and Biggart, N. W. (2006). "Markets as Regimes: Explaining Change and Stability, Competition and Consensus in Economic Orders." University of California, Davis, Davis, Calif.

Bechky, B. A. (2003). "Object Lessons: Workplace Artifacts as Representations of Occupational Jurisdiction." *American Journal of Sociology*, 109(3), 720–752.

Bill, D. T. (1997). "Contributing Influences on an Individual's Attitude Towards a New Technology in the Workplace." Association of Architecture Schools Australasia Conference

Cuff, D. (1991). *Architecture: The Story of Practice*, MIT Press, Cambridge, MA.

CURT. (2004). "Collaboration, Integrated Information and the Project Lifecycle in Building Design, Construction and Operation ", Construction Users Roundtable Cincinnati, OH.

Dossick, C. S., and Neff, G. (2008). "How Leadership Overcomes Organizational Divisions in BIM-enabled Commercial Construction." 2008 Specialty Conference Leadership and Management in Construction, Lake Tahoe, CA.

Eisenhardt, K. M., and Schoonhoven, C. B. (1996). "Resource-Based View of Strategic Alliance Formation: Strategic and Social Effects in Entrepreneurial Firms." *Organization Science*, 7(2), 136-150.

Glaser, B. G., and Strauss, A. L. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*, Aldine de Gruytner, Hawthorne, NY.

Hagedoorn, J. (1993). "Understanding the Rationale of Strategic Technology Partnering: Interorganizational Modes of Cooperation and Sectoral Differences." *Strategic Management Journal*, 14(5), 371-385.

Harty, C. (2005). "Innovation in construction; a sociology of technology approach." *Building Research & Information*, 33(6), 512-522.
Holzer, D. (2007). "Are you talking to me? Why BIM alone is not the answer." Association of Architecture Schools Australasia Conference.
Katsanis, C. J. (2006). "Network Organizations: Structural and Strategic Implications." *2nd Specialty Conference on Leadership and Management in Construction*, 108-115.
Kleinknecht, A., and Reijnen, J. O. N. (1992). "Why do firms cooperate on R&D? an empirical study" *Research Policy, Elsevier*, 21(4)(4), 347-360.
Kogut, B. (1989). "The Stability of Joint Ventures: Reciprocity and Competitive Rivalry." *The Journal of Industrial Economics*, 38(2), 183-198.
Liston, K., Fischer, M., Kunz, J., and Dong, N. (2007). "Observations of Two MEP iRoom Coordination Meetings: An Investigation of Artifact Use in AEC Project Meetings." *WP106*, Stanford University.
Maher, M. L., Cicognan, A., and Simoff, S. J. (1998). "An experimental study of computer mediated collaborative design." *International Journal of Design Computing*.
Mikati, S.O., Roller, T.G., Tommelein, I.D., and Khanzode, A. (2007). "Priority Conversations: A Case Study on Priority Walls." Proc. 15th Ann. Conf. Int'l. Group Lean Constr., East Lansing, MI, 431-441.
Mitropoulos, P., and Tatum, C. B. (2000). "Forces driving adoption of new information technologies." *J. Constr. And Mgmt.*, 126(5), 340 – 348.
Morton, S. C., Dainty, A. R. J., Burns, N. D., Brookes, N. J., and Backhouse, C. J. (2006). "Managing relationships to improve performance: a case study in the global aerospace industry." *International Journal of Production Research*, 44(16), 3227-3241.
Mowery, D. C., and Teece, D. J. (1993). "Strategic alliances and industrial research." *Unpublished manuscript*.
Nithamyong, P., and Skibniewski, M. J. (2006). "Success/Failure Factors and Performance Measures of Web-Based Construction Project Management Systems: Professionals' Viewpoint." *Journal of Construction Engineering and Management*, 132(1), 80-87.
O'Brien, W. J. (2000). "Implementation Issues in Project Web Sites: A Practitioner's Viewpoint." *Journal of Management in Engineering*, 16(3), 34-39.
Orlikowski, W. J. (2000). "Using Technology and Constituting Structures: A Practice Lens for Studying Technology in Organizations." *Organization Science*, 11(4), 404–428.
Sommerville, I., Rodden, T., Sawyer, P., Bentley, R., and Twidale, M. "Integrating ethnography into the requirements engineering process." *Requirements Engineering, 1993., Proceedings of IEEE International Symposium on*, 165-173.
Taylor, John E., "Antecedents of Successful Three-Dimensional Computer-Aided Design Implementation in Design and Construction Networks", Journal of Construction Engineering and Management, 122 (12): 1-10.

VIRTUAL CONSTRUCTION AUTOMATION FOR MODULAR ASSEMBLY OPERATIONS

Jacek Olearczyk[1], Mohamed Al-Hussein[2], Ahmed Bouferguene[3], Avi Telyas[4]

ABSTRACT

On large construction sites crane positions tend to be determined through a process of trial and error. The analysis of complicated spatial static equipment locations is not an easy task. It requires understanding of many complicated aspects of not only the lift procedures or crane equipment limitation but also knowledge of the lifted objects. The virtual, an three-dimensional (3D) CAD modeling process allow for the storage, not only of shape and color (visual aspect), but also material properties, and parametric dependency (intelligent aspect). The utilization of advanced CAD tools allows for the exploration of the behavior of a structure. Digitally animated and simulated, modular construction assembly operation illustrate benefits of implementing 3D and 4D modeling for analysis of lifts and sequence optimization.

This paper provides an example of development and methodology to optimize crane selection operation process for the onsite erection of five, three stories dormitory buildings in McGregor Village for Muhlenberg College in Allentown, Pennsylvania USA. Fully habitually modular assembly units were delivered securely on flatbed trailers in advance to the site. A 600 Tone mobile hydraulic crane was placed in the center of construction site to lift over 100 modules in order to construct the 5 buildings in only 10 working days.

Created CAD models were efficiently utilized to optimize detailed schedule. The process includes the creation of kinematic movement for each module lift then simulation sequences and finally compile AVI video movie for review and approval.

[1] Ph.D. Candidate, Civil and Environmental Engineering Department, Hole School of Construction 1-047 Markin/CNRL Natural Resources Engineering Facility Edmonton, AB T6G 2W2, Phone +1 780/492-8093, FAX 780/492-0249, jaceko@ualberta.ca,

[2] Associate Professor, Civil and Environmental Engineering Department, Hole School of Construction 3-011 Markin/ CNRL Natural Resources Engineering Facility Edmonton, AB T6G 2W2, Phone +1 780/492-0599, FAX 780/492-0249, malhussein@ualberta.ca,

[3] Associate Professor, Campus Saint-Jean 8406, Marie-Anne-Gaboury Street (91 Street) Edmonton, AB T6C 4G9, Phone +1 780/465-8719, FAX 780/465-8760, ahmed.bouferguene@ualberta.ca

[4] Kullman Building Corp., One Kullman Corporate Campus, Lebanon, New Jersey 08833, Phone +1 908/236-0220, Fax +1 908/236-8596;atelyas@kullman.com

INTRODUCTION

Modular – or manufactured – housing is well known in the construction industry. The primary advantages to this approach are cost and completion time. If properly designed and constructed, modular housing can be developed for the fraction of the cost of traditional housing and still meet the highest quality standards. Once the completed product is transported to the place, the setup can be completed in a matter of days.

However, modular construction term is associated with single housing; some authors refer it to at the most low-rise multi-family housing [Murdock 2005]. Effort to automating the model development process or using robotics in modular construction to reduce on site labor has been reported in the later return [Nasereddin et al. 2007, Bock 2007, Editorial Ca - Leonard 2007]. Also, the challenge related to a large number of modular units needed for international events is addressed [Yoders 2005]. But the most significant niche for implementing this type of building is for school facilities, campus/dormitory living, and affordable housing [Dolan 2006, Cardenas and Domenech 2005, Atkinson et al. 2001]. Some reported cases demonstrated a shift from traditional thinking of modular construction, which was focusing only on low-rise accommodations to be considered for high-rise facilities [Cartz and Crosby 2007]. Other examples of successful implementation of the modular concept includes the construction of airport roofs; NASA spacecraft architecture; and health care units, from single check-up rooms to operating theatres or pharmacy centers [Veale and Postawa 2007, Smith 2006, Editorial Health 2007, Editorial Hospital 2007, Editorial Operating 2007, Editorial Pharmacy 2008]. These facilities or units can be customized over the internet similar to the manner in which an automobile may be customized by the purchaser [Booth 2007]. Ready modules are delivered to the site for assembly, and in this respect a heuristic algorithm for optimization assembly operation can be well utilized [Da Cunha et al. 2007]. Furthermore, unskilled labor issues as well as the effect on the reduction of electricity consumption of using modular technology and the benefits of off-site construction have garnered the attention of scholars [Rehfeld 2006, Riley 2007, Editorial Off-Site 2006].

When complicated mechanical components or multi-dimension construction site movement are involved, transforming the intellectual ideas into drawings is not an easy task. Two-dimensional or isometric hand sketches on the paper are the fist media to receive human brain idea output. Often, these sketches are the only surviving evidence of new and evolutionary development. They are not recorded any other way. Today technology makes this intellectual property transparent, either allow scan or convert to digital configuration of solid modeling, and then virtually transform creating simulation or animations.

Analyzing and testing cranes in 3D has a proven record of success in assisting the construction industry or analysis assembly and complicated movement using tilt-up panel construction method [Al-Hussein et al. 2005, Manrique et al. 2007]. Closing the gap between simulation and visualization and address visualization of the design constraints are the other examples of virtual technology assistance [Xu 2001, Olearczyk and Al-Hussein 2006]. Communication as an important way of exchange information and solve the problem is a key factor not only on construction site. To better understand concept of design, schedule and allocation resources over

construction time virtual reality (VR) tool plays significant role. This dynamic graphical depiction is able to shows the proposed design just as the final product would appear in the real world. It provides visual inside information of modeled construction operation as well as helps realistically identify the proposed design [Messner et al. 2006, Okyere 2004]. VR as educational tool creates its path in academic curriculum fast and with purpose [Otto et al. 2005]. However, it is present in the industry over the past two decades and offer visualization in several level of details, does not mean limitation and constraints is not recognized [Staub-French and Khanzode 2007]. Interdisciplinary recognition of value, which VR can offer, shows utilization this technology beyond pioneers, automotive and aerospace industry, and encompasses specialized fields of human brain research, such as psychotherapy and psychology [Ehrsson 2007, Lenggenhager et al. 2007].

METHODOLOGY

Figure 1 shows the main process of the proposed methodology. "Construction process" block set of operation cannot function without meaningful input parameters, which include objects, crane and rigging data strictly related to equipment information. Example of crane data includes dimensions, radii, and lifting capacities related to boom length at specific radii. These crane configurations are placed and temporary relocated on the construction site in the computer model and consequently site data has to be included as input parameter.

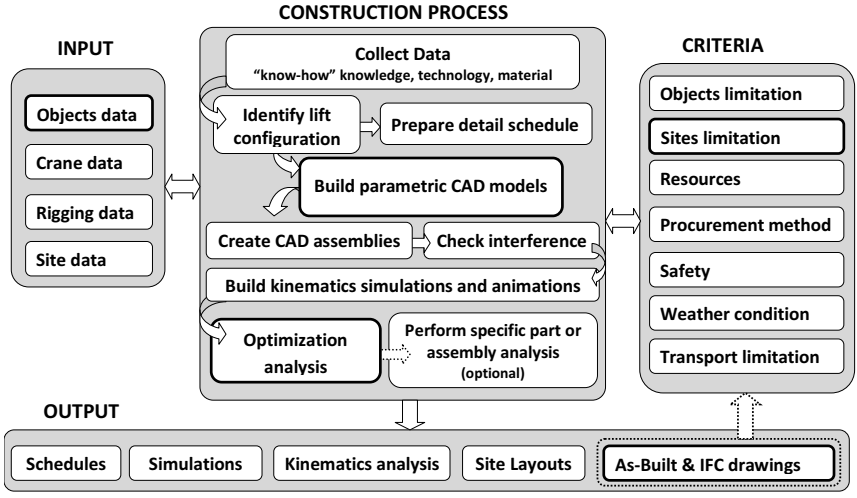


Figure 1; Methodology flow chart

The main process, "Construction Process", contains sub-functions blocks operations related to different tasks such as "Collect Data" which refers to exclusive knowledge, technology or materials. In the next step particular crane configuration is established and detailed schedule prepared. Based on presented information parametric CAD models are created, which further, forms the sub-assemblies or assemblies. The first

check operation which is performed at "Construction Process" module is interference check, this operation is critical since assembled modules cannot perform uninterrupted kinematics simulation and then animation tasks. Some processes at the certain steps required optimization algorithm to be run to optimize movement, initial start position in order to reduce operation time and cost. Operations performed under "Construction Process" umbrella are subject to several criteria listed in the "Criteria" module. This module contains object, transportation and sites limitations, resources availability and functionality of procurement method used, as well as safety concerns and weather condition effect on the construction process. Separate module reflects on received output, which could be collected at any stage of the construction process operation. "Output" contains electronic schedules, simulation, and kinematics or stress analysis reports and also could be presented as hard printed copy.

PROBLEM DEFINITION – CASE STUDY

Rectangular modules, sized to fit standard flatbed truck trailers, were manufactured at Kullman shop in Lebanon, New Jersey and delivered to the Muhlenberg College in Allentown, Pennsylvania for assembly into five new buildings. Over ninety units placed together into five different locations like a puzzle, to create three-storey dormitory buildings, which were to house 145 students. The five new buildings replaced seven single-level "shelters" built in 1981 to accommodate only 56 pupils. Figure 2 shows exploded view of one dormitory building.



Figure 2; Dormitory exploded view

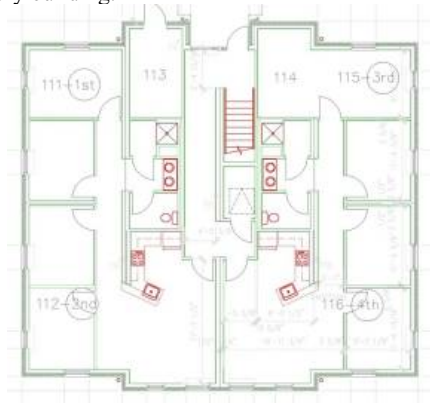


Figure 3; Typical floor layout

Figure 3 shows typical floor layout with spacious rooms for its occupants. Time factor was the main construction contract constraint. The 5-buildings must be built during summer months only. Traditional stick-building construction method was eliminated since this technique required much longer on-site construction time. Manufacturing the units ahead of time, during the school time, at the factory floor assembly (module construction), allow assembling the 5-buildings on site in three weeks. Planning in advance all procedures related to fabrication, transportation, and final assembly operation would not be possible without detailed schedule and logistic preparation. Detailed flow chart (see Figure 4) was created of final assembly for all

dorms and fine schedule (in minutes-by-minutes) of each lift and assisting operation was created (see Figure 5).

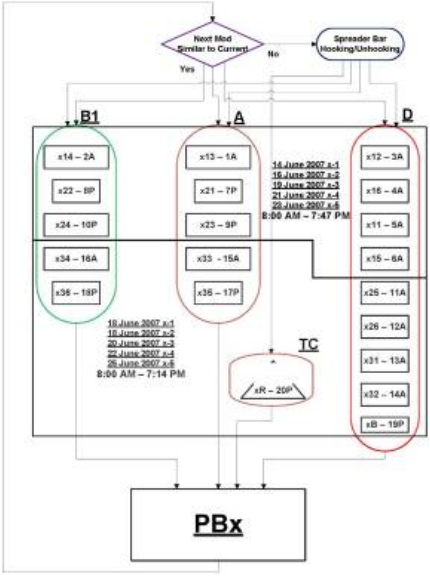


Figure 4: Building operation flow chart

	oper code	activity/operation		module	place start	crew	workers/crane time p (min)	ml (min)	o (min)	place finish
	13-Jun-07									
1	K1	unwrapping module		113	B1	4	25	20	15	B1
2	K1	hooking module		113	B1	4	20	17	15	B1
3	K1	folding tarp for next module			B1	4	25	15	10	B1
4	T1	removing empty trailer			B1		7	5	3	-
5	C-sb	load hoisting up	↑	113	B1					
6	C-sb	load booming up	‖	113			10	7	5	
7	C-sb	load swing	‖	113						
8	C-sb	load hoisting down	↓	113						PB1-1
9	K2	securing-lining up		113	PB1-1	1	30	20	15	PB1-1
10	K2	securing-bolting together		113	PB1-1	2	30	22	15	PB1-1
11	K2	unhooking-remove lift lugs		113	PB1-1	2	25	22	15	PB1-1
12	K3	welding bottom - one side		113	PB1-1	1	30	20	15	PB1-1
13	K3	welding bottom - other side		113	PB1-1	1	30	20	15	PB1-1
14	C-sb	return to next position			PB1-1		3	2	1	B1
15	T2	placing trailer module for lifting		114	-		7	5	3	B1
16	K1	unwrapping module		114	B1	4	25	20	15	B1
17	K1	hooking module		114	B1	4	20	17	15	B1
18	K1	folding tarp for next module			B1	4	25	15	10	B1
19	C-sb	load hoisting up	↑	114	B1					
20	C-sb	load booming up	‖	114			10	7	5	
21	C-sb	load swing	‖	114						
22	C-sb	load hoisting down	↓	114						PB1-1

Figure 5: Daily schedule (minute-by-minute)

In Figure 4 vertical columns of rectangular boxes representing delivered modules coded to shows the pick points areas B1, A and D; the solid line divide modules on to two separate days of lift operations. Module identification name and coding schema was unique to the project and followed: first number was related to one of five buildings, second floor and third floor module number, after dash number represents sequence of assembly, suffix letter A and P represents morning and afternoon operation respectively. Accordingly, one building was assembled in two days where in the second day; the last lift operation was to cover the building with the preassembled roof. Figure 5 shows spreadsheet schedule of operation with "p, ml, o" values representing pessimistic, most-likely and optimistic data respectively, for triangular distribution input analysis simulation. Accumulated data allowed optimize each assembly operation, and then create project Gant Chart schedule (see Figure 6). Detailed schedule was created independently for each assembly day. On the schedule, prior field operation, critical path was identified and tasks involved in critical path procedures were carefully planned and checked.

Utilizing crane selection algorithm (Al-Hussein 2005) Demag AC 500-1 mobile hydraulic telescopic crane was chosen to perform this assignment. With a lifting capacity of 600 tons (500,000 kg) allowed to place the units in the positions optimized by Center-of-Gravity moment effect algorithm (CoG). However, crane was operating with maximum boom length of 183 feet, defined assembly sequence made critical the last lift operation (the roof of the 5th building). Boom crane came to close

proximity of already placed building 4 and detailed clearance analysis had to be performed.

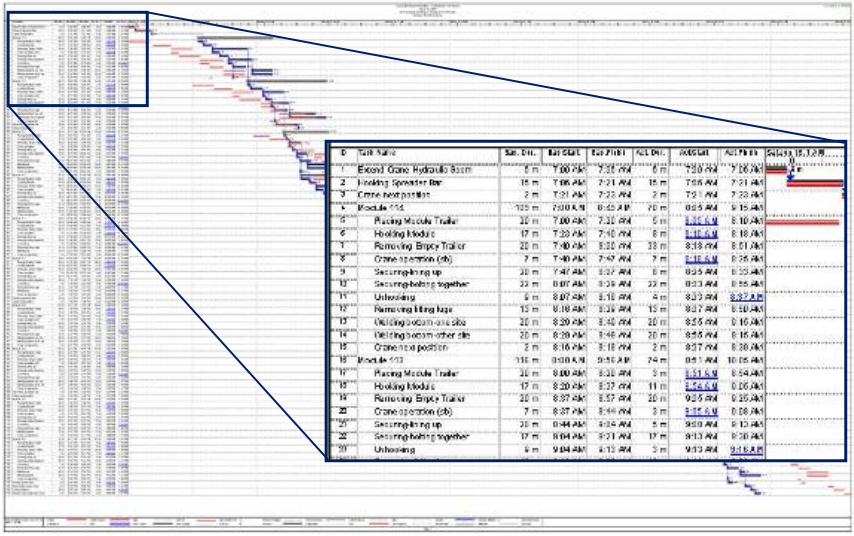


Figure 6: Day detail schedule planned vs. actual

During the entire assembly only two rigging equipment configuration were used; direct 10 feet steel cables for small modules and 50 foot long spreader bar for roofs and large modules.

VIRTUAL CONSTRUCTION

Analysis of complicated spatial static equipment locations is not an easy task. It requires understanding of many complicated aspects of lifting procedures, and crane and equipment limitation. To practitioners with limited experience the virtual, 3D-CAD modeling process allows for the storage, shapes and colors (visual aspect), and material properties, and parametric dependency (intelligent aspect).

After optimization of the crane location and securing pick points for delivered modules, simulation optimization was performed on Simphony software (AbouRizk 2000); in order to provide the modules lifting sequences, resources allocation and timing operations of the assembly schedule. Project assembly operation was ready for CAD modeling and virtual validation. Intelligent digital objects have been assigned proper material properties and texture mapping for visualization effect. In two occasions, separate detail crane site access analysis was performed to accommodate road width limits and allowable crane boom clearance. Assigning kinematic movement to each major crane components and lift for each motion to time frame allows executing full real-like digital movies. Concatenation sets of separate hoist, swing, placing and returning operations permit to create optical illusion of 4D construction operation. Figure 7 shows a snapshot of full length digital construction movie of one building.

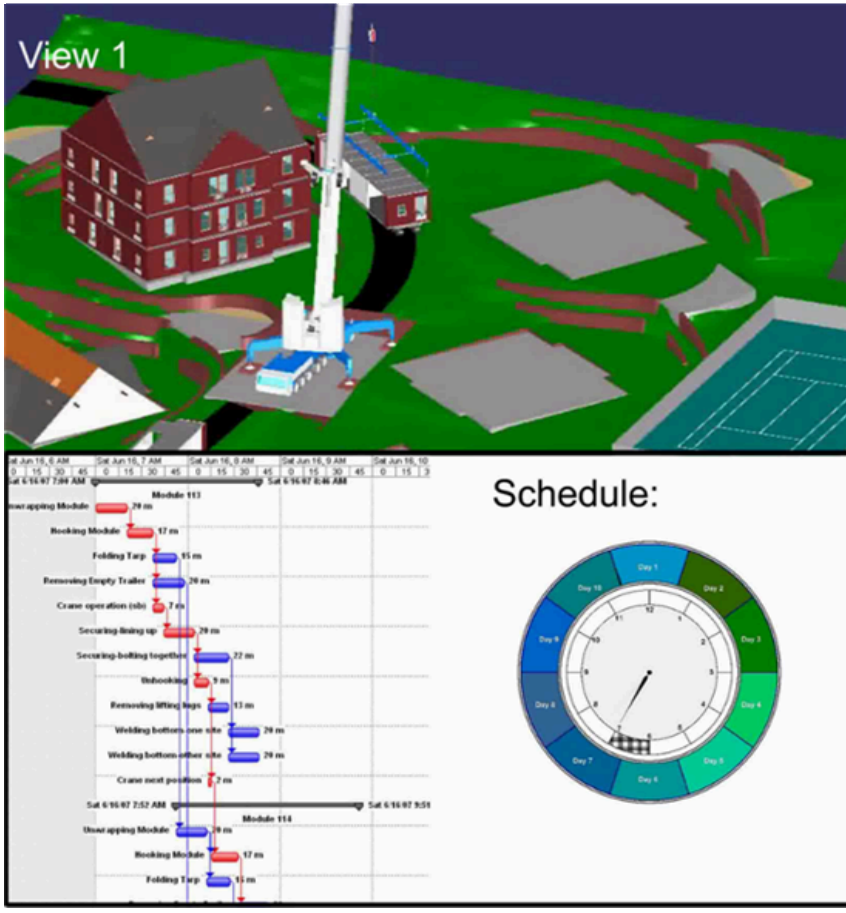


Figure7: Snapshot of construction movie

Placing each module at defined time frame, gives the ability to recognize potential bottlenecks ahead of actual construction. In addition, since the 3-D model was front-loaded with resources assignment, the 4-D model relocated and utilizes resources as well. Other advantage of running animation several times, especially in presents of the rigging crew, created mental pictures of planned activities and prepared the crew to actually learn-from-movie lesson. Construction projects are unique and assembly crews learning from the already performed tasks increasingly improve their productivity. In case of Muhlenberg College project, the rigging crew productivity was close to optimal at the beginning of assembly project due to the short learning-curve time.

Last lift of the project (critical lift), placing the roof for building 5 was virtually tested at many different options. Its complexity describes the fact that the crane boom was

in conflict with already erected unit and was out of the operator view. Performing virtual analysis allow reconfigure the crane boom (add extension) and avoid problem during physical lift. Figure 8 shows collision the crane boom with building roof before reconfiguration and Figure 9 view after extension was added.

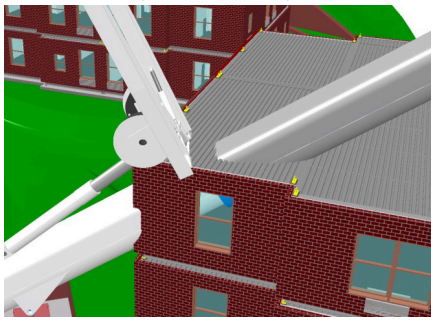


Figure 8: Collision detection

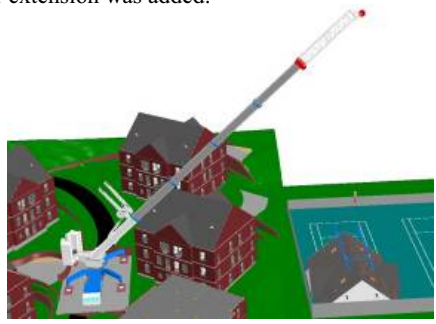


Figure 8: Extension added

CONCLUSIONS

The preparation aspect of the project and construction operations virtual implementation steps were covered in this paper. Economic benefit was undisputable, shortening preliminary schedule from 21 days to 10 days without sacrificing safety and quality created psychological "win" approach for all crew members. Adopted new technologies for crane layout optimization, introducing "minute-per-minute" construction schedule operation are few of many grounds-braking improvement tactics used in this project.

Virtual interpretation of assembly operations has its own chapter in this state-of-art project management undertaking. In many cases decision makers do not see tangible benefits of creating CAD models for only assembly operations, usually models utilized at this final stage of procurement are outputs from design and manufacturing processes. For Muhlenberg College project modeling was done only for assembly operation, modules design and fabrication assistance was already established and it proved to be worth investment even for final steps of entire project scope.

Virtual preparation is not easy task and required combination of working knowledge of CAD software with its separate module of kinematics, simulation and animation as well as understanding of "know-how" of any construction operations that has to be digitally prepared. Critical aspects of any optimization analysis are proper and valid interpretations of result and outputs. Provided case study was used to demonstrate effectiveness of the developed methodology in avoiding accidents, reducing the time and cost associated with planning and execution of lifts on construction site. As an additional benefit of virtual implementation of construction assembly operation was a data, which effectively enhance marketing communication with potential clientele.

REFERENCES

AbouRizk, S. and Mohamed, Y. (2000). "Simphony – an Integrated Environment for Construction Simulation" *Winter Simulation Conference Proceedings, 2000*. Vol. 2, Issue , 2000. 1907-1914.

Al-Hussein, M., Alkass, S. and Moselhi, O. (2005). "Optimization Algorithm for Selection and on Site Location of Mobile Cranes". *Journal of Construction Engineering and Management*, ASCE 131(5), 579-590.

Atkinson, A., Payling, J., Lucas, B. and Gray, K. (2001). "Affordable Housing Adaptation Using Modular Construction - A Case Study in Applied Project Management." CIB World Building Congress, Wellington, New Zealand.

Bock, T. (2007). "Construction Robotics." *Autonomous Robotics* 22, 201-209.

Booth, W. (2007). "House Proud." *Smithsonian Magazine. Science and Technology.*

Cardenas, A. and Domenech, F. (2005). "Assembly Required." *American School & University*, 74(4), 39-41.

Cartz, J.P. and Crosby, M. (2007). "Building High-Rise Modular Homes." *The Structural Engineer*, 9, 20-21.

Da Cunha C., Agard, B., and Kusiak, A. (2007). "Design for Cost: Module-Based Mass Customization." *IEEE Transaction on Automation Science and Engineering*, 4(3), 107-121.

Dolan T.C. (2006). "Instant classrooms." Construction*, School Planning and Management*, 4(1).

Editorial Hospital (2006). "Modular technique builds new hospital wing." News, *Hospital Development* (HD). July 20, 2006, Published by Wilmington Media Ltd, 3.

Editorial Health (2007). "Building Systems: Modular mission." *Hospital Development* (HD). April, 2007, 29.

Editorial Leonard (2007). "RAIC Award – Innovation in Architecture: "Leonard Avenue Modular Housing." *Canadian Architect*, 05, 28-29.

Editorial Off-Site (2006). "Off-site construction guide goes online." News, *Hospital Development* (HD). September 21, 2006, Published by Wilmington Media Ltd., 3.

Editorial Operating (2007). "Modular operating theatres for Cannock Chase Hospital." News, *Hospital Development* (HD). May 03, 2007, Published by Wilmington Media Ltd., 3.

Editorial Pharmacy (2008). "Modular build for hospital pharmacy." News, *Hospital Development* (HD). August 28, 2007, Published by Wilmington Media Ltd. 4.

Ehrsson H. (2007). "The Experimental Induction of Out-of-Body Experiences." Brevia, *Science*, 317, 1048.

Lenggenhager B., Tadi, T., Metzinger, T., and Blanke, O. (2007). "Video Ergo Sum: Manipulating Bodily Self-Consciousness." Reports, *Science*, 317, 1096.

Manrique, J.D., Al-Hussein, M., Telyas, A., and Funston, G. (2007). "Constructing a Complex Precast Tilt-Up-Panel Structure Utilizing an Optimization Model, 3D CAD and Animation." *Journal of Construction Engineering and Management*, ASCE, 133(3), 199-207.

Messner, J., Riley, D., and Moeck, M. (2006). "Virtual Facility Prototyping for Sustainable Project Delivery." *Journal of Information Technology in Construction*, 11, 723-738.

Murdock, J. (2005). "The Modular Squad." *Architecture*, 94(6), 25-28.

Nasereddin, M., Mullens, M.A., and Cope, D. (2007). "Automated Simulator Development: A Strategy for Modeling Modular Housing Production." *Automation in Construction*, 16, 212-223.

Okyere, M. K. (2004), "Virtual City: A Heterogeneous System Model of an Intelligent Road Navigation System Incorporating Data Mining Concepts." Published in the Proceedings of the National Conference on Undergraduate Research (NCUR), Indianapolis, Indiana, April 16, 2004.

Olearczyk, J. and Al-Hussein, M. (2006). "Oil Sands Construction Automation 3D Solid Modeling and Animation." Published in the Proceedings of the International Conference on Computing and Decision Making in Civil and Building Engineering, Montreal, Canada, June 14-16, 2006.

Otto, G., Messner, J. and Kalisperis, L. (2005). "Expanding the Boundaries of Virtual Reality for Building Design and Construction." *Computing in Civil Engineering*, 79(12) 1061-1071.

Rehfeld, B. (2006). "Even Some Contractors are Choosing Modular Homes." *The New York Times (East Coast)*, New York, NY, Sept. 30, 2006.

Smith, K. (2006). "Advantages of Modularity and Commonality in a Spacecraft Architecture." Published in the Proceedings of the 10th Biannual International Conference on Engineering, Construction, and Operations in Challenging Environments (Earth & Space 2006) and the 2nd NASA/ARO/ASCE Workshop on Granular Materials in Lunar and Martian Exploration, League City/Houston, TX, March 5-8, 2006.

Staub-French, S. and Khanzode, A. (2007). "3D and 4D Modeling for Design and Construction Coordination: Issues and Lessons Learned." *Journal of Information Technology in Construction*, 12, 381-407.

Veale, J. and Postawa, L. (2007). "Preparing for take-off, – designing the New Terminal Building at Madrid Barajas Airport, Spain." Evening Meeting, *The Structural Engineer*, 3, 39-44.

Xu, J., (2001). "CAD-Based Integrated Simulation Environment (CAD-ISE)." Dissertation for the degree of Doctor of Science in Construction Engineering and Management, University of Alberta, Edmonton, Canada, January, 2001.

Yoders, J. (2005). "Reinventing Modular Construction." *Building Design and Construction*, 8(5), 2.

IDENTIFICATION OF DATA ITEMS NEEDED FOR AUTOMATIC CLASH DETECTION IN MEP DESIGN COORDINATION

Fernanda Leite[1], Burcu Akinci[2], and James Garrett, Jr.[3]

[1]PhD Candidate, Department of Civil and Environmental Engineering, Carnegie Mellon University, 5000 Forbes Ave. Porter Hall, 119, Pittsburgh, PA, 15213; email: fll@cmu.edu
[2]Associate Professor, Department of Civil and Environmental Engineering, Carnegie Mellon University, email: bakinci@cmu.edu
[3]Professor, Head, Department of Civil and Environmental Engineering, Carnegie Mellon University, email: garrett@cmu.edu

Abstract

This paper discusses a study carried out during the mechanical, electrical and plumbing (MEP) design coordination of a 210,000 square feet facility, currently under construction in Western Pennsylvania (Project X). We have compared types of clashes identified in their manual coordination process (overlay of 2D drawings on a light table by pairs of subcontractors) and through automatic clash detection using a building information model (BIM) in NavisWorks JetStream v5. The automatic clash detection identified several clashes that were missed by the subcontractors, who were performing this task manually. Also, the manual clash detection identified clashes which could not possibly be found by the automatic clash detection software, since one of the clashing objects (e.g. cable trays) was not modeled in the BIM. This study also included site observations of field detected clashes, some of which were not identified in either manual or automatic processes. Results show that the combination of clashes identified in coordination meetings, those automatically detected, as well as those identified in the field enable identification of objects that need to be modeled in order to capture the largest possible number of clashes. This paper was limited to the comparison of types of clashes identified in each of the three methods during a specific project. Although these results cannot be generalized, they still provide insight towards the need to identify what needs to be modeled in a BIM for MEP coordination prior to the start of the coordination process.

Introduction

Problems with design coordination, such as time consumption and ineffectiveness related to the current 2D paper-based process, are some of the top concerns of a gen-

eral contractor, since late conflict correction increases the potential for errors in the field. In order to address this issue, there have been an increasing number of Architecture, Engineering and Construction (AEC) firms utilizing building information models (BIM) in their coordination and clash detection processes, which according to practitioners, allows for increased coordination and fewer field problems (Kiviniemi et al., 2008; Khanzode et al., 2008). Kiviniemi et al. (2008) conducted a survey in European AEC firms and identified that 25% of Engineering firms and 13% of contractors utilize BIM in their coordination/clash detection processes. Also, several research efforts focused on identifying benefits and challenges related to applying BIM tools specifically to Mechanical, Electrical and Plumbing (MEP) coordination (e.g. Khanzode et al., 2005; Staub-French and Fischer, 2001; Tatum and Korman, 2000).

Even with the increasing adoption of BIM and studies in this area, many practitioners are still unsure as to what needs to be modeled in a BIM for construction coordination (Kiviniemi et al. 2008). Hence, there is a need to bridge this gap by identifying what needs to be modeled in a BIM for construction coordination. This paper discusses a study carried out during the coordination of a 210,000 square feet facility, currently under construction in Western Pennsylvania. We have collected types and counts of clashes as well as the information exchanges between subcontractors in this project. We compared the types of clashes identified in their manual coordination process, which involves overlaying of 2D drawings on a light table by pairs of subcontractors, and those identified through automatic clash detection using a BIM in NavisWorks JetStream, version 5. Later, field detected clashes were observed during the MEP installation in Floor 1 through Request for Information (RFI) documents from subcontractors that are posted in the general contractor's (GC) online collaboration system.

Background Research

Reinertsen (1997) states that the function of the design process is to generate information. If the generated information is incomplete, this represents a loss for the project owner, since time and money were invested and the return is below expectations (Reinertsen, 1997). This statement can be applied to MEP design coordination, since late conflict correction increases the potential for errors in the field, which can cause delays in project delivery. MEP coordination is a process that involves the detailed layout and configuration of the various building systems such that these systems comply with design, construction, and operations criteria (Barton 1983; Tatum and Korman, 2000). Specialty contractors are typically responsible for the coordination of MEP systems, including responsibility for checking clearances and identifying routes, fabrication details, and installation locations (Tatum and Korman, 2000). Moreover, many aspects of current projects constrain this activity; limited building space, increasing complexity of all building systems, and limited engineering budgets and installation schedules for MEP systems. Combined with increasing pressures for better, faster, and cheaper projects, these constraints highlight the need for an improved work process for MEP coordination (Tatum and Korman, 2000). Several re-

search efforts focused on identifying benefits and challenges related to applying BIM tools to MEP coordination specifically (e.g. Khanzode et al., 2005; Staub-French and Fischer, 2001; Tatum and Korman, 2000; Khanzode et al., 2008).

Khanzode et al. (2008) described lessons learned from application of BIM tools to a complex process of MEP coordination for a medical facility. Challenges addressed by Khanzode et al. (2008) included determining how to organize the project team and structure the coordination process to best utilize BIM tools, how to set up the technical logistics, and how to perform the coordination in a single room. Khanzode et al. (2008) also pointed out a few lessons learned related to the level of detail in the BIM, even though this was not the focus of their research. Tatum and Korman (2000) conducted a study with four types of buildings that contain complex MEP systems: a hospital, a hotel, three laboratories, and five biotech manufacturing facilities. The authors presented the knowledge that needs to be represented for developing a computer tool to assist with MEP coordination, which includes design and construction knowledge, as well as knowledge related to the remainder of the project life-cycle (Tatum and Korman, 2000). Although their study involved several projects, Tatum and Korman's (2000) data collection was limited to interviews and direct observation in coordination meetings. Thus, Tatum and Korman's (2000) approach did not capture what objects needed to be modeled in a BIM to capture most of the possible clashes.

Our approach involved collecting data in coordination meetings, automatic clash detection and field detected clashes posted in Project X's online collaboration website. This paper will present a comparison between data items identified as needed during the manual coordination process, the application of automatic clash detection software and field detected clashes. Results provide insights as to what objects need to be modeled in a BIM so as to capture most possible MEP clashes.

Motivating Case

Project X is a multi-storey building currently under construction in Pennsylvania. It consists of two buildings and an underground garage with 150 spaces. The two buildings include approximately 210K gross square feet of area. It is a 3-year project with an estimated construction cost at approximately $70 Million. This was a Design-Bid-Build project. After the construction documents were completed, a short list of contractors had been established by the owner and invited to bid. This list was comprised of contractors that the owner had equal confidence in from previous experience.

The general contractor (GC) who won the bid decided to use BIM after notice to proceed. The GC passed the 2D CAD drawings they had received on to a third party (Company A), whom they hired to develop the model in Graphisoft Constructor 2007, now Vico Constructor. Company A delivered an initial version of the BIM using 85% complete 2D architectural, structural, and mechanical, electrical and plumbing (MEP) drawings. When construction for the building's underground garage was being carried out, the GC requested and received a new BIM from Company A, based

on 100% complete drawings. By this time, the heating, plumbing, fire safety, electrical and sheet metal subcontractors had started their weekly coordination meetings. The project team decided to coordinate the MEP designs by overlaying 2D drawings on a light table, since most of the subcontractors did not design in 3D and felt more comfortable with the traditional approach. During coordination meetings, subcontractors used BIM to measure clearances. All actual coordination was done on 2D drawings, which gave the research team the opportunity to collect the number and types of clashes as well as the information exchange between each pair of subcontractors. These were later used to compare with the clashes identified through automatic clash detection, which is a feature of NavisWorks JetStream, version 5.

Approach

For five months (October 2007-February 2008), a researcher attended weekly coordination meetings for Project X. In these meetings, five types of subcontractors (Ductwork/HVAC, Electrical, Plumbing, Fire Protection and Heating) overlaid their drawings, two by two, and per section and floor of Project X. The researcher collected data on number and types of clashes identified by pairs of subcontractors and their information exchange for each iteration. Information exchange data consisted of what queries were asked between subcontractors (e.g. clearance between top surface of duct and bottom surface of ceiling).

In order to compare the same section of the building for both manual and automatic approaches, the research team used the first floor of Project X, which was going through design coordination. During the coordination meetings, the team collected data during the contractors' process of overlaying a pair of 2D drawings on a light table. For the automatic approach, the team used a BIM (exported from Graphisoft Constructor 2007 into 3D CAD format) in NavisWorks JetStream v5, running clash detection by pairs of subcontractors as well, for the first floor only. Since the clashes needed to be isolated for the first floor for this study, the research team extracted information about that floor from the full BIM. Following this, transparency was applied to all structural and architectural objects, so that the clashes within the building could be visualized clearly. No other modifications were made to the original BIM. The BIM contains Architectural, Structural, Ductwork, Electrical, Plumbing and Fire Protection designs. The only subcontractor not represented in the BIM is Heating.

After comparing the counts in clashes detected during coordination meetings and through automatic clash detection, we analyzed precision and recall of clashes identified in both processes, keeping track of objects that were and were not modeled, which had impact in precision and recall. Precision and recall calculation were based on formulas from the information retrieval domain (Rijsbergen, 1979). They are:

$$precision = \frac{relevantClashes \cap retrievedClashes}{retrievedClashes}$$

$$recall = \frac{relevantClashes \cap retrievedClashes}{relevantClashes}$$

These were later compiled into a list of objects that need to be modeled to identify the largest number of clashes, with increased precision and recall. Also, field detected clashes were observed during the MEP installation in Floor 1 through Request for Information (RFI) documents from subcontractors posted in the GC's online collaboration system.

Results

Results of the types of clashes and information exchange collected in the manual clash detection process, as well as the comparison between the clashes identified through manual and automatic clash detection are discussed in the following subsections. Finally, examples of field detected clashes, observed during the MEP installation in Floor 1, are discussed.

Types of clashes and information exchange identified through manual coordination process

Table 1 presents the types of clashes identified in the coordination meetings for Project X. Table 2 presents information requests between pairs of subcontractors during the manual coordination process for Project X. Table 1 represents the objects that should be modeled in a BIM in order to enable automatic identification of clashes. Table 2 represents the level of detail at which these objects should be modeled.

Table 1: Types of clashes between pairs of subcontractors identified in manual coordination

	Electrical	Heating	Plumbing	Fire Protection
Ductwork	**DE1:** Light and duct; **DE2:** Cable tray and duct	**DH1:** Hanger and duct; **DH2:** Heating line and duct	**DP1:** Plumbing line and duct; **DP2:** Blocking of sleeves by duct	**DF1:** Sprinkler head and duct; **DF2:** Sprinkler line and duct
Electrical	N/A	**EH1:** Cable tray and pipe; **EH2:** Lights and heating line	**EP1:** Cable tray and plumbing line; **EP2:** Lights and plumbing line **EP3:** Hanger and plumbing line	**EF1:** Cable tray and sprinkler line; **EF2:** Cable tray and sprinkler head; **EF3:** Lights and sprinkler line; **EF4:** Light and sprinkler head
Heating		N/A	**HP1:** Heating line and plumbing line	**HF1:** Heating line and sprinkler line; **HF2:** Heating equipment and sprinkler line
Plumbing			N/A	**PF1:** Sprinkler head and plumbing line; **PF2:** Sprinkler line and plumbing line

Table 2: Information requests between pairs of subcontractors in manual coordination

	Ductwork	Electrical	Heating	Plumbing	Fire Protection

Duct-work to	N/A	Distance from top surface of finished floor to bottom surface of light fixture	Distance between outermost surface of pipes (to route duct)	Direction and degree of sloped pipes (waste, vents and storm lines)	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe; location of sprinkler heads
Electrical to	Distance from top surface of finished floor to bottom surface of duct; location and cut sheets of equipment	N/A	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe with insulation	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe with insulation	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe; location of sprinkler heads
Heating to	Possibility of flattening duct and moving away from wall, so that pipes can run between duct and wall and above and below ducts	Which electrical equipment can be crossed over; distance between conduits and pipes	N/A	Location of floor drains to run condensate lines to	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe; location of sprinkler heads
Plumbing to	Hanging methods (trapeze or straps); elevation of ducts and units; actual size of duct with insulation and supports; additional reinforcement around large ducts	Distance from top surface of finished floor to bottom surface of light fixture; light sizes; distance from top surface of finished floor to bottom surface of cable trays; location of feeds	Outer diameter of pipe with insulation; elevations of branch pipe off mains when crossing plumbing	N/A	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe; location of sprinkler heads
Fire Protection to	Distance from top surface of duct to bottom surface of ceiling; Distance from top surface of finished floor to bottom surface of duct	Location of cable trays; equipment; light and cable tray elevations	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe with insulation; location and elevation of equipment	Distance from top surface of finished floor to bottom surface of pipe; outer diameter of pipe with insulation	N/A

Comparison between manual and automatic clash detection

The result of the first step in comparing the clashes between pairs of subcontractors identified in the coordination meetings and the automatic clash detection is shown in

Table 3. This table shows a larger count in clashes identified through the automatic clash detection.

Table 3: Count of clashes between pairs of sub-contractors in Floor 1. CM=collected in coordination meetings, AT=identified through automatic clash detection in NavisWorks JetStream v5

	Electrical		Heating		Plumbing		Fire Protection	
	CM	AT	CM	AT	CM	AT	CM	AT
Ductwork	4	29	0	NA	0	50	2	42
Electrical			0	NA	0	3	0	2
Heating					0	NA	1	NA
Plumbing							1	23
Fire Protection								

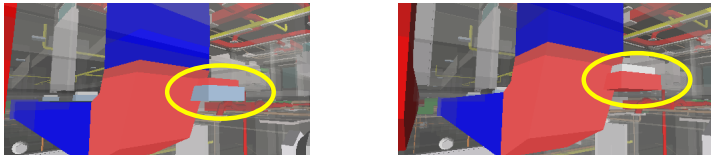
After comparing the counts in clashes detected during coordination meetings and through automatic clash detection, the research team analyzed precision and recall of clashes identified in both processes, keeping track of objects that were and were not modeled. Table 4 shows recall and precision of all observed instances of clashes in automatic clash detection and the coordination meetings for floor 1. These instances mainly captured coordination issues between HVAC and Electric, HVAC and Plumbing, Electrical and Plumbing, Electrical and Fire Protection, and Plumbing and Fire Protection subcontractors. Table 4 also highlights objects needed to be modeled to capture all possible clashes between these pairs of subcontractors. An example of an object that was not modeled in the BIM and was identified as causing clashes in the coordination meetings is *cable tray*.

Table 4: Recall and Precision of all observed instances of clashes in automatic clash detection and coordination meetings for Floor 1, coordinating between pairs of subcontractors, as well as objects needed to be modeled to capture all possible clashes

Pairs of subcontractors analyzed		2D (coordination meeting)	3D (automatic clash detection)	Objects needed to capture all clashes
HVAC and Electric	**Recall**	4/10 = 0.40	6/10 = 0.60	Lights, ducts, cable trays
	Precision	4/4 = 1.00	6/29 = 0.21	
HVAC and Plumbing	**Recall**	0/6 = 0.00	6/6 = 1.00	Plumbing lines, ducts
	Precision	0/0 = 0.00	6/50 = 0.12	
HVAC and Fire Protection	**Recall**	2/5 = 0.40	5/5 = 1.00	Ducts, sprinkler lines
	Precision	2/2 = 1.00	5/42 = 0.12	
Electrical and Plumbing	**Recall**	0/2 = 0.00	2/2 = 1.00	Lights, plumbing lines
	Precision	0/0 = 0.00	2/3 = 0.67	
Electrical and Fire Protection	**Recall**	0/1 = 0.00	1/1 = 1.00	Lights, fire protection lines
	Precision	0/0 = 0.00	1/2 = 0.50	
Plumbing and Fire Protection	**Recall**	1/5 = 0.20	5/5 = 1.00	Plumbing lines, fire protection lines
	Precision	1/1 = 1.00	5/23 = 0.22	

Table 4 shows a general high recall and low precision for the automatic clash detection process, and low recall and high precision for the manual approach. The low precision in the automatic clash detection was due to how the BIM was modeled. Some objects were not modeled in the BIM (e.g. cable trays) and, hence, clashes related to these were not detected. Moreover, other objects were modeled in several

pieces, which led to the detection of multiple clashes related to them, where it was actually only a single clash. An example is shown in Figure 1, in which a single light fixture was modeled as two separate objects and, hence, two clashes were detected in the automatic process instead of one.



(a) (b)

Figure 1: Example of a light fixture modeled as two separate objects. Different pieces of the same light fixture, shown in circles in (a) and (b), were considered as two separate objects in the automatic clash detection

Table 4 gives insight as to what objects needs to be modeled in order to capture all possible clashes. Objects only captured in the manual approach were not in BIM. Had they been modeled, they would have also been identified in the automatic process. Moreover, objects modeled in multiple pieces need to be aggregated before running the automatic clash detection. Otherwise, multiple clashes would be returned, when, in fact, they represent a single one.

Field Detected Clashes

During the MEP installation in floor 1, several clashes were also identified in the field, causing delays in the schedule. These were observed through RFIs from subcontractors posted in the GC's online collaboration system. Two examples of field detected clashes from Project X include: between heating line hangers and ducts, and between sprinkler lines and cable trays. In the first example, hangers were not coordinated in the manual process, nor modeled in the BIM, causing several field detected clashes between different trades. In the given example, the heating subcontractor began installing his lines before the ducts were installed. Thus, when the ducts came in, there were several hangers that needed to be replaced, in order to fit the ducts in their designed spaces. A similar observation is described in Khanzode et al. (2008). In the second example, in a room in floor 1, the door height was specified as 7' 0", and the highest point of the electrical switch that needed access was 8' 3 1/2". But, there was a 6" sprinkler main running along the front of the 5Kv switch that was approximately 12" from the face of the switch and approximately 8' 4 1/2" high. This meant that the sprinkler line was occupying the height designated for the electrical subcontractor. At the time of writing this paper, this clash has yet to be resolved. The identified objects in the field detected clashes also illustrate objects that need to be modeled in the BIM in order to capture the most possible clashes in an automatic clash detection process.

Conclusions

Results from this study show a general high recall and low precision for the automatic clash detection process, and low recall and high precision for the manual approach. The low precision in the automatic clash detection was due to how the BIM was modeled. Some objects were not modeled in the BIM (e.g. cable trays) and, hence, clashes related to these were not detected. Moreover, other objects were modeled in several pieces, which led to the detection of multiple clashes related to them, where it was actually only a single clash. Results provide insights as to what and how objects need to be modeled in a BIM so as to capture and precisely identify most of the possible MEP clashes. This paper was limited to the comparison of types of clashes identified in each of the three methods for Project X. Although these results cannot be generalized, they still provide insights into what needs to be modeled in a BIM for MEP coordination prior to the start of the coordination process. The results presented in this paper are part of an ongoing research project. Further research will be carried out regarding the level of detail needed in a BIM to be used by various MEP trades in automatic clash detection.

Acknowledgements

This project is funded by a grant from the Pennsylvania Infrastructure Technology Alliance (PITA). PITA's support is gratefully acknowledged. Any opinions, findings, conclusions or recommendations presented in this paper are those of the authors and do not necessarily reflect the view of the Pennsylvania Infrastructure Technology Alliance.

References

Khanzode A; Fischer M; Reed D. (2005). Case Study of The Implementation of The Lean Project Delivery System (LPDS) using Virtual Building Technologies on a Large Healthcare Project, Proceedings 13th Annual Conference of the International Group for Lean Construction, IGLC-13, Sydney, Australia.

Khanzode, A; Fischer, M; Reed, D (2008). Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing (MEP) systems on a large healthcare project, ITcon Vol. 13, Special Issue Case studies of BIM use, pg. 324-342, http://www.itcon.org/2008/22

Kiviniemi, A.; Tarandi, V.; Karlshøj, J.; Bell, H.; Karud, O.J. (2008) "Review of the Development and Implementation of IFC compatible BIM" Erabuild, 128p.

Reinertsen, D.G. (1997) Managing the design factory: a product developer's toolkit. New York: The Free Press, 267 pp.

Rijsbergen, C.V.: Information Retrieval (1979). London; Boston. Butterworth, 2nd Edition. ISBN 0-408-70929-4

Staub-French, S. and Fischer, M. (2001). Industrial Case Study of Electronic Design, Cost, and Schedule Integration. Technical Report No. 122, Center for Integrated Facilities Engineering, Stanford University, CA. Available at: <www.stanford.edu/group/CIFE/Publications>

Tatum, C.B. and Korman, T.M. (2000). Coordinating building systems: process and knowledge, Journal of Architectural Engineering, Vol. 6, No. 4, 116-121.

EARLY DESIGN ENERGY ANALYSIS USING BIMS (BUILDING INFORMATION MODELS)

Annette Stumpf[1], Hyunjoo Kim[2] and Elisabeth Jenicek[3]

[1] Principal Investigator, US Army ERDC (Engineer Research and Development Center), Champaign, IL 61826, PH (217) 373-4492, Annette.L.Stumpf@usace.army.mil
[2] Researcher, US Army ERDC, Champaign, IL 61826, PH (217) USA-CERL ext 7539, Hyunjoo.Kim@usace.army.mil
[3] Principal Investigator, US Army ERDC, Champaign, IL 61826, PH (217) 373-7238 Elisabeth.M.Jenicek@usace.army.mil

ABSTRACT

An emerging area of interest within the A/E/C industry is designing sustainable buildings, as evidenced by the increasing use of the US Green Building Council (USGBC) LEED® (Leadership in Energy and Environmental Design) green building rating system. This research utilized Building Information Modeling (BIM) for energy analysis during the conceptual design phase. Most building energy analyses are conducted late in the design by energy analysts. This paper describes a process of exploring different energy saving alternatives in early design using 3D-CAD (computer aided design)/BIM technology. The recommended process allows project teams to utilize BIM models in energy simulations and compare results quickly. In order to test the feasibility of the proposed approach, a prototype energy modeling process was developed and tested on a new construction project, the Community Emergency Service Station at Fort Bragg, North Carolina with a team led by the U.S. Army Corps of Engineers. The energy modeling process was applied to explore different building envelope and equipment scenarios to enable energy conscious decisions early in the design process when they make the biggest impact on building life cycle costs.

INTRODUCTION

Traditionally, most building energy analyses have been conducted late in design, by energy analyst specialists who are usually mechanical engineers. At this stage, the focus is to design a mechanical system that will support space conditioning requirements for the final building form. The ability to model different building configurations early in the design process to identify energy saving alternatives does

not typically occur. This is due to the difficulty and expense of modeling the building and energy systems. Project resources are limited so effort to analyze building energy use is expended in the late stages of design using the current suite of energy modeling tools (Brucker et al. 1996). Today's 3D-CAD/BIMs (Building Information Models) provide the user with an opportunity to explore different energy saving alternatives in early design while avoiding the time-consuming process of re-entering all the building geometry, enclosure, and HVAC information necessary for a complete energy analysis. This method enables project teams to make energy conscious decisions early in design when they impact building life cycle costs the most. The BIM energy analysis approach also supports cost effective decision-making during construction and creates a set of data files that will remain with the project through design, construction, and its operating life. This method can also be used to compare energy-saving alternatives for retrofit projects such as how many inches of rigid insulation should be put on the roof during re-roofing. The product of this research is a process the Army Corps of Engineers could adopt to use BIM models to conduct energy simulations during early building design. The results from this process were compared with those from a commonly used energy modeling tool, eQUEST.

LITERATURE REVIEW

The industry standard LEED®, assigns ratings of platinum, gold, silver or bronze in recognition of total credits earned by the project. The industry standard for energy efficiency, ASHRAE 90.1, is incorporated into LEED through Energy & Atmosphere (EA) Prerequisite 2 – Minimum Energy Performance; EA Credit 1 – Optimize Energy Performance; EA Credit 2 - On-Site Renewable Energy. The U.S. Army policy requires all new buildings to be certifiable at the LEED silver rating. Fort Bragg established the goal of LEED platinum by 2020 for all facilities.

For the past 50 years, a wide variety of building energy simulation (BES) analysis tools have been developed, enhanced, and applied throughout the building energy community. Examples of these tools are BLAST, EnergyPlus, eQUEST, TRACE, DOE2, and ECOTECT. Input data in these tools are complex, 2D drawing or text-based applications which require a great deal of time to learn (Crawley et al. 2005). Building designers consider energy analysis a time-consuming process and leave it to mechanical or electrical engineers late in the design process. Several research papers describe energy analysis as a holistic evaluation (Abaza, 2002). Dahl et al. (2005) and Lam et al. (2004) showed that decisions made early in a project have a strong affect on the life cycle costs of a building. As Grobler (2005) presented in Figure 1, building designs (conceptual and detailed designs) affect most of the life cycle costs of the construction and operation of a building. A recent innovation in building design and construction, Building Information Modeling (BIM) has received tremendous interest for its impact on sustainable development and provides the opportunity to develop energy analysis software programs for the industry. It is also worth noting that several researchers proposed to combine Lean and BIM technologies to improve modeling process in sustainable development (Riley et al, 2005). While the converging approach would enable virtual simulation in collaborative environments, and thus is expected to change the A/E/C industry in

terms of delivery and management of the built environment, it is found that the approach emphasizes the whole process in design and construction processes. Yezioro et al. (2008) conducted assessing building performance using 3D CAD model for energy analysis in the early design stages. Early design energy analysis provides an opportunity to make cost-effective decisions early in the building life cycle, and to meet federally mandated energy conservation targets. (The Energy Policy Act of 2005 mandates that all new federal facilities must be at least 30% more energy efficient than the base case of ASHRAE 90.1 2004). Healthy buildings can pay for themselves since building construction, operation and energy costs typically amount to small portion (about 10%) of a business's costs while 90% goes towards salaries (USGBS, 2008).

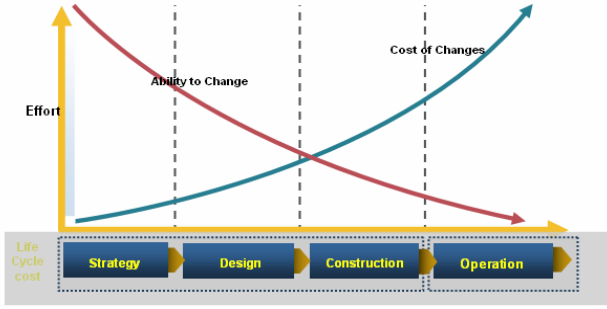


Figure 1. Level of Influence on Costs as compared to time (Grobler, 2005)

BIM Approach for Energy Analysis Solutions

The goal of this research was to use the building geometry and details contained in a BIM model to quickly build an energy analysis model to compare energy-related tradeoffs early in design. More than just the lines and arcs associated with traditional computer-assisted drawing (CAD) tools, BIM includes associated benefits of visualization, built-in intelligence and simulation, intelligent objects of a structure, such as spatial data (3D), unstructured data (text), and structured data (databases, spreadsheets), as shown in Figure 2. With the addition of building geometry data in a BIM model, the volume can be calculated and energy estimates made based on building envelope characteristics (doors and windows) and building orientation.

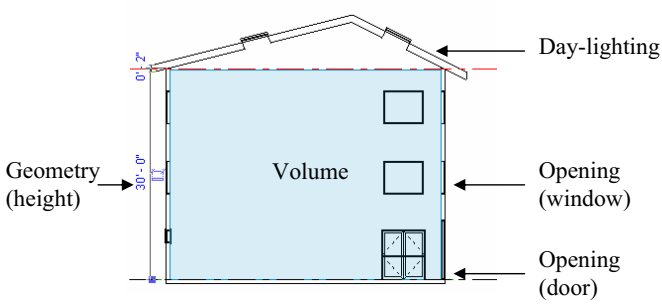


Figure 2. 3D-CAD/BIM model

While there are several different BIM-based energy modeling software programs available, Green Building Studio (GBS) works with gbXML that was specifically developed to exchange energy-related information. That is, gbXML output from BIM programs can be imported into GBS. GBS automatically checks for the correctness of the BIM model by warning the user of issues with the model before it is exported to the gbXML format. Therefore, the GBS was selected for energy modeling for the entire process which was subsequently validated with a separate energy modeling program.

GBS (Autodesk, 2008) is a web-based service that works with a gbXML file exported from various BIM applications including ArchiCAD, Revit and TriForma (Beta version) and uses the building information to perform an energy evaluation with established tools such as DOE-2, eQUEST, and EnergyPlus. It allows various changes in design alternatives to the building design such as orientation, glazing, roof and wall construction, lighting, and HVAC to be quickly analyzed to determine which options are the most energy-efficient.

While we were exploring different BIM energy modeling software programs, we realized that there is a limitation in the BIM software. That is, BIM software does not have the capability to check for model integrity, correctness, or completeness. With the notion of garbage in and garbage out (GIGO), an incomplete BIM model will result in inaccurate energy analyses. In our experience, attractive renderings created by the BIM modeler during the charrette clearly showed the design intent to the customer, but the spaces were not consistently represented so the gbXML file could be read immediately by GBS. The GBS error checking routine helped us iteratively refine the BIM model so it would accurately represent the building geometry in GBS. Similarly, inaccurate representation of building geometry within traditional energy analysis programs will result in inaccurate energy analysis.

CASE STUDY

In order to conduct an energy analysis in early design phase, we developed a process of how an energy analysis model may be developed from a 3D CAD or BIM model and used to explore different energy use alternatives. In this section, a sequence of three different steps in the energy modeling process is outlined, as shown in Figure 3. The first step is to identify the project requirements. This may present

several challenges as many projects have constrained budgets, schedules, and resources. It is essential that all building stakeholders--including owners, designers, engineers and contractors--have a clear understanding of problem definition and participate in identifying a set of design alternatives early in the project planning process. The second step, energy modeling, is divided in two phases, concept design and detailed design. Energy modeling in concept design is mainly for building envelope shape and orientation, while that in detailed design is for building elements such as size, shape, and material of wall penetrations. The third step, the refinement process, supports the essential need to validate results of early design energy analysis using an independent energy modeling software program. Crawley et al. (2005) stated that many users rely on a single energy simulation tool when they might be more productive having a suite of tools from which to choose. In this research, the validation was conducted by comparing the results from the GBS analysis with results from an eQUEST analysis.

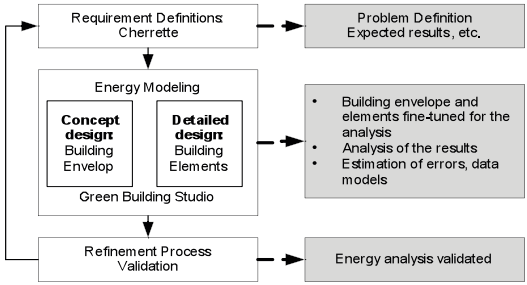


Figure 3. Process for early design energy analysis

Requirement Definition: Charrette

The project described in this paper is a new Community Emergency Service Station (CESS) facility at Fort Bragg, North Carolina. This building will provide fire fighting, medical and police support services for a residential neighborhood on this military installation in Fayetteville, NC. The station consists of offices, training rooms, physical training, day room, kitchen, dormitory area, apparatus room, decontamination room, storage area/rooms, latrines, communication and electrical closets, and a mechanical room. The size of the proposed new facility is approximately 8,300 SF. The apparatus room was sized for a fire truck, military police car, and ambulance. Space for hose drying, lockers and a work bench were also required in the apparatus room.

Identification of requirements for the CESS facility was accomplished using the charrette process. A charrette is held at the beginning of a project where a group of designers, engineers, and contractors may draft solutions to design problems. For our case study, the charrette took place in the early stage of design and also included

stakeholders outside of the design/build team. Each participant presented his/her work to the full group. The charrette served as a way of quickly generating solutions while understanding and integrating the interests of different groups of people. The outcome of the charrette was a 35% complete integrated building design.

Energy modeling in the case study presented several challenges. First, it was essential to provide energy analysis results to the participants during the 4 day charrette so we could identify energy-saving improvements while the design was being modified. In addition, energy modeling usually involves the time-consuming process of re-entering all the building data for an energy analysis. In order to meet the time demands of energy modeling "live" during the charrette, we convinced the A/E that it was essential to bring a BIM modeler to try out various building design alternatives. Our team could then use the BIM models to quickly explore energy impacts using the Green Building Studio tool.

Energy Modeling

The first step in the early energy modeling process requires the use of energy modeling software to generate annual energy consumption and cost data for a set of building design alternatives. Annual energy use will vary depending on building configuration and design details. The energy modeling process is grouped into two sub-processes: the Macro-level Energy Analysis focuses on comparing building size, shape, and orientation; and, the Micro-level Energy Analysis considers building details such as wall penetrations and building system details.

Concept Design: Macro-level Energy Analysis

1) Building Shape: The first step of energy modeling is to develop an energy model at the macro level. It includes exploring different building shapes and orientations that are usually considered in conceptual design process (Figure 4).

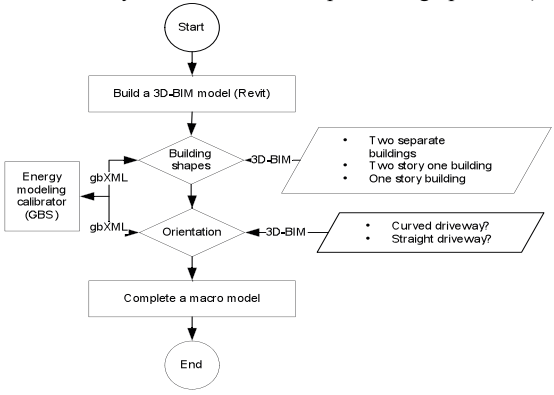


Figure 4. Energy modeling for building configuration and orientation

In order to meet the requirements of the CESS at Fort Bragg as determined in the charrette process, two different spaces were required, a main office and an apparatus room. During the charrette, three distinct building configurations were

considered: 1) the use of two separate buildings (an office building and an apparatus building), 2) a single two-story building, and 3) a single one-story building. Computer renderings of these configurations are shown in Table 1.

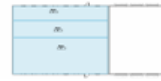
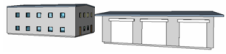
	Model 1	Model 2	Model 3
Type	Two separate buildings	Two-story building	One-story building
Plan			
3D-CAD			

Table 1. Comparison of building configurations

Figure 5 shows the comparison of estimated annual energy costs of the three building configurations. The dominant energy load for this building is summer cooling, due to its location in Fayetteville, NC. According to Figure 5, the single one-story building is expected to have the lowest annual energy costs. Ground source heat pumps were considered an optimum source for cooling based on interviews with mechanical engineers who had researched the cost and effectiveness of various options. Therefore, the one-story building configuration for office and apparatus spaces as shown in Model 3 in Table 1 was chosen to be the most energy efficient building envelope.

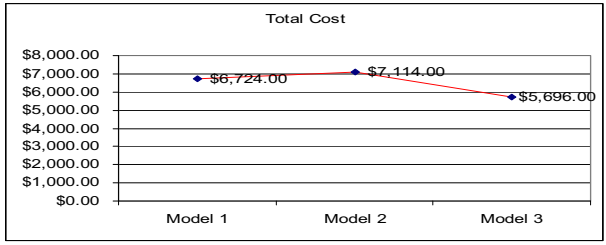


Figure 5. Comparison of estimated annual energy costs of three building configurations

2) Building Orientation: Different orientations were considered at the conceptual design stage. Typically, a building will be oriented to minimize energy requirements. For example, in many cases, facing the long axis of a building to the south minimizes energy required to heat and cool it because solar gain can easily be controlled by horizontal shading.

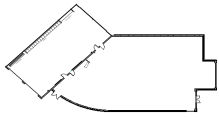
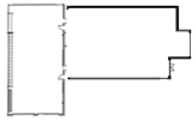
	Model 4	Model 5
Rotation	15 degree deviation	No rotation
Plan		

Table 2. Different orientations of the CESS building at Fort Bragg

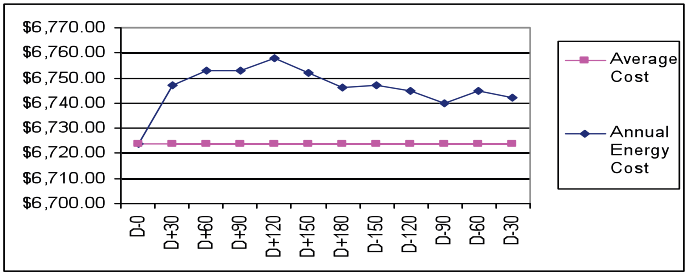


Figure 6. Comparison of estimated annual energy costs of building orientations

During the charrette, the designers wanted to rotate the orientation of the apparatus room by 15 degrees from the rest of the building to allow easy exit of emergency vehicles onto the access street. While analyzing the differences in energy load for each orientation, it was found that the 120 degrees generated the highest energy cost, as shown in Figure 6. The designer's request for a 15 degree rotation resulted in only $34 increased annual energy cost. Therefore, the concept design was modified because we discovered that a true south orientation is not an absolute requirement.

Detailed Design: Micro-level Energy Analysis

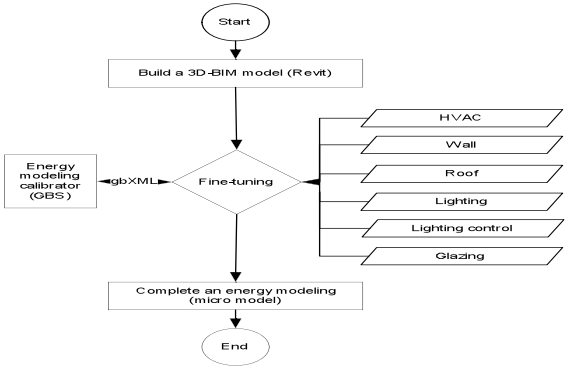


Figure 7. Energy modeling for building elements and design details

Once a general building configuration and orientation were selected, the next step in the process was to develop a detailed energy analysis incorporating design and system details. In this section, a micro-level energy modeling process was developed as shown in Figure 7. This analysis considers a number of options for building elements such as HVAC, roof, walls, windows, mechanical systems, and lighting. Six different categories of building elements were modeled in BIM software. For this study, Revit MEP was used because we could create thermal zones. The gbXML file was exported to GBS. Each potential system component was considered for its impact on overall annual energy costs. Building energy cost comparisons were made using consistent local annualized energy rates and consumption information, for example, expected occupancy of the building. Comparison of annual energy costs for each design alternative was conducted in the six categories (10 different options in HVAC, 17 in glazing, 20 in roof, 15 in walls, 4 in lighting, and 3 in lighting control) of building elements that were considered using GBS.

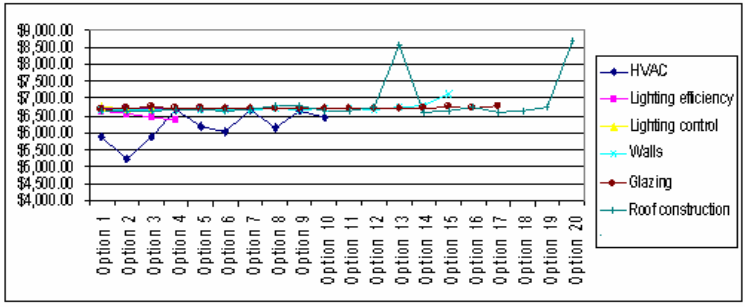


Figure 8. Comparison of different energy estimation

The comparison in Figure 8 shows that different building elements result affected the energy estimations. Compared to the baseline building performance, HVAC options had the greatest impact on annual energy costs, with estimated $1,507 saving using a 17 SEER/0.85 AFUE Split/Pkgd. On the other hand, lighting controls had the least impact on energy costs: $11-17/year. Based on the results of Figure 8, the following design alternatives were recommended:

- HVAC: 17 SEER/0.85 AFUE Split/Pkgd <5.5 ton
- Lighting efficiency: LPD 40% less than base run
- Lighting control: Occupancy sensors
- Roof: Cool Roof - R38 continuous ins. over roof deck
- Wall construction: Insulated Concrete Form (ICF) Wall, 14" thick form
- Glazing: Clear Wall Panel, (U-0.10, SHCG 0.06, Tvs 0.04).

Refinement Process

There is an essential need to validate results from early building energy modeling because the inability to adequately evaluate energy analysis may become the limiting factor in our ability to utilize energy modeling technologies. Energy

engineers input data into most of the existing energy analysis tools using electronic 2D DWG drawings and manual data input describing the building, envelope, and mechanical system and occupancy parameters to estimate energy consumption. Each energy analysis tool generates different results based on different assumptions and input data. Validation for the CESS building was conducted by comparing the results for the same building configuration from BIM based energy modeling with building energy analysis completed using eQUEST, an energy modeling software that is an industry staple.

Validation with eQUEST

A comparison was made in Figure 9 between the baseline model and proposed design model generated by GBS and eQUEST, where ten different zones (corridor, office, dorm, PT, mechanical, high bay, reception, kitchen and open space) were modeled. The assumption of baseline models is based on the building design as defined in ASHRAE 90.1-2004 Informative Appendix G. Then, energy simulations of the proposed design models were conducted in GBS and eQUEST with the same assumptions such as glazing factors, window sizes, U values, zoning requirements and so on, provided by the designer.

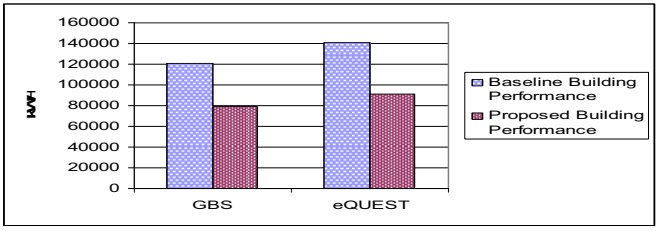


Figure 9. Comparison of GBS and eQUEST results for baseline and proposed design

Comparison of the two models revealed that the difference is in a range of approximately 9 % (6% between baselines; 15.5% between proposed). Also the differences between baseline model and proposed model were in 35-40% at the confidence level of 80-85%, which shows that BIM based energy modeling was successful. Looking closer at the GBS and eQUEST models, which were done by two different people, we found variations that accounted for much of the variation in thermal loads. However, there is a need for further work in developing ways in which to perform the validation in detail for different energy models.

CONCLUSIONS

Utilizing BIM-based energy modeling technology, this research conducted an energy modeling process where project teams may utilize BIM models in energy simulations and see the results quickly and early in the design process. To date, energy modeling tasks are usually left to mechanical or electrical engineers due to its time consuming data entry and occur late in the design process. The case study revealed that BIM based energy modeling eliminated "additional work" to get files/ products into a format that is usable by the various energy models, and produced

results much quicker than using the traditional energy modeling approach. The process conducted by this research could be used to guide designers and engineers through the process of completing an early design energy analysis based on their own BIM model.

REFERENCES

Abaza, H. (2008), "An interactive design advisor for energy efficient building", Journal of Green Building

Autodesk (2008), "Building Information Modeling in Sustainable Design", http://images.autodesk.com/adsk/files/bim_for_sustainable_design_jun05.pdf

Brucker, B., and Stumpf, A. (1996), "Applying collaborative engineering to the facility delivery design", USACERL Technical Report 98/32

Crawley, D., Hand, J., Kummert, M. and Griffith, B. (2005), "Contrasting the capabilities of building energy performance simulation programs", Joint Report, Version 1.0

Dahl, P., Horman, M., Pohlman, T. and Pulaski, M (2005), "Evaluating design-build-operate-maintenance delivery as a tool for sustainability", Construction Research Congress

Lam K.P., Wong, N.H., Mahadavi, A., Chan, K.K., Kang, Z., and Gupta, S. (2004), "SEMPER-II: an internet-based multi-domain building performance simulation environment for early design support", Automation in Construction V. 13

Lapinski, A., Horman, M., and Riley, D. (2005), "Delivering sustainability: lean principles for green projects", Construction Research Congress

Mora, R., Rivard, H., and Bedard, C. (2005), "From architectural sketch to feasible structural system solution", Computing in Civil Engineering

Grobler, Francois. (2005), "A Practical Guide to IFC or Surviving in the BIM Economy: What you need to know", AEC-ST, Orlando, FL

Riley, D., Sanvido, V., Horman, M., McLaughlin, M., and Kerr. D. (2005), "Lean and green: the role of design-build mechanical competencies in the design and construction of green building", Construction Research Congress, ASCE.

Shaviv, E., Yezioro, A., Capeluto, I.G., Peleg, U.J., and Kalay, Y.E. (1996), "Simulations and knowledge-based computer-aided architectural design (CAAD) systems for passive and low energy architecture", Energy and Buildings V. 23

USGBC (2008). https://www.usgbc.org/ShowFile.aspx?DocumentID=2583

Yerioro, A., Dong, B., and Leite, F. (2008), "An applied artificial intelligence approach towards assessing building performance simulation tools", Energy and Buildings

IMPROVING SITE UTILIZATION PLANNING THROUGH THE USE OF INTERACTIVE WORKSPACES

Robert M. Leicht[1] and John I. Messner[2]

[1] PhD Candidate, Penn State, rmleicht@engr.psu.edu, 104 Engr Unit A, University Park, PA 16802
[2] PhD, Associate Professor, Penn State, jmessner@engr.psu.edu, 104 Engr Unit A, Univ. Park, PA, 16802

Abstract:
In ongoing research into the value of Interactive Workspaces for improving team collaboration, this paper reports on the value demonstrated for different forms of interaction while teams performed site utilization planning designs. Interactive workspaces are spaces with potential for ubiquitous electronic interaction to allow for enhanced communication and capture of information. In the experiment reported, 24 groups of students with typically 4 group members were asked to perform site utilization planning for three phases of the Long and Foster Headquarters project in Chantilly, VA. The focus of the study was to identify changes in the students' interactions when using the space, and the difference when different forms of software and display interaction were introduced. The change in the team communication is based on the number of students with easy access to shared visual information. The teams were provided with either tablet PC's, one per student, or a single interactive whiteboard to sketch the schematic design of the site as they developed their plans. Students typically found the use of the interactive whiteboard to provide a more collaborative environment than using tablet PC's, but at the same time value in utilizing multiple displays with the parallel interaction using the tablets. All teams found working in the interactive workspace more enjoyable than typical meetings and would be interested in using the space for similar tasks in the future.

1. Introduction

Team collaboration plays a central role in the design and construction of buildings, infrastructure and other facilities. Recent developments in technology, such as building information modeling, virtual reality, and computer mediated communication, have been shown to add value to this collaborative process. Previous

work into virtual environments (VE) has found that benefits from design and construction are focused on team design support and decision making tasks (Gopinath, 2004). Despite this value, it is hard to document the traits which are essential in virtual environments and how these contribute to improved team interactions. Defining these benefits and relating them to specific characteristics would provide a means for comparison between different setups, interactions, and applications of VE's. To these ends we have undertaken a study to compare between two different variables within an interactive workspace to study how teams value the use of the different tools which are available.

While the term VE is often used in discussion of virtual reality and display media, there is ambiguity in the definition, specifically the difference between the physical world where the user(s) interact with the system, and the digital aspects such as a model or software. Virtual environments are environments which are partially or totally reliant on computer generated sensory inputs (Air Force, 1994). A VE is the bringing together, and by definition, the blurring of the line between these two aspects (Leicht et al, 2007). In breaking down the system by traits, it is necessary to separate these two main aspects into variables which can be generalized to all systems. The physical aspects, for the purpose of this report, will be referred to as the interactive workspace. Since the focus of this research is the use of the system for collaboration, the report will not look in depth at systems which focus on single user displays, such as a head-mounted system, or the software or electronic design content. The two traits of the interactive workspace to be studied are the ability of more than one user to be able to work in parallel to add and display information, and the value of sketching and having a 3D model for site utilization planning.

2. Use of Interactive Workspaces

The available literature offers evidence of improved performance when teams meet and work using improved visualization tools and software within interactive workspaces. Fruchter (2005) studied their use for a class project utilizing virtual teams. In the study, a group of industry members are given a team's project at a set point to discuss and generate ideas for future directions and challenges while the students observe and ask questions, in both a collocated and virtual capacity. In the findings, Fruchter identifies the unique aspect that the virtual attendees are actually more engaged in the content due to their proximity to the developed material than the physical attendees. Wang et al (2007) performed a comparative observational study to discern the role that software played when using a virtual environment for team problem solving for a construction scheduling task, finding greater enjoyment and interest from the student when meeting in an interactive workspace. Issa et al found added value for student design projects when using the Interactive Collaboration Lab at the University of New Brunswick. Students were surveyed at the end of an extended design course and the students found that the lab enabled them to collaborate more effectively, make more educated decisions, more effectively use their time, and produce higher quality work (Issa et al, 2007). The studies demonstrate added engagement and greater value derived from meetings using interactive workspaces, but the specific impacts of hardware and interface considerations are not the focus.

Some of these efforts have proven beneficial in field construction settings as well. Liston compared traditional construction project meetings with project meetings using 4D visualization and identified increased efficiencies in communications among team members (Liston et al, 2001). Khanzode found improved coordination among specialty contractors on the Camino Hospital Project when the team developing the shop drawings for the duct, piping, plumbing, and sprinkler systems were housed in the "Big Room" there was a shorter time and more economic process for collaborating. (Khanzode et al, 2008). While these studies demonstrate the value which can be derived from the visualization and teaming aspects created in interactive workspaces, it is still not clear which traits of the systems is adding value, the value is considered in the context of meetings and not for performance of differing tasks.

3. The Immersive Construction Lab

The interactive workspace utilized for this study was the Immersive Construction (ICon) Lab at Penn State. The ICon Lab was developed in stages starting with a single rear-projected screen. Currently, the ICon Lab has three 6 feet (1.8m) tall by 8 feet (2.4m) wide screens, with the two side screens angled at 30 degrees from parallel from the center screen as shown in Figure 1. All three screens are rear projected, with two projectors for each to allow for passive stereo visualization. The display is run from a single Windows-based desktop computer.

In addition to the central display, a single interactive whiteboard is set up adjacent to the left side of the main display. The interactive whiteboard is connected to a separate computer from the main display. Along with the interactive whiteboard a set of 20 tablet PC's are housed within the ICon Lab. The tablets are set up to allow the users to wirelessly push the screen image to one of the three screens of the central display.



Figure 1: Images of teams using different lab configurations and a rendering of the Immersive Construction Lab at Penn State.

4. Research Methodology

The undertaken analysis is an intermediate step in an ongoing study to develop a framework for utilizing interactive workspaces more effectively. In this analysis, an undergraduate class in architectural engineering at Penn State performed a site utilization planning activity in the ICon lab as part of a semester long project. The project was a team project, the student teams performed estimates, scheduling,

and site utilization planning for the Long and Foster Headquarters building, located in Chantilly, VA. The 95 students in the class were randomly assigned to 24 groups of three or four members. The class was very homogeneous, since the class admission is limited to students in architectural engineering with 6th semester standing, the student body is aged 20-22 years old for over 95% of the students and 80% male with 35% having some limited design or construction experience.

The task was held during the 11th week of a 16 week semester, with the students working with the same team for the entire term. The task for the students while in the lab was to generate the conceptual layouts for the site utilization plan for three phases of construction. The three phases and approximate timeframes were provided to allow for consistency of the tasks amongst the 24 groups. The 24 groups were randomly assigned to one of four different arrangements within the lab. The arrangements were set up around 2 central variables, display interaction and availability of a 3D model.

When the students arrived for the activity they were provided with a brief overview of the lab layout and the tools available, then they were given one hour to draft conceptual layouts for the site utilization plans. The students then finished the designs outside of the lab and submitted formal site utilization plan drawings. At the end of the one hour period, the students were asked to rate 20 statements about the utility and value of the lab on a 1-5 Likert Scale.

The teams were required to perform the task in the lab as part of their project, with the option of submitting the questionnaire, limiting error based on a volunteer population. Since the task was graded, the students had an incentive to perform well, but the professor and teaching assistant were not present for any of the activities and did not see the results until after final grades were submitted for students.

As shown in Table 1, there were four different configurations of the ICon Lab based on the traits of the interactive workspace. In Layout 1 a tablet PC was made available to each member of the team for drawing the site utilization plan, with an additional computer set up displaying a navigable 3D model of the Long and Foster Headquarters building. The teams had the option of changing which of the tablets were displayed on any of the screens at any time during their period in the lab, including the model display. In Layout 2, there was again a tablet PC available for each team member, but no additional computer displaying the 3D model was provided. In Layout 3, the interactive whiteboard was set up for drawing the site utilization plan, with the left screen of the central display showing the navigable 3D model. In Layout 4, the interactive whiteboard was set up for drawing on the site utilization plan, with no 3D model available. In these configurations, the differing hardware influenced the availability of interfaces for team members to draw upon, while the software interaction was based on the availability of the 3D model and sketching capabilities of the interfaces.

Table 1: Matrix showing the breakdown of the four layouts used for the study.

	Tablet PC's	Interactive Whiteboard
3D Model	Layout 1: 	Layout 3: 
No 3D Model	Layout 2: 	Layout 4: 

While the large class does provide a large sample for study, by breaking the 24 groups into 6 configurations, the subsets for each layout are not large. Also, because the feedback is based on the questionnaire responses the results are based on subjective evaluations of the team experience, and may be biased. Particular bias may result from this being the students' first time using the ICon Lab creating a small novelty effect, though that should hold true for the whole sample. Also, since the participants were all students there was little to no construction experience which means the process and discussions were less efficient and may have created an added level of difficulty when putting the students into a new environment to perform the task.

5. Results and Discussion

Of the 95 students in the course, 86 survey responses were received for a 91% response rate. The responses to the surveys were organized into four sections:

1. General statements
2. Display Interaction
3. Software Interaction
4. Collaboration

5.1 General Interactive Workspace Responses

To begin the questionnaire after the students participated in the activity, several statements were offered relating to the overall experience in the ICon Lab. Figure 2 shows the responses to the statements regarding the general statements in the questionnaire.

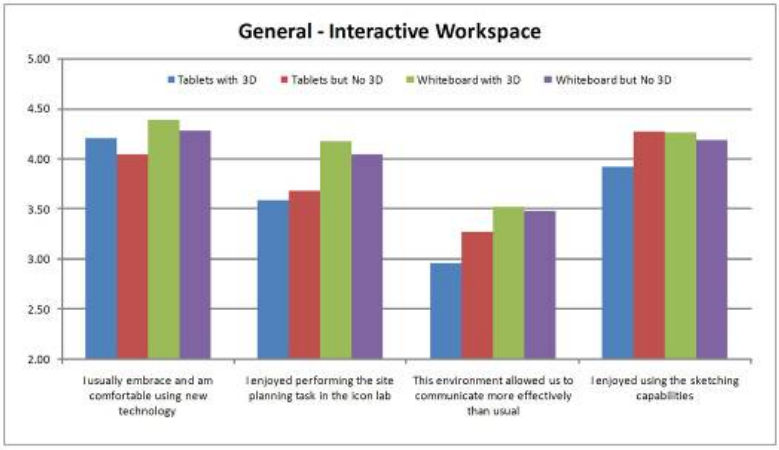


Figure 2: Chart showing the responses to the general statements about using the interactive workspace with the statements listed on the X-axis and a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) on the Y-axis.

The chart in Figure 2 shows the responses to the four general statements posed regarding the students activity in the ICon Lab. The first statement was intended as a simple gauge of the students' perceptions of technology. Based on the response, the student averages shows most to be comfortable with trying new technology. Also, it the averages for the four different layouts were fairly consistent, with a range of less than 0.3 points on the scale. The second statement focuses on the students' enjoyment level for the activity. While all of the averages are higher than a score of 3.0, which was neutral, layouts 3 & 4 clearly had higher averages than layouts 1 & 2. Layouts 3 & 4 were the two utilizing the interactive whiteboard rather than the tablet PC's.

The third statement was focused on whether the teams felt their communication was more effective in the ICon Lab than usual. The average for three of the four layouts was higher than 3.0, but by a fairly small margin, with one set leaning toward being less effective. This could be a result of the introduction of new tools which affected the normal flow of meetings, or it could indicate that while fun the tools used were not as easy to use as traditional tools. The final statement was concerned with the students' enjoyment of the sketching capabilities available. All of the average responses are within a small margin of 4.0, indicating that in general the students liked being able to sketch in the ICon Lab.

5.2 Display Interaction

There were several statements focused upon the manner of interaction with the hardware in the ICon Lab asked of the students after their activity. Figure 3 shows the responses to the statements regarding the interaction with the hardware in the questionnaire.

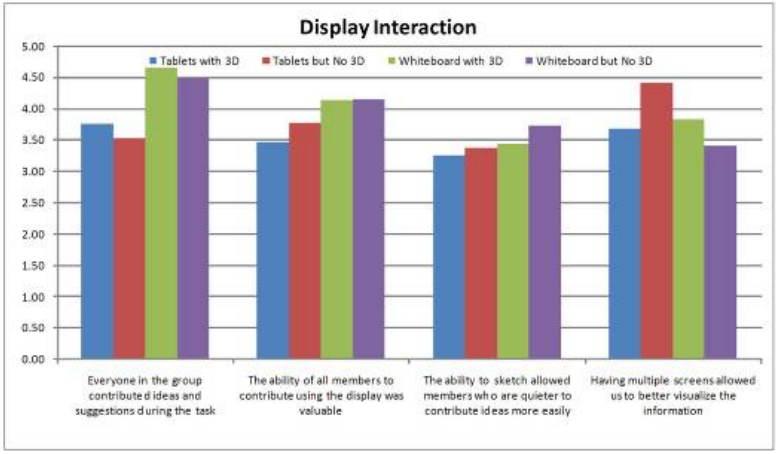


Figure 3: Chart showing the responses regarding display interaction in the interactive workspace to the statements listed on the X-axis on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) on the Y-axis.

The second area of statements the students responded to were focused on the interactions the students had with the display. The first question focused on whether all group members contributed to the task when creating the site utilization plans. The responses for the teams having the tablets, layouts 1 & 2, are approximately one full point below the responses for the teams using the interactive whiteboard. This shows that teams using an interactive whiteboard seemed to create more interaction and teamwork than did those using the tablet PC's. The second statement asked if there was value in all members having the ability to contribute using the display. Interestingly, while there seemed to be much greater emphasis by the teams with an interactive whiteboard on the contributions of ideas, the use of the display was approximately ½ point lower, while the teams with Tablet PC's stayed almost the same. It's possible this could simply vary with the quality of the contributions by the team members more than the ability to contribute using the displays.

Along the same lines the third statement asked the students if the ability to sketch allowed more timid group members to contribute more easily. While the averages indicate there may be some value for more timid members, the value seems to be fairly small. The final question was the value of having multiple screens available for the team members to share information. The responses vary by a large amount. The groups with tablets and the model utilizing three screens, layout 1, found some value in having multiple screens. The students using tablets without a model, also utilizing three screens, rated this almost a full point higher. It would seem that having the model displayed was detracting from the value of the screens. Looking at the team that had the interactive whiteboard and a screen with the model displayed, layout 3, they rated the value similarly to layout 1. And the students using just the interactive whiteboard with no additional screen, layout 4, fell just above neutral.

5.3 Software Interaction

While we asked questions about the interaction with the software, they were focused upon the manner of interaction more than specific details of the software applications used. Figure 4 shows the responses to the statements regarding the interaction with the software in the questionnaire.

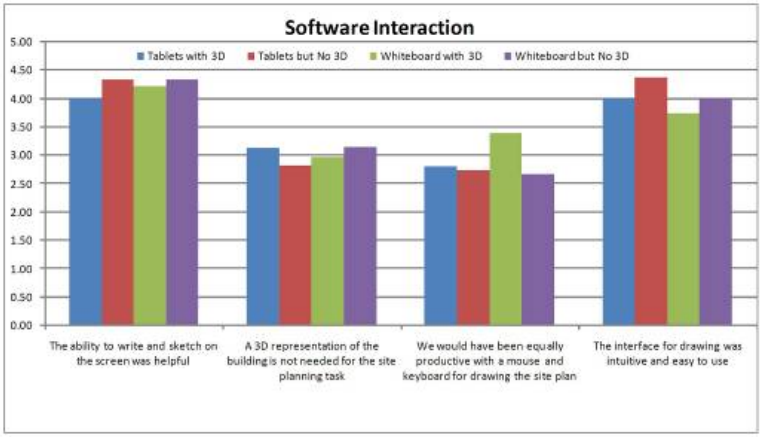


Figure 4: Chart showing the responses regarding software interaction in the interactive workspace to the statements listed on the X-Axis on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) on the Y-Axis.

The first statement regarding the use of the software simply asked if having the ability to write and sketch was helpful. The averages for all of the layouts were between 4 and 4.5 indicating general agreement that these abilities were useful for site planning. The second statement considered whether there was value in having a 3D model available during the site utilization planning. Two of the averages resulted about 3.0, with two resulting below. However, one of the layouts above 3.0 had a model available and one of the layouts below had a model available, with none being more than 0.3 points away from neutral. This seems to suggest that having the model available was not needed, but that there may be some value since none disagreed with the statements either.

The third statement compares the use of the sketching capabilities with the use of a mouse and keyboard. While those in layout 3 tended toward agreeing that a mouse and keyboard functioned equally for the task as the sketching capabilities, the other three teams tended to disagree, though none of the layouts strayed too far from neutral. The last question for considered the ease of use of the sketching interface. With some minor variation, all of the teams found the sketching capabilities intuitive and easy to use.

5.4 Collaboration

The final set of statements asked questions about the collaborative efforts of the teams while in the interactive workspace. Figure 5 shows the responses to the statements regarding the interaction and collaboration in the lab.

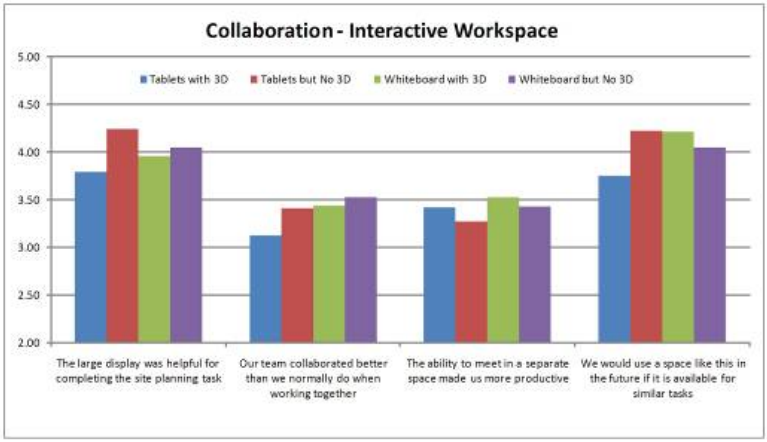


Figure 5: Chart showing the responses to the statements regarding collaboration in the interactive workspace listed on the X-Axis on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) on the Y-axis.

Regarding the value of the interactive workspace for collaborative efforts, the first question asked about the value of having a large display to use. The four different layouts all averaged around 4.0 showing the large display was believed to be helpful. The averages were not as high, but again fairly consistent at 3.5 in agreement that the teams collaborated better than usual while they were working in the ICon Lab. Part of the reasoning for this can be seen in the next statement regarding the value of having a separate space to hold a meeting. Typically students use one of the department computer labs when collaborating on a project which requires a computer. The value of having a separate space scored similarly to that of collaborating better than usual, though the scores by layout changed somewhat indicating that solitary space is not the only factor. The last statement summarizes the overall value with the groups scoring near 4.0 in agreement that they would be interested in using the space for similar tasks in the future.

6. Conclusions & Future work

This paper presented questionnaire results for teams utilizing an interactive workspace for site utilization planning. The teams found the experience in the lab more enjoyable than typical meetings and would again use the interactive workspace for performing similar tasks in the future. In general the teams using the interactive whiteboard found the experience more enjoyable and found the team to communicate more effectively when in the lab than did the teams using the tablet PC's. The teams using multiple tablet PC's found more value in having multiple screens to display information.

Regardless of the layout used, the students typically enjoyed and found valuable the ability to write and sketch directly on the screen while performing the site planning design. The use of the 3D model was not considered nearly as valuable, but was not completely without value, suggesting that the form of information available should meet the needs of the specific task. Also, there was some disagreement about the comparison between sketching and using a mouse and

keyboard. All in all the teams found added value to meeting in the interactive workspace.

Future work in this area will explore more thorough analysis of the displayed value of the systems when collaborating through observational studies of these tasks. The study will also explore other tasks that may find value in utilizing interactive workspaces. Also, studies of the value of different forms of interaction depending on the task at hand and interests of the team members involved.

7. Acknowledgements

We would like to thank the student participants for agreeing to be observed and recorded during the study presented in this paper. We also thank the National Science Foundation for their support of this research through Grant No. 0348457 and 0342861. Any opinions, findings, conclusions, or recommendations are those of the authors and do not reflect those of the National Science Foundation or the project participants.

8. References

Air Force (1994). Glossary, Proceedings of the NSIA Spacecast 2020 Symposium, 9-10 November 1994, Washington, DC, USA. http://www.fas.org/spp/military/docops/usaf/2020/app-v.htm

Fruchter, R. (2005). Degrees of engagement in interactive workspaces, *AI & Society*, 19, pp. 8-21.

Gopinath, R., and Messner, J. I. (2004). "Applying immersive virtual facility prototyping in the AEC industry." *Proceedings of the 4th International Conference of Construction Applications of Virtual Reality,* Lisbon, Portugal, Sept. 14-15, 79-86.

Issa, M., Rankin, J., Christian, J., and Pemberton, E. (2007). Using interactive workspaces for team design project meetings. *CONVR 2007: 7th Conference of Construction Applications of Virtual Reality,* State College, PA, USA, Oct. 22-28.

Khanzode A., Fischer M., and Reed D. (2008). Benefits and lessons learned of implementing building virtual design and construction technologies for coordination of mechanical, electrical, and plumbing systems on a large healthcare project, *Journal of Information Technology in Construction*, Vol. 13, Special Issue: Case studies of BIM use, pp. 324-342.

Leicht, R., Maldovan, K. and Messner, J. (2007). A framework to analyze the effectiveness of team interactions in virtual environments, *Proceedings of the 7th International Conference on Construction Applications of Virtual Reality*, University Park, PA, USA, October 22-23.

Liston K., Fischer M., and Winograd T. (2001). Focused sharing of information for multi-disciplinary decision making by project teams. *Journal of Information Technology in Construction*, 6, pp. 69-82.

Wang L., Messner J., and Leicht R. (2007) – Assessment of 4D modeling for schedule visualization in construction engineering education, *Proceedings of 24th CIB w78 conference on information technology in construction*, June 26-29, 2007. Maribor, Slovenia.

NANOTECHNOLOGY: BENEFITS, BARRIERS, AND IMPACT ON CONSTRUCTION

Manu Venugopal[1], Jochen Teizer[2], and Winfried Teizer[3]

Abstract
Nanotechnology research and product development is actively conducted in many industries, for example, in manufacturing, electronics, and health sectors. As many research studies show, the construction industry follows these trends, but does not take a leadership role in most of the current efforts in Nanotechnology. With proper knowledge about the products and techniques offered by nanotechnology, the construction industry has the potential to improve the efficiency of some of its own processes and offer better products to customers and clients. This research tries to understand nanotechnology in the context of construction and explores the current scenario of nanotechnology in the construction industry. In order to identify the potential benefits and existing barriers, an extensive literature review and survey were conducted, which is supplemented by several personal interviews. This paper also performed an impact analysis to evaluate existing and developing nanotechnology products and their applications in construction. Recommendations and guidelines for a path forward for nanotechnology in construction industry are provided.

[1]PhD Student, RAPIDS Laboratory, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA, 30332-0355, PH (404) 894-8269, FAX (404) 894-2278, e-mail: manu.menon@gatech.edu
[2]Assistant Professor, RAPIDS Laboratory School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Dr. N.W., Atlanta, GA, 30332-0355, PH (404) 894-8269, FAX (404) 894-2278, e-mail: teizer@gatech.edu
[3]Assistant Professor, NANOLAB, Department of Physics, Texas A&M University, College Station, TX 77843-4242, PH (979) 845-7730, FAX (979) 845-2590, e-mail: teizer@tamu.edu

1. Introduction

According to the United States of America, National Nanotechnology Initiative (NNI): "Nanotechnology involves research and technology development at the atomic, molecular, or macromolecular levels, in the length scale of approximately 1 to 100 nm range, to provide a fundamental understanding of phenomena and

materials at the nanoscale and to create and use structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size."

Apart from general and publicly transmitted views and understanding of nanotechnology, the construction industry lacks specific knowledge regarding the use, benefits, and barriers towards construction. This paper investigates the economic scenarios and market availability for nanotechnology in construction. Research and development work underway in the United States is presented. The potential benefits and existing barriers to the application of nanotechnology in construction are explained in detail. This paper furthermore presents results of a survey among member companies of the Construction Industry Institute (CII). Recommendations and the path forward for the construction Industry are presented by integrating the literature review and the analysis of survey results with the data available from personal interviews conducted with subject matter experts.

2. Background

Construction has been ranked in many studies among the top ten areas for nanotechnology applications. The most widely known ranking was provided by the United Nations and is called the "Millennium Development Goals (MDGs)." Salamanca-Buentello et al. (2005) correlated the top ten applications of nanotechnology and the MDG. Forecasts for nanotechnology in construction show that the market for nano-materials in construction is expected to grow from less than $20 million in 2006 to $100 million by 2011, and $1.75 billion by 2025. 73% of the revenue is expected to be made in coatings, 12% in composites and the remaining 15% in other applications (Fredonia 2004).

The National Nanotechnology Initiative (NNI) in the United States, launched in 2000, can be regarded as the starting point for nanotechnology research programs among the world leading economies. Funding for nano-science, however, was already established in many regions of the world by this time, with Europe being a leader in nano-materials since the mid 1980s. Up to now, many other countries have dedicated considerable research and development programs and funding to nanotechnology. Recent market surveys, as shown in Figure 1 and 2, indicate the United States to lead in funding nanotechnology related research, but not on a per capita basis.

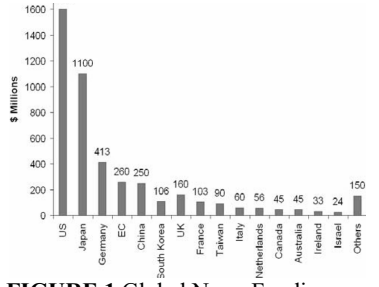


FIGURE 1 Global Nano-Funding

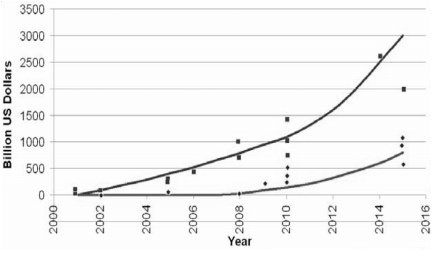


FIGURE 2 World Market Forecast

Most of the unique properties of nanotechnology are due to the smaller dimensions, enabling high speed and high functional density, high sensitivity and special surface

effect (for example, lotus effect), large surface area, providing reinforcement and catalytic effects. Some of the properties of nano-materials relevant to the construction industry are reactivity, corrosion resistance, high strength and durability. A smaller size will lead to denser metal clusters, ultimately leading to a stronger metal-to-metal bond formation in comparison to bulk metals, significantly reducing the possibility of reactions leading to corrosion. Strength of crystalline materials increases with the decrease in grain size, as the number of dislocations in the pile-up increases and nano-particle properties allow more durable polymer and organic coatings

3. Research Objectives

This research aims to analyze the market, funding scenarios and the research and development undergoing in United States for nanotechnology in construction industry. The potential benefits and also the existing barriers to the use are summarized. A survey among the CII member companies was conducted and the results were analyzed in detail and correlated with the findings of literature review and personal interviews. The top five nanotechnology products with the most impact on construction industry are identified using a multi criteria decision analysis (MCDA) model. The research shows a path forward for nanotechnology in construction.

4. Methodology of research

A comprehensive literature review was conducted covering most of the nano-materials, techniques and fabrication processes, and products and applications which are directly or indirectly related to construction. A survey instrument was developed to supplement the literature review and make a representative study of the construction industry outlook on nanotechnology. The survey results were corroborated by conducting personal interviews with industry leaders and subject matter experts. The results were used to identify the risks and benefits of nanotechnology in construction industry and also to predict the top areas in construction where nanotechnology can have maximum impact.

4.1. Survey

A four page digital survey was sent to 149 data liaisons of the Construction Industry Institute (CII) member companies. The objective of the survey was to complement findings of the literature and background review that could not be that easily found elsewhere, e.g. personal interviews at several research laboratories revealed already a weak or non-existent link between the construction industry and nanotechnology research centers. In detail, the survey focused on 6 main sections. The first section was designed to gauge the experience of the participants of the survey in nanotechnology. In the second section, the current involvement of CII member companies in nanotechnology were explored, followed by a third section on the projected involvement of CII member companies in nanotechnology. The fourth section concentrates on analyzing the potential and impact of nanotechnology in construction and the fifth one on the benefits, risks, and barriers in the construction industry. The final and sixth is a more descriptive section which is meant to collect the nanotechnology success stories and other comments of the respondents.

4.2. Multi-Criteria Decision Analysis

This research focuses on end user demands rather than individual technologies. By grouping the available products in a way that meet the end users' demands, a framework using MCDA (Linkov et al. 2007) identifies the top five products. Nanotechnology products are therefore ranked against existing products and technologies that compete for the same application and market. Since most of the nanotechnologies identified are still in the experimental or development stage, a measure of the likelihood of the success of the nanotechnology and the implementation time-span was included. In summary, MCDA model is developed taking into consideration all available quantitative and qualitative factors.

5. Benefits of Nanotechnology

From the literature review, CII member survey and interviews the benefits that nanotechnology products will have on the construction industry are summarized:

5.1. Improved Mechanical and Physical Properties

One of the major expectations from nanotechnology is the improvements in the strength of existing materials and also the development of new high strength materials which could be put to use in the construction industry. Nanotechnology can impact the development of higher strength concrete, steel, pipe lines and composite building materials. The modification of materials at the nano-scale holds the promise of greatly enhancing material properties like strength in a cost-effective manner. One example is the introduction of nano-fiber reinforcements into concrete shows a significant jump in the compressive strength to 180-240 MPa, which is much higher than that of ordinary Portland cement concrete (Jachimovicz 2008). Also, nano-composites formed by introducing nano-particulate fillers into a macroscopic material are found to exhibit drastically enhanced mechanical properties such as stiffness and strength. Nano-modification can make a material impermeable, less resistant to shear, highly ductile and flexible, but the most important aspect is the ability to control the properties to the desired level to make custom products which fit specific needs.

Nanotechnology has the potential to deliver materials that are highly durable compared to the conventional materials like polymers. The use of nano infrastructural materials in place of traditional materials makes the buildings and structures last longer. The introduction of carbon nano-tubes into steel could lead to the development of structure which is more durable at the same time light weight. Corrosion of industrial pipes is a major issue that could be mitigated with the use of nano-based coatings and paints.

5.2. Economical Benefits

The application and product categories that undergo existing and expected research and developments in nanotechnologies are likely to reduce resource consumption and support ongoing sustainability efforts in the construction industry. Owners and contractors which embrace nanotechnology could save in the construction, operation and maintenance, and disposal phase of their assets. By introducing materials which are easier to handle and install at sites and by cutting down on the number of components required, nanotechnology aims to reduce labor costs required. One example is the introduction of nano-modified concrete which is not weak in strain

could lead to rebar not being required. Customer satisfaction is one of the main indices of project success and nanotechnology can help an organization to improve customer's satisfaction such as the use of nano-additives to help improve concrete to develop earlier strength, which can overall lead to reduced construction schedules, and an earlier start-up phase. Nanotechnology can also help the companies have a competitive balance over the competition and also help to improve the aesthetics of current products as well.

5.3. Sustainability Benefits

The consumption of construction materials has been increasing over the years. This puts a severe load on the environment. Lack of quality raw materials encourages prices to increase. Use of nano-based materials instead of traditional materials for construction could help to reduce the material consumption. Higher strength and durability will mean less materials required per unit section. The use of certain additives in place of conventional materials could help to reduce the pollution problems. At minimum cost, due to low maintenance and infrastructure required, a fully integrated and self-powered failure prediction and forecasting mechanism could be installed for high capital structures (i.e. reservoirs, nuclear power plants, and bridges). The construction industry, being the most straightforward user group could benefit a lot by adopting these technologies.

6.0 Existing Barriers to Nanotechnology Implementation

The main nanotechnology obstacles can be summarized using the information of the literature review, the CII member survey and interviews.

6.1. Environmental and Social Barriers

There is not enough data to support or deny the claims that nano-material and nano-particles have undesirable effects on the environment. The potential applications of nanotechnology can challenge the existing social, ethical and legal framework. Exposure of humans and animals to nano-particles is a subject which is hindering the commercialization of products and applications based on nanotechnology. The current hesitation in nanotechnology could also be attributed to the prevailing experiences over the use of materials like asbestos which were claimed to be useful in initially, but turned out to be harmful to health (Gee and Greenberg, 2001). In summary, limited studies have been conducted on resolving environmental and social issues that nano-materials can have.

6.2. Organizational Barriers

A main concern is that given nanotechnology's unique properties, it may not be possible to apply same rules that exist under current regulatory regimes. Legislative and/or regulatory and policy reforms may become necessary. New policies in the context of nanotechnology will require cooperation between various levels of government, R&D agencies, manufacturers, and other industries.

6.3. Competence Barriers

Good metrology and standards are necessary to understand and characterize materials in terms of dimensional properties. They are vital in developing the terminology and

nomenclature of nano-products. Such instrumentation and metrology standards, however, are yet to be fully developed. A second barrier of similar high importance is the production of nano-materials in bulk quantities.

The type of workers employed in nanotechnology research and development usually have interdisciplinary backgrounds, often including broad range of expertise in fields such as physics, chemistry, engineering, biology, and also ethical, societal issues, and public outreach. Further dialogue between academia and industry in order to identify future training needs, perhaps in the form of a roadmap is needed.

7. Results

From the literature review, it was evident that the major application areas for nanotechnology in construction are bulk materials (i.e. concrete, wood, steel, asphalt, and glass etc.), functional surfaces (i.e. coatings, paints, and emulsions etc.), composites, fire and safety, energy and water, metrology and sensors..

7.1 Survey Results

The survey conducted among the CII member companies revealed a general lack of awareness about nanotechnology and applications. Almost 35 percent of the respondents stated their knowledge in the area of nanotechnology is limited. 30 percent had little or no knowledge about nanotechnology in comparison to the 8 percent who responded that they are aware of the developments in the nanotechnology. As a result, the majority of respondents have little or no knowledge in nanotechnology. Another issue which should be of concern is that 46% responded that their organization does not have a dedicated R&D group for nanotechnology compared to eight percent of the respondents that do. 4% of these companies said they outsourced research work. As a result, a large number of organizations did not have a dedicated research program in nanotechnology. Even though the overall research spending on nanotechnology research in construction is low, more companies are starting to allocate a part of their budget for construction related nanotechnology applications. 57% of the respondents said that their company allocates 1-5% of their overall budget allocation for construction related nanotechnology application. Also twelve percent of respondents marked more than 5% percent as an answer. The percentage of respondents who said none was 8%.

Respondents were provided with a list of twelve existing nanotechnology tools including focused ion beam, atomic force microscopy, and others to gauge their awareness. Survey results show that almost 70% of the respondents have never heard of any of these tools or techniques. 19% said they have heard about 1 to 5 applications and 12 percent said they knew more than 5 applications. Only 15% of the respondents knew of a problem in construction, which they thought could be solved with the help of nanotechnology. Some of the areas where nanotechnology could solve issues related to construction are: Modular construction, higher strength material, utility metering, and increasing durability. As a result, little understanding exists on how nanotechnology can impact the construction industry. But 12% of the respondents think there will be more than a significant impact due to nanotechnology in their field of construction. 35% believe there will be minimal impact from nanotechnology and 30% are not sure if there will be any impact. As a result, detailed impact studies on specific nanotechnology products eventually can help the

respondents in understanding the benefits and risks better. The low level of literacy in nanotechnology could also have affected the responses on impact in construction.

In terms of funding, 21% of the respondents are not sure where construction related R&D funding will come from. 28% said "research contracts" while 21% said "product sales". Twelve percent are expecting funding from "internal sources" and nine percent from "joint ventures". Nine percent of the respondents answered "various funding sources". In terms of areas in construction which might have the biggest impact, 22% of the respondents said "coatings" and another 22% responded "composites". Votes are equally split between concrete, sensors and metrology and chemical and fluids (12%). Glass received three percent and steel received 5% of all votes. The results are shown in Figure 3.

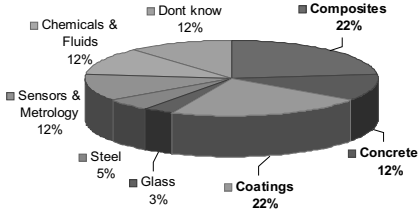


FIGURE 3 Impact of Nanotechnology by Construction Industry Application

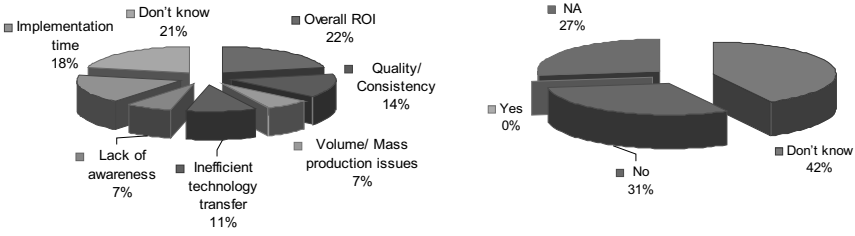


FIGURE 4 (a) Risks/Barriers (left) and (b) Institutional Collaboration (right)

The majority of the people believe that economical factors such as return on investment (ROI) drive the development of nanotechnology in construction. 22% of the respondents selected "ROI" and 18% percent selected "implementation time" as the biggest barrier. 14% of the respondents believe that quality or reliability issues are their biggest concern. Results are shown in Figure 4a. Twelve percent of the respondents expect nanotechnology to have an immediate impact, (i.e. within one to five years). 31% expect a time frame of five to ten years for nanotechnology to make an impact in the construction industry. But they feel missing guidelines and infrastructure can be a risk to organizations that plan to commercialize new technology and products. None of the respondents believe that there are enough guidelines, (i.e. whitepapers or regulations). 26% of the respondents said a lack of guidelines and infrastructure exists, while 48% did not know which option to prefer. The survey also revealed a major gap between the construction industry and academia which needs immediate attention. None of the respondents believes there is enough

interaction between industry, universities and research labs. 31% of respondents think there is "definitely not enough interaction" while 42% said "don't know". The information is shown in Figure 4b.

7.2. Multi-Criteria Decision Analysis

Results of a Multi-Criteria Decision Analysis, which was conducted to determine the top 5 application areas, are summarized below, with their corresponding scores. Nine decision criteria such literacy, education and research collaboration, return on investment, time span to commercialize, technological challenges, safety, health, social and environmental, product acceptance, quality and life-cycle were included to make the overall impact analysis method more robust. The scores were calculated out of 10.

TABLE 1 Examples of Use, Benefits and Limitations for the top-five Nano-Products.

Product categories	Score	Main Uses	Key Benefits	Key Limitations
Composites	8.46	Building materials (Polymer, Steel, Piping), Energy applications. Protective clothing.	High strength, lightweight, durable structures, ductility, wear and corrosion resistance, earthquake resistance..	Technical limitations and bulk volumes, environmental impact during disposal phase.
Coatings	8.31	Functional surfaces, exterior and interior building surfaces, Industrial piping, Glass.	UV protection, antimicrobial, Scratch, corrosion resistance, water proofing, durability. self-cleaning, longer life, aesthetics.	Cost to produce, not available in bulk.
Concrete	7.53	Bulk material in building construction and capital structures (nuclear, power plants, dams).	Strength and durability, long lasting, aesthetics, schedule.	Manufacturing cost at the level of mass production, higher initial investment, lobbying, environmental at end of life-cycle…
Energy	6.57	Energy storage, production, transmission, extraction, catalysts, devices for solar and wind energy	Cost and efficiency of exploration, for example, oil, longer life of batteries, less losses	Technical limitations, Manufacturing cost at the level of mass production
Sensors & Metrology	6.17	Remote sensing, non destructive evaluation technique (NDE), for example, cracks, fire protection sensors	Low maintenance, minimum infrastructure requirements, Precise and accurate measurement techniques	Product acceptance, Standards and Guidelines

8. Recommendations and Projections

By 2015, the National Science Foundation (NSF) estimates that nanotechnology will have a $1 trillion impact on the global economy. It divides the global industry sectors into $300 billion for electronics, $340 billion for materials, $180 billions for pharmaceuticals, $100 billion for chemical manufacturing, $70 billion for aerospace, $20 billion for tools, $30 billion for improved healthcare, and $45 billion for sustainability. To achieve these market size predictions, all industries together will employ nearly 2 million workers of which 1 million will be working in the United States (Roco and Bainbridge 2001).

Advances in many nano-materials, nanostructures and nano-systems are expected to drive development in the field. Examples, projected market share, and potential applications in construction are presented in Table 2 (NNI 2006). Many industries, including construction, may prefer monitoring development in research agencies and laboratories before making substantial investments.

TABLE 2 Examples of Nano-materials, Projected Market Share, and Applications

Product Category of Nanomaterial	Market [$ Millions]		Material Costs [$/kilogram]	Primary Applications with Potential
	2005	2010		
Ceramic	179	1,500	1-1000	UV absorber, plastics, coatings, photocatalytic coatings, glasses
Metal	89	770	10-10,000	Antimicrobial effect
Nanoporous	54	690	10-10,000	Insulation, optics, polymers, silicon, oil pipelines
Carbon Nanotubes	43	260	10-10000	Structural composites, memory, sensors, thermal management, display layers, coatings
Nanotstructured Metal	28	198	100-10000	Hard coatings or structural components in aerospace, equipment, pipelines, anti-corrosive coatings
Dendrimers	12	42	100-10000	Coatings, composites, inks, adhesives
Quantum dots	4.3	38	~1000	Optoelectronic applications like LEDs, displays, solar cells, inks and paints
Fullerenes	2.5	60	~1000	Composites, antioxidant additives fuel cells, lubricant
Nanowires	<1	16	~1000	Electronics, for example, Conductive layers for displays, solar cells, logic devices

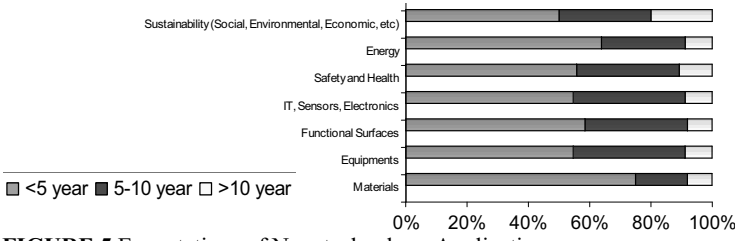


FIGURE 5 Expectations of Nanotechnology Applications

Regulatory framework needs to be put in place before use of nanotechnology is widespread. It must include consideration of environmental, transportation, handling, occupational exposure, security, safety and health impacts (Linkov et al. 2007). Transfer of knowledge between nanotechnology regulatory agencies, owners, contractors, suppliers, and end users needs to bridge education gaps and share technical expertise. Awareness of Nanotechnology and its significant impact on the construction industry should start in university programs and the industry itself to encourage education and research. In addition, many areas of Nanotechnology domain have not been researched and do not provide sufficient background information for decision makers. Researching, cataloguing, identifying and promoting best practices can be a first step to create a healthy and productive relationship between industry, researcher, and manufacturers. The construction industry is not fully involved in current research and development efforts in the nanotechnology industry. According to the survey results and interviews, the majority of participants believe nanotechnology will impact construction in many significant areas within the next ten years (see Figure 5). However, few construction companies presently consider Nanotechnology applications in part of the core operations.

9. Conclusions

Nano-construction activities are already emerging around the world, where the development is entering a decisive realization phase in which the dominant application areas are consolidating and becoming more specific. The activities in nano related products for the construction industry are not well marketed and are difficult for industry experts to identify. A large-scale and visible initiative from nano-science and nanotechnology in the construction area could help seed construction related nano-technological development.

Although a disconnect between the construction industry and researchers/academics unit that focus on nanotechnology research and development exists, a survey and personal interviews conducted in this research indicated that the construction industry would embrace products to solve existing problems and needs.

This disconnect is most likely due to the fragmentation of the construction industry. The lack of awareness of industry professionals shows, however, the need for an industry wide approach towards nanotechnology research and development. Knowledge transfer and exchange of information of the potential benefits and barriers of nanotechnology in construction may assist the industry as a whole. In a first step, this research has identified the major application areas and products in nanotechnology that will have impact on construction.

Most of the discussed areas and products will have a significant impact on construction within the next ten to fifteen years. Increased performance of materials, such as composites and coatings, will most likely yield quickest return on investment in research and development. This research concludes with a roadmap and strategic action plan on how nanotechnology can have its biggest impact on the construction industry.

References

Freedonia Inc. (2004). "Nanotech Tools to 2008: Nanotech Tool Technologies – Microscopy"<http://freedonia.ecnext.com> (Accessed March 10, 2008).

Gee, D. and Greenberg, M. (2001). "Asbestos: From Magic to Malevolent Material", EEA Environmental Issue 2001. <www.nanorisk.org> (Accessed Dec. 23, 2007).

Jachimovicz, F., and Bentur, A. (2008). "The Future of Concrete", AFN15T Workshop on the Promise of Nanotechnology for Concrete at the 87th Annual Meeting of Transportation Research Board, Washington D.C., January 13, 2008.

Linkov, I. et al. (2007). Multi-Criteria Decision Analysis Approach for Prioritization of Performance Metrics. US Gov. Performance & Results Act and Oil Spill Response.

National Science Foundation (1998). "Nanostructure Science and Technology", WTEC Panel Report, Washington D.C..

Roco, M.C. and Bainbridge, W., (2001). "Societal Implications of Nanoscience and Nanotechnology", NSET Workshop Report, NSF, Arlington, VA.

Salamanca-Buentello, F., et al. (2005). "Nanotechnology and the Developing World", Plos Medicine.org, 2(4), e97.<http://www.utoronto.ca>(Accessed March 6, 2008).

Teizer, J., Teizer, W., Venugopal, M., and Sandha, B. (2008). "Nanotechnology and Its Impact on Construction", Report to the Construction Industry Institute (CII), 2008.

ONTOLOGY-BASED, SEMI-AUTOMATIC FRAMEWORK FOR STORING AND RETRIEVING ON-SITE CONSTRUCTION PROBLEM INFORMATION – AN RFID-BASED CASE STUDY

Tarek Elghamrawy[1]; Frank Boukamp[2]; and Ho-Sung Kim[3]

[1] PhD Student, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign
[2] Ph.D., Assistant Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign
[3] Graduate Research Assistant, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign

ABSTRACT

Construction projects are information-intensive. Quick information retrieval and correct information capturing on construction sites is important to support project management. This paper presents the prototype of a semi-automatic framework for storing and retrieving on-site construction problem information using context information. Created problem records are indexed with context concepts taken from developed Web Ontology Language (OWL)-based ontologies, which enable semantic searches through problem records. However, since selecting appropriate concepts from large sets of concepts defined in the ontologies can be cumbersome, the prototype offers capturing context concept information automatically through the use of Radio Frequency Identification (RFID). A Java-based reasoning mechanism has been developed to support the user by inferring other applicable and related concepts based on the automatically identified and selected ones. The framework is described in this paper, including findings obtained from a case study and challenges identified.

INTRODUCTION

During construction of any facility, problems are experienced and associated data is captured. The recording of problems' data and its availability throughout the construction of projects are essential not only for project monitoring, but also to build a repository of historical project information that can be used to improve future project performance. Recent advances in data capturing techniques and new technologies for data acquisition and storage in the field promise to provide not only new and better data, but to improve progress monitoring as well. Progress monitoring and quality control process can be enhanced by the access to supporting data, such as information on past problems and related construction documents (Tserng and Lin 2004).

A number of research studies claimed the successful application of expert systems to the construction industry for diagnosis of construction problems during different phases of the construction process (Mohan 1990). On the one hand, expert systems are suitable for use in diagnostics by giving adequate answers to users' questions in the knowledge area. On the other hand, many expert systems failed to simulate useful rationalities of the human mind allow humans to jump to the right findings despite irrelevant information (CIB-W86 1993). Lima et al. (2005) claimed that human knowledge can be efficiently presented through semantic systems that utilize ontologies to encapsulate and manage the representation of relevant contexts. Much of the information being generated in architecture, engineering, construction, and facility management (AEC/FM) systems is context-specific, i.e. it applies or relates to a specific situation or a specific category (Caldas et al. 2002; Zhu et al. 2007).

Correct identification of contexts is important for the integration of project data and information contained in different data and information repositories. Contexts thereby can be used as a storage and retrieval index for the information items, such as construction reports and lessons learned (Boukamp and Ergen 2008). However, often construction context information is intuitively determined based on observations and experience of construction personnel.

We developed a framework that relies on the use of concept ontologies for describing and indexing the construction problem context information. The concept ontologies in this framework are serving as semantic knowledge models that provide knowledge about concept hierarchies and associative relations linking concepts across these hierarchies to simulate human mind rationalities. These concept ontologies can help the user classify construction problems and the respective lessons learned according to the problems' context when storing them. When retrieving lessons learned, the concept ontologies can be used to describe the current target context and help better identify relevant lessons learned that have been stored.

A semi-automatic identification of appropriate construction concepts has been developed to support the user in the accurate identification of construction concepts describing the user's actual on-site context. The developed framework uses Radio Frequency Identification (RFID) technology. RFID technology was tested and found suitable for component identification (Shiftehfar and Boukamp 2008).

In the proposed framework, construction context information (e.g., product types, applicable resources, and construction processes) is captured through scanning RFID tags on-site. Other information related to the problem description will be stored manually by construction engineers. The framework is supported by an ontology-driven reasoning mechanism that enables users to further query for information about past problems based on related "concepts", rather than on mere "keywords" used in the problem description. This paper presents the proposed framework that shall enable the deployment of a semi-automatic system for storing and retrieving on-site construction problem information and enable off-site learning from past construction problems. Findings obtained from an RFID-based case study are discussed and future challenges are highlighted,

RESEARCH BACKGROUND

This literature review targets two main topics related to our proposed methodology. The first topic is knowledge-based systems and project document management in the construction industry. The second topic is RFID technology in the construction industry.

Knowledge-based Systems for Construction

Many knowledge-based systems have been developed that aim to support different construction areas such as site planning, risk management, document sharing, project control, progress monitoring, and cost estimation. Kartam (1996) presented a knowledge-based system for constructability improvement, where construction lessons were analyzed and classified into the 16 divisions of the 1983 MasterFormat from the Construction Specification Institute (CSI). The system provided alternative means to information access including the generation of multiple views of the knowledge-base to improve on-site construction processes.

El-Diraby and Zhang (2005) developed a web-based knowledge management system to support the representation and utilization of corporate memory in the construction domain. The system used ontologies for building construction to retrieve semantically related construction reports and meeting agendas. The main concepts used were: Project, Process, Product, Actor, and Resource.

Zhu et al. (2007) developed a system to support processing unstructured content in request for information (RFI) forms. This system utilizes Industry Foundation Classes (IFCs) as a basis for developing a metadata model for RFIs. The metadata model aimed to offer users flexibility in defining views for handling documents and aimed to complement data mining-based approaches.

Soibelman et al. (2008) presented a prototype system for data analysis on particular types of non-traditional construction data sources. The prototype was developed to verify and validate the Text Information Integration Methodology (TIIM) in which each object in the project model must be linked to a class defined in an external classification source. The external classification source used in this study was the 2004 CSI MasterFormat. We build on findings from these research projects to guide our development of context ontologies for representing knowledge about construction problem contexts.

RFID Technology

Radio Frequency Identification (RFID) refers to any identification system in which electronic devices are communicating through radio waves or pulsating magnetic fields with identification units/tags attached to objects. RFID technology consists of a transponder (usually called tag), a reader, an antenna and required middleware. The basic functionality supported is to read tags with unique identifiers using readers.

RFID was initially brought to construction industry for material delivery tracking, equipment handling, tool tracking, management and detection of buried assets, and location identification (Shiftehfar and Boukamp 2008). Despite the various applications of RFID in the construction industry, its application in the construction field is rare and most common in prototype projects (Sorensen et al. 2008). Compared to barcodes, another common object identification technique, RFIDs are more durable, have a longer read range, and do not require line-of-sight for reading the IDs.

The research presented in this paper proposes that on-site context identification can be supported with different levels of automation by using RFIDs to identify entities on the construction site and thereby deriving context knowledge from this information by mapping entities' IDs to concepts within the concept ontologies.

THE FRAMEWORK

We developed an object-oriented, Java-based system that allows construction managers to store and retrieve on-site construction problem information. The system resides on a tablet PC connected to an RFID reader and enables construction managers to automatically scan for RFID tags attached to construction components associated with on-site problems. The only information stored on the RFID tags themselves is their ID information. The system uses a database that contains information about the construction concepts that are associated with the tagged components. This facilitates modifying and updating the concepts associated with each tagged component. The system can identify contexts associated with readable RFID tags and thus support construction mangers when specifying contexts that describe the problem at hand. Applicable contexts will be highlighted in the concept ontologies and used as index for storing the construction problem record (see Fig.1).

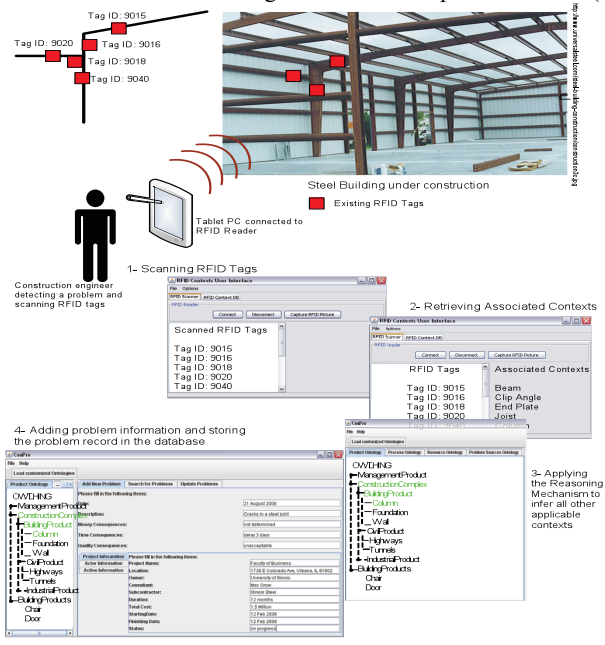


Figure 1: Snap shot of the system depicting the four stages of storing construction problems

The user is responsible for detecting construction problems that need to be recorded. The methodologies adopted in discovering or classifying these problems are not the scope of this research, but rather the techniques used for storing and retrieving problem records.

In our system, each construction problem description has two main parts: a construction concept index describing the general context to which the problem applies and a body that contains detailed information about the problem (see Fig. 2).

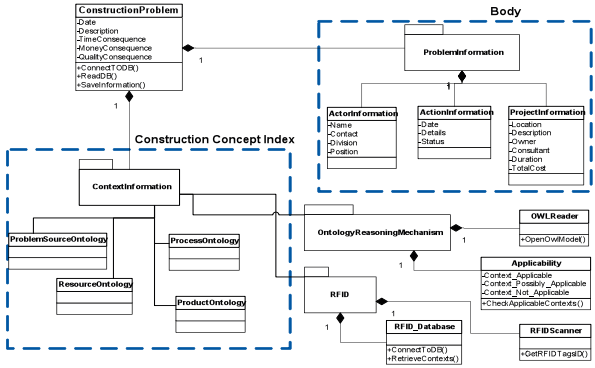


Figure 2: A partial view of the system classes

The Body

The body includes the substance of the problem information in the form of some commentary and other related fields. Some of these fields are mandatory such as the problem date and the problem description. Other fields represent the project information, the actor information, and the action information. These fields are important for the full description of any on-site problem. Depending on a company's needs, the body may have to be changed to account for other data that needs to be captured in the problem description. This can be achieved by adding new classes and attributes to the body model and does not affect the usability of the problem storage and retrieval mechanism discussed in here.

The Construction Concept Index

Through the use of construction concepts taken from a concept ontology, the problem records are indexed and provide a powerful means to support searching for problem information related to concepts rather than on mere keywords. Concepts chosen from the concept ontology can be combined to describe more specific concepts. For example, the concept "Column" can be combined with the concepts "Concrete" and "Reinforcement" to describe the specific context "Reinforced Concrete Column".

While the development of a concept ontology that covers contexts of the entire building construction industry is a difficult task that was outside the scope of this research, we developed four prototype ontologies using OWL (Web Ontology Language) to illustrate the value of ontologies for this purpose. The concept ontologies contain concepts that can be used to describe contexts of example on-site problems. The construction concept information (i.e., product types, applicable resources, construction processes, and problem sources) is structured in four sub-ontologies as discussed in more detail in a later section.

System Deployment

To create a problem record (see Fig.3), a user will first scan available RFID tags in the area of the construction problem. The system then retrieves the associated context

concepts from which the user chooses the appropriate ones and saves them in a database together with other problem related information. This fosters a uniform usage of standardized concepts for storing and retrieving on-site problem records and enables concept ontology-based searches later.

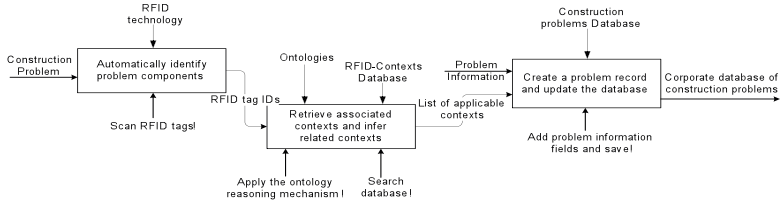


Figure 3: Construction Problem Information Storage Process using RFID combined with ontology reasoning mechanism

To search for specific, stored on-site problems related to a current problem (see Fig.4), the user will first identify the possible contexts describing his/her problem, and retrieve saved problems from the database for which the context indices are similar or related to the context indices used to describe the current problem. Through this, the system allows construction engineers to better share and use corporate knowledge when searching for records of past problems and their remediation actions to identify actions appropriately to their on-site construction problems.

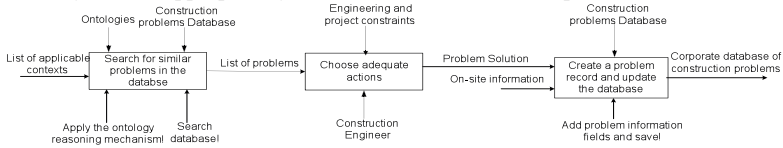


Figure 4: Construction Problem Information Retrieval Process

Concept Ontologies

Ontologies are a technique used to represent and share knowledge about a domain by modeling the concepts in that domain and the relationships between those concepts (Gruber 1993). Ontologies provide a knowledge representation using a system of concept hierarchies, associative relations (to link concepts across hierarchies), and axioms (El-Diraby et al. 2005). In the construction industry, ontologies play a crucial role in representing knowledge for reasoning about semantics between the domain concepts (Lima et al. 2005; Rezgui 2006).

As described earlier, each construction problem will be indexed using construction concepts that describe the construction context. This index enables retrieval of construction problem records related to construction contexts. The construction concepts are structured in a number of concept ontologies. The concept ontologies are supposed to allow representing all construction contexts that can be used to describe an on-site problem. We propose to use a set of four ontologies: *Product* ontology, *Process* ontology, *Resource* ontology, and *Problem-Sources* ontology. On the one hand, the relationships between the concepts defined in the ontologies can help guide the user in choosing the appropriate terms for the problem description. On the other hand, this will enable ontology-driven search mechanisms to return more significant results relevant to the search parameters specified by the user when searching for similar problems in the database.

Ontological Engineering

Ontology languages allow users to write explicit, formal conceptualizations of domain models (El-Diraby et al. 2005; Lima et al. 2005; Rezgui 2006). The main requirements are a well-defined syntax, efficient reasoning support, formal semantics, sufficient expressive power and convenience of expressions. The OWL Web Ontology Language is a specification by the World Wide Web Consortium (W3C) and serves as a fundamental component of the Semantic Web initiative (Antoniou and Harmelen 2004).

Different tools have been developed to support ontology creation in OWL. Among them is Protégé (http://protege.stanford.edu). In our research project, we used Protégé 3.4 beta for the ontology development. Protégé, as a free, open source ontology editor and knowledge-base framework, serves as a rapid prototyping environment in which ontology designers can create ontologies and test the semantic reasoning. The powerful expressiveness of OWL allows the user to reason about different concepts predefined in the ontology. Further (afore implicit) knowledge can be deduced from explicit OWL facts. Using semantic relationships definable in OWL, e.g. subclassOf, subPropertyOf, disjointWith, and others, the reasoning mechanism can infer the applicability and non-applicability of ontology concepts based on the user-selected concepts. The functionality of the reasoning mechanism is discussed in examples taken from the case study.

CASE STUDY

We performed a case study to evaluate our framework's ability to support a user, through available RFID information, in the selection of context concepts for classifying problem information and retrieving stored problem solution records related to the encountered problem. For this, we developed an object-oriented, Java-based prototype of the framework which leverages RFIDs and OWL-based ontologies for reasoning about construction contexts for the purpose of problem recording and retrieval of corporate knowledge. This prototype was supplied with an example database of past problem recordsets which are indexed using concepts from the OWL-ontologies that describe the construction context in which the problems appeared. An engineer was then asked to use this system in a hypothetical scenario.

Scenario

In our chosen hypothetical scenario a quality controller discovers a defect while carrying out a field water-tightness test on one of the installed exterior windows. The field water-tightness test reveals water seepage through joints between the exterior metal frame window and the brick veneer wall. The quality controller uses the prototype mentioned above for storing information about the problem and retrieving information about solutions related to similar past problems.

Set Up

The hardware used in this case study is: DELL LATITUDE XT tablet PC, Tagsense ZR-USB Active RFID Tag Reader, and 30 Tagsense ZT-50 Active RFID Tags. In the case study, an area of an office building was chosen and elements in this area were equipped with RFID tags. Each RFID tag was linked to one or more ontological concepts through the earlier described database.

Execution

This case demonstrated the different phases of the framework represented in Fig.3 and Fig.4. In a first phase, the user started scanning for RFID tags attached to different construction elements that surrounded the hypothetically defective window. This process was carried out using the reader connected to the tablet PC. Nine tags were scanned. Out of these nine tags, eight were in the same room as the engineer and one was in a room in the immediate area. The system then automatically obtained the context concepts associated with the scanned tags that were selected by the user (see Fig.5). Next, the user was asked to choose which of the RFID related contexts were relevant to the problem identified. Among the nine scanned contexts, the user chose two contexts that were relevant to the problem. The first context was *Steel Frame Window* and the second one was *Brick Veneer Masonry Wall.* Among the contexts that had been neglected by the user were: *Exposed Column*, *Ceiling Suspension System*, and *Interior Lighting Fixture*. The two selected contexts were defined in the Product Ontology. Following the identification process, the reasoning mechanism inferred other contexts that could be applicable for describing this problem. Among the contexts inferred by the ontology reasoning mechanism were: *Membrane Water Proofing*, *Water Repellent*, *Shim*, and *Sealant*. The user chose to keep these contexts.

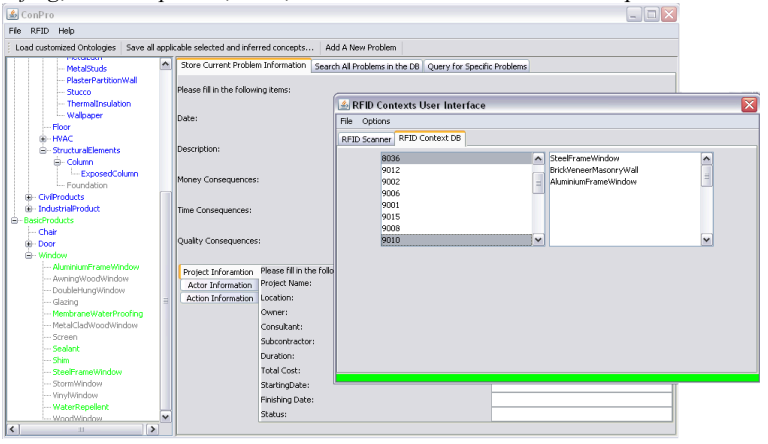


Figure 5: A screen shot of the prototype used in this case study

Next, the user used the prototype to search for similar problems that happened in the past and were related to the same contexts that were identified in the current problem. The construction problems database retrieved five records of past problems. After reviewing these records, the user recommended one of the recorded problems' solutions to be applied to overcome the current problem. This solution was indexed with the concept "Sealant", which the reasoning mechanism had inferred to be a related concept, and recommended the usage of a specific grouting and sealing type to seal the gap based on the gap sizes. In a final phase, the user finalized the record of the current problem in the database by adding information about the proposed solution, so other users can share and benefit from this experience.

Lessons learned

Interacting with the concept ontologies to select appropriate product-, process-, resource-, and problem source-concepts to describe the context of a problem can be cumbersome due to the large number of concepts in each ontology. While hierarchical organization of concepts provides structure to the large set of concepts (see Fig. 5), it also can make it difficult for a user to manually find a concept which is located deeper in the hierarchy. Context information provided through RFID tags in the form of concepts mapped to the tags' ID proved helpful in supporting the user. The system was able to highlight concepts that related to entities in the surrounding area, of which a few actually represented concepts related to the hypothetical problem. Such an initial selection of applicable and non-applicable context concepts facilitates the interaction with the concept ontologies, since applicability of other related concepts can be automatically inferred and can guide the user in the appropriate selection of other applicable concepts. For example, by selecting the concept SteelFrameWindow as applicable, the system was able to automatically identify 28 out of 93 concepts as "not applicable" and 7 additional concepts as "applicable".

The number of RFID tags used in the case study was limited to 30 tags. The user was able to review the whole list of the scanned RFID tags and the associated contexts stored. However, the actual number of RFID tags on a construction site that surround a specific component is expected to be much higher than the tested 30 tags which can eventually make context identification process very cumbersome as the user has to review the entire list of contexts associated with the scanned tags. In order to improve this situation, it is advisable that the context inference mechanism described earlier be applied at this stage. This would allow the user to review the list of concepts and by declaring individual concepts as applicable or not applicable, infer non-applicability of some of the listed contexts, thus eliminating them from the list to be reviewed.

SUMMARY

Quick information retrieval and correct information capturing on construction sites is important to support project management. This paper presented the prototype of a semi-automatic framework for storing and retrieving on-site construction problem information. The framework relied on the use of four concept ontologies developed in OWL for describing and indexing the construction problem concept information. These four concept ontologies served as semantic knowledge models that provide knowledge representation about concept hierarchies and associative relations linking concepts across these hierarchies. A semi-automatic, RFID-based identification of appropriate construction concepts was developed. In the presented approach, construction concept information (e.g., product types, applicable resources, and construction processes) was captured through scanning RFID tags on-site. Other information related to the problem description was stored manually by construction engineers. A Java-based reasoning mechanism was developed to enable users to further query for stored problem information based on the related "concepts" identified, rather than on mere "keywords" used in the problem description. A case study highlighted the benefits of the semi-automatic context identification approach and also highlighted opportunities for improvement that should be addressed in future research. Specifically, future research should aim to develop tools that can extract contextual concepts from other sources, such as the textual descriptions of the

problem provided by the user or information obtainable from a related Building Information Model (BIM). Also, more comprehensive ontologies should be developed and the types of semantic relationships between concepts should be defined more comprehensively than done in this prototype. Finally, the methodology adopted in this research has been developed in a way that it is expected to be extendable to comprise other unstructured construction documents management such as request for information (RFI) forms, meeting minutes, construction pictures, and other construction documents. Future research in deploying other concept ontologies as construction concept indices for managing additional types of unstructured documents is needed.

References

Antoniou, G., and Harmelen, F. V. (2004). A Semantic Web Primer, The MIT Press,

Boukamp, F., and Ergen, E. (2008). "A Proposed System Architecture For Context Identification Support on Construction Sites." *AEC 2008 - 5th International Conference on Innovation in Architecture, Enrg and Constr*, Antalya, Turkey.

Caldas, C. H., Soibelman, L., and Han, J. (2002). "Automated Classification of Construction Project Documents " *Journal of Computing in Civil Engineering*, 16(4), 234-243.

CIB-W86. (1993). *Building Pathology A state-of-the-art report*, June 1993 Ed.

El-Diraby, T. E., Lima, C., and Feis, B. (2005). "Domain Taxonomy for Construction Concepts: Toward a Formal Ontology for Construction Knowledge." *Journal of Computing in Civil Engineering*, 19(4), 394-406.

El-Diraby, T. E., and Zhang, J. (2005). "A Semantic Framework to Support Corporate Memory Management in Building Construction." *Auto in Construct*, 15, 504-521.

Gruber, T. R. (1993). "Towards Principles for the Design of Ontologies Used for Knowledge Sharing." *Intl J. of Human and Com Studies*, 43(5/6), 907-928.

Kartam, N. A. (1996). "Making Effective Use of Construction Lessons Learned in Project Life Cycle." *J. of Constr Engineering and Management*, 122(1), 14-21.

Lima, C., El-Diraby, T. E., and Stephens, J. (2005). "Ontology-Based Optimization of Knowledge Management in e-Construction." *Information Technology in Construction*, 10, 305-327.

Mohan, S. (1990). "Expert Systems Applications in Construction Management and Engineering." *J. of Construction Engineering and Management*, 116(1), 87-99.

Rezgui, Y. (2006). "Ontology-Centered Knowledge Management Using Information Retrieval Techniques." *Journal of Computing in Civil Engineering*, 20(4), 261-270.

BUILDING INFORMATION MODEL: THE ROLE AND NEED OF THE CONSTRUCTORS

Pooyan Aslani[1], F. H. (Bud) Griffis, F.ASCE[2] and Lawrence Chiarelli, F.ASCE[3]

ABSTRACT

Much of the discussion thus far associated with the employment of building information modeling (BIM) has focused on the design phase; the preparation of the model by the designers, "ownership" of the model, and liability for others' use of and reliance on the model. The first generation of BIM employed by constructors involved the creation of a three-dimensional model based upon the two-dimensional drawings prepared by the designers. One of the greatly touted advantages of the next generation of BIM is the creation of a single model for the project to which the designers, constructors and owners will contribute. The manner in which the model is generated and the additional information associated with the model, however, will impact the utility of the model for the designers, constructors and owners. The functions for which BIM will be most beneficial to constructors include the preparation of schedules and estimates, tracking and managing changes to the work and shop drawings, and managing site logistics and temporary structures and services, with particular attention to site safety. The purpose of this paper is to identify the constructor's requirements for the preparation of a building information model during the design phase so as to most efficiently address the concerns of the designers, constructors and owners. In addition, the paper will examine the processes employed by constructors in the management of the construction project.

INTRODUCTION

In 1988, an early research project concerning the application of three-dimensional computer models and their associated databases in the management of construction was conducted for the National Science Foundation as a joint venture with the then Stone and Webster Engineering Corporation. For that project, a three-dimensional computer model for a fourteen story science building on Columbia University's campus was created manually, based upon two-dimensional drawings, using CATIA on a mainframe computer in Boston. That study concluded:

> …….that it is not cost effective to construct a three-dimensional model only for the management of construction when the design is done in two-dimensions for a commercial building. While there are some advantages to having a three-dimensional computer model and

> associated databases on site during the management of construction, most of the building projects are not designed in three-dimensions. Since they normally do not involve complicated piping and mechanical systems buildings are considered so straight forward as not to require a three-dimensional model for their design. Therefore, since the model is of little advantage to the designer, it is thought not to be worth the cost of development.[4]

That was at a point in history when the IBM XT or AT was the state-of-the-art in desktop computing power. Any major three-dimensional computer modeling or analysis had to be accomplished on a main frame computer. Also at about that time, Bechtel Corporation was developing 3DM®, a three-dimensional plant design software system, and WalkThru®, which provided a three-dimensional visualization tool. Both products were ultimately acquired by Bentley Systems and incorporated into the MicroStation® software suite.[5] Thus, the only substantive three-dimensional design that was being done was in the process and commercial power construction industry.

Many things have change since that project twenty years ago. Three-dimensional computer models and their associated databases evolved into something called FIAPP – Fully Integrated and Automated Project Processes. The purpose was to bring together all of the participants in the design. procurement and construction process. These efforts were supported by research funded by the Construction Industry Institute (CII). The term FIAPP is not heard much any more. It seems to have been replaced by BIM - Building Information Modeling.

Bill Gates is alleged to have said at an early microcomputer trade show in Seattle in mid-1981 that 640K ought to be enough for anybody.[6] A major impediment at the conception of the use of three-dimensional models was the capacity of the software and hardware to handle a seemingly infinite quantity of data. We now have gigabytes of ram and a zillion gig hard drives. Processors are faster than the mainframe computer processors were then. Is the conclusion from that 1988 study still valid? We think not.

More and more owners of construction projects are inquiring as to the feasibility of (and some demanding) the use of building information models for their projects. Contractors and construction managers are beginning to understand that the savings in cost and time gained from the use of these models can increase their bottom line. Most major construction organizations are trying to develop a BIM strategy. And for those making the foray into BIM, there are many questions that need to be addressed, for which there are no consensus answers.

- Who should develop the model?
- How will it be developed?
- What level of detail should the model include?
- Who owns the model?
- Who should control changes to the model?

- What governs in the event of a discrepancy among the model, the drawings, and the specifications?
- Who is liable if the model contains a mistake and a contractor builds to the model?
- How does the model improve the management of construction?

The industry is struggling with these questions. Some will not be answered until they are addressed judicially or legislatively. Many are being addressed using trial and error. This paper will discuss how some of the answers are evolving.

WHAT, EXACTLY, IS A BIM?

A building information model is a three-dimensional computer model with its associated databases. Therefore it consists of data. What one visualizes is the result of an interface with a graphics database. The models have some intrinsic knowledge that results from shapes, sizes and locations. This is the geometric databases. Each design element has geometric attributes. A steel beam, for instance, has explicit attributes that can represent all of its geometric data: length, width, height, location, cross-sectional properties, centroid, moment of inertia, section modulus, etc. Some of this information can be included in the database, or it can be derived from the other data. More detailed information can be included to address the interface or interconnections of the various elements. The result is a three-dimensional representation of the physical structure. Any or all of the components of a structure can be included: architectural elements, structural members, and mechanical and electrical materials and equipment. The utility of modeling in ever-increasing detail is discussed later.

In addition to the geometric attributes which define the physical model, each element in the model can have any number of non-geometric attributes associated with it. One non-geometric attribute might be an activity ID from a time schedule. By linking the schedule activities to the model geometry, a time-lapsed visualization of the assembly of the structure can be generated. This has traditionally been referred to as a 4D model, with time being the fourth dimension. Although a three-dimensional model of the physical structure itself can be of great utility, the creation of additional "dimensions" can increase considerably the uses of the model.

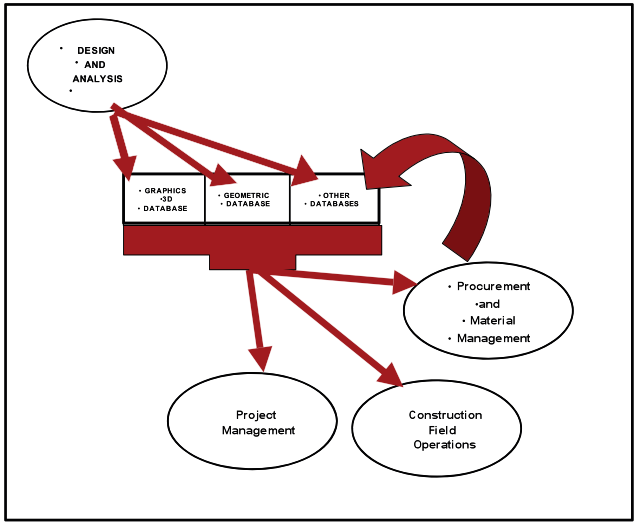


Figure 1 Schematic description of BIM. [7]

WHO SHOULD DEVELOP THE MODEL?

In one sense, it is immaterial who prepares the model. That there is a model that contains the information each of the various parties needs is the objective. Just as with the goal of allocating risks to the parties in the best position to insure or otherwise protect against those risks, the responsibility for contributions to the building information model should be by the parties who are the best sources of such information. There need not be a rule that a particular party, such as the architect or construction manager, should be the keeper of the building information model. In some cases, the relationships among the various parties on a particular project may contribute to this determination. There may also be circumstances when possession and control of the content of the model will transition from one party to another, such as from the architect during design to the construction manager during construction. At some point the owner may take possession of the building information model in order to operate and maintain the structure. What is more important, however, is maintaining the integrity of the model. Since the goal of the process is to give all participants in the planning, design, construction and operation of the project access to a unified database of information, a protocol must be established to insure that information that becomes part of the building information model can be traced to its source. The technical challenge is to optimize, yet control, the continuous exchange of data, while maintaining the proper lines of responsibility. Also, within the context of a building information model in which designers, contractors, construction managers and others might rely upon unrelated systems to generate data that will be incorporated into the model, interoperability can be a critical issue. A National Building Information Systems Standard (NBIMS) has been proposed and is being

developed under the direction of the buildingSMART alliance of the National Institute of Building Sciences (NIBS) "to provide the framework and foundation to encourage the flow of information and interoperability between all phases of a facility's life from inception onward."[8] Until such a standard is in place, utilized by all participants and tested for reliability, there may be occasions where information may be lost or corrupted.

In the process and commercial power industry, design has been done in three-dimensions for some time. In addition, much of that construction in those industries is accomplished using design-build contracts. Design-build contracting arrangements have generally involved a greater level of collaboration between the design and construction functions during the design phases of a project. By fostering a greater collaboration during design, the engineering procurement and construction (EPC) contractor can have a three-dimensional computer model by the time the design is done. If the design organization is organic to the contractor, the project may be fast tracked whereby the designer will issue partial models to the constructor as they are completed. In this case, the constructor may have a simplified model earlier in the planning process from which to prepare estimates and schedules. On the other hand, if a design-build arrangement is made between a design organization and a constructor, the constructor may not get the model until the design is complete and approved. Regardless, the three-dimensional model is provided by the designer.[9]

Traditionally, residential and commercial buildings have been designed in two dimensions. That is not to say that three-dimensional modeling for such uses as massing and lighting are not used during the design. That being the case, how does one get a building information model? As previously discussed, the first generation of building information models was the result of the efforts of constructors working from completed two-dimensional designs. In their BIM Handbook[10], Eastman, Teicholz, et. al.present the flow chart shown in Figure 2 as the process for dealing with two-dimensional designs and converting them into BIM models.

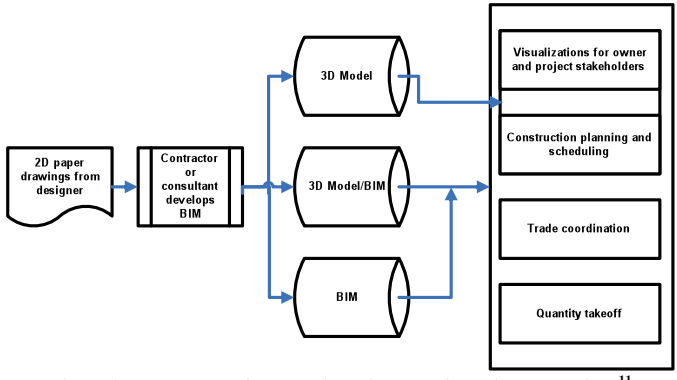


Figure 2. BIM process flow starting with two-dimensional drawings[11]

The transition to the use of building information models for architectural construction has been much slower. In the late 1990's, a few owners and fewer architects started experimenting with the application of three-dimensional computer models in the management of construction. The Construction Industry Institute (CII) initiated two studies to (1) examine the benefits associated with using a three-dimensional computer model in the management of construction,[12] and (2) determine how to use FIAPP (the then newly coined term for three-dimensional computer models and their associated databases) in the management of construction. Most of the CII member companies were apart of the process and commercial power side of the construction industry. In 2005, however, the United States General Services Administration (GSA) announced that beginning in 2006, AEC firms will be required to provide a building information model with their designs.[13]

For construction based upon a three-dimensional architectural design, the first form of building information model will likely be the design prepared by the architect in conjunction with the engineering and other consultants. The architectural design establishes the overall geometry for the structural, mechanical, electrical and other engineering disciplines. In the simplest case, providing the geometry with which the other designers must conform allows for the continual confirmation of interferences and the expeditious notification of such conditions to all the designers. Preliminary models which contain information similar to what would appear in conventional conceptual design, schematic design and design development documents would enable the owner or its contractors, construction managers and vendors to prepare preliminary schedules and estimates of construction cost. As the design progresses, these schedules and estimates can be refined. What is different about this process when employing a building information model? Essentially, the process of retrieving the data and recalculating the schedules and estimates can to some extent be automated. Results based upon revised information can be updated, while results based upon new or added information can be included.

This process is illustrated, in part, in the capstone course as part of the Bachelor of Science in Construction Management program at the Polytechnic Institute of New York University.[14] Students acting in the role of a potential owner's representative are provided drawings and preliminary specifications for a commercial retail development and asked first to prepare estimates based on areas and volumes and schedules based on milestone dates, as well as a three-dimensional model. Revised drawings and specifications are later provided, and the models, estimates and schedules are updated accordingly. A major change of scope is also introduced into the process. The resultant building information model is used to evaluate the impacts of this change of scope on the cost and schedule of the project. While only a rudimentary application on a relatively small scale, it demonstrates the facility with which some of these techniques can be employed.

Ideally, the relationship among the design disciplines and the open sharing and reliance upon the building information model should be independent of whether the engineering and other consultants are employed by the architect or directly by the

owner. Some forward-thinking designers are forging ahead and have found that they can produce a better product and be more efficient using three-dimensional designs and building information models.[15] However, since the design and construction of architectural structures using two-dimensional drawings is the well-established norm, the decision to design with a building information model may depend upon several factors, including the additional cost to prepare a three-dimensional design to the level of detail required by the owner for the various disciplines and the willingness of the owner to release the designer from liability for damages resulting from "irregularities" in the model. The potential liability of the architect and engineering and other consultants has led to reluctance by some designers to give full and open access to electronic data. Nevertheless, there has been some discussion of balancing risks and rewards.[16] If the owner is getting the benefit of an improved product (the design "documents"), the owner can save money on construction because of improved efficiencies in the construction process, while the design professional is required to make a substantial investment and may be exposed to greater liability, then the design professional should (a) receive greater compensation, (b) be indemnified by the owner for certain claims arising out of the preparation of the design documents, or (c) be insured by a project policy provided by the owner. There is no question (at least in the minds of the authors) that designers must be able to be profitable and not subject to unreasonable liability exposure. Ultimately, the marketplace will prevail.

On projects where the design is represented on two-dimensional drawings, building information models can be prepared to facilitate any number of construction purposes. In this case, though, there is a loss of efficiency and a duplication of effort.

LEADERSHIP IS ESSENTIAL TO BIM'S VALUE ON A PROJECT

Leadership is important is any collaborative endeavor. This statement is especially true in the context of adopting change. In the context of BIM, change is happening on two fronts; within the individual organizations that plan, design and build projects, and among those same organizations in terms of how they will interact going forward. BIM is a process that will be more successful if there is acceptance by all participants and a greater level of collaboration among the parties to a project.

As in any industry, there are individuals in design and construction who have been doing their work in much the same way for a long time. Designers have been preparing drawings for construction which have contained essentially the same information for more than a century. Even the introduction of computer-aided drafting did not change the overall content of the final product, but rather the manner in which information was assembled. Successfully implementing BIM requires that designers assemble their work product in a whole new medium and constructors extract information so as to enable them to plan and execute the design. If the individuals in each of the organizations are not committed to the process, those entities will either diminish the value of the collaborative product, or they will be unable to take advantage of the benefits it offers.

HOW DOES THE PROJECT BENEFIT FROM BIM?

The full use of BIM in the management of construction is still evolving. Eastman enumerated six important applications of BIM that apply to most constructors:

- Clash Detection
- Quantity Takeoff and Cost Estimating
- Construction Analysis and Planning
- Integration with Cost and Schedule Control and other Management Functions
- Offsite Fabrication
- Verification, Guidance, and Tracking of Construction Activities[17]

There are several other applications that can be added, such as

- Site Logistics and Management
- Procurement
- Materials Management
- Document Control
- Change Management
- Site Safety Planning
- Operational Analysis

There likely will be many more applications that are discovered as the use of BIM on the construction site becomes more common-place. The building information model is not prepared within a single software package, unlike two-dimensional drawings. Data for the model will come from many different sources. The identification, collection, and organization of the data for the three-dimensional model and the non-geometric databases will require that it be interchangeable. For example, a four-dimensional model is comprised of activity scheduling data that comes from scheduling software such as Primavera® or Microsoft Project®, which is linked through an interface to design objects in the three-dimensional computer model that may have been constructed with any number of software packages. The ability of different software to exchange data reliably is defined as interoperability. Within a single provider, interoperability is less of a concern because the same entity has control of the proprietary information necessary to facilitate the transfer of information. Some of the newer software applications on the market and under development have broadened functions which can diminish the problems associated with interoperability. To further extend the four-dimensional model into an "n^{th}-dimensional model", such attributes as cost and resources data may be extracted from resource loaded schedule databases, cost estimates and other databases.

It is useful to think of the building information model in the context of its data sources, then look at the data output and consider how these outputs feed the construction management applications. An example is shown in Table 1.

Data Source	BIM Data Out	CM Application 1	CM Application 2	CM Application 3	CM Application 4
3D Model	**Visualization**	Trade Collaboration	Safety Planning	Marketing	Simulation
3D Model	**Geometry**	Clash Detection	Off Site Fabrication		
3D Model	**Quantities**	Cost Estimate	Schedule	BOM	4D Model
Primavera	**Resources**	Cost Estimate	Schedule	Change Management	4D Model
Primavera	**Cost of Resources**	Cost Estimate	Change Management		4D Model
Analysis	**Production Rate of Res.**	Cost Estimate	Schedule	Change Management	4D Model
Analysis	**Work Packaging**	Trade Coordination	Schedule		
Analysis	**Procurement Data**	Procurement	Buy Out	Material Management	
Analysis	**Installation Data**	Material Management	Project Control		
3D Model	**Site Layout**	Const Op Analysis			
Analysis	**Maintenance Data**	Facilities Management			

Table 1. BIM output and CM applications

The visualization is based on the graphics data and interface. It provides one of the major benefits of the model. In the preconstruction stage, it may be used to market the project to the owner, investors, or future occupants. They can explore the model and thoroughly understand the designer's intentions and suggest modifications to suit their needs. Although it is difficult to quantify, the visualization provides stimulus for ideas, possible construction methods, and scheduling efficiency. Visualization is also used for trade collaboration. Coordinating the actions of HVAC, structural, electrical and other subcontractors is a major benefit during construction operations. Site safety planning can be considerably enhanced by being able to visualize the future project and its relationships. Finally, varying approaches to construction may be simulated.

The geometry of the project and its design components provides intelligence to the model. This allows one to determine interferences among the design components. This clash detection is a major function of the model and can eliminate much of the rework that used to occur when only two-dimensional drawings were used. Early studies by the Construction Industry Institute showed that rework can range from 0 to 25% of the installed cost of construction and the use of a three-dimensional computer model in the management will reduce that amount of rework by an average of 65%.[18] The geometric output enhances the ease by which some design components can be fabricated offsite.

Quantities that come directly from the three-dimensional model component of the BIM can generate a bill of materials directly and when combined with resources, cost of resources, production rates of resources, and material and equipment databases, can generate a cost estimate and provide durations for the schedule. The resources, cost of resources, and the material and equipment databases are components of BIM but their source is generally separate software packages such as Primavera Project Planner or Microsoft Project. The resource production rate comes from separate analyses and may be part of the non-geometric database associated with each design element. The quantities may provide input for permanent materials procurements and materials management on site.

Procurement date, installation data, and maintenance data may be part of the non-geometric databases and provide input for procurement systems, materials management systems, commissioning startup and facilities management. An example of materials management is to turn a copy of the three-dimensional computer model red. As material arrives on site, using either barcode or RFID technology, color each component yellow as it is received on site. As it is installed, change its color to green. As the project progresses, items that were over looked during the procurement process can be identified.

Site logistics and management, change management, document control, site safety planning, construction operation planning and many other CM applications can be obtained from the BIM. These applications can have a major impact on the success of the project.

SUMMARY AND CONCLUSIONS

Unlike the high-tech worlds of computers and electronics, the implementation of new technologies in the construction industry is more akin to the tortoise than the hare. Because BIM is perceived to be in its infant stages, seasoned construction professionals are hesitant to rely on its product. However, regardless of construction professionals' preference for traditional 2D drawings, BIM, through the complete collaboration of all parties, yields a fully integrated product that is conducive to timely project delivery, the conservation of resources and facilitates fully informed collaboration.

---

[1] Project BIM Engineer, Turner Construction Company, Inc., New York, NY and Adjunct Professor, Dept of Civil Engr'g, Polytechnic Inst. of NYU, Brooklyn, NY

[2] Professor, Dept of Civil Engr'g, Polytechnic Inst. of NYU, Brooklyn, NY

[3] Professor, Dept of Civil Engr'g, Polytechnic Inst. of NYU, Brooklyn, NY

[4] Griffis, F.H. , "Benefits of Using Three-dimensional Computer Models in the Management of Construction", *National Science Foundation Report*, 1988.

[5] Bechtel, Bentley and Jacobus Announce Trilateral Strategic Alliance; Bechtel to Standardize on MicroStation, Jacobus to Acquire Bechtel 3DM Plant Design Products, BNET Business Network, Business Wire June 7, 1995.

[6] A Brief History of Computing – A Complete Timeline, Stephen White, 1996-2005, http://trillian.randomstuff.org.uk/~stephen/history/timeline.html. (Note: Bill Gates is said to have denied making this comment.)

[7] Griffis, F.H**.** and Carrie Sturts**,** *Applications of the Fully Integrated and Automated Project Process in the Management of Construction*, Research Report 152, Construction Industry Institute The University of Texas at Austin, Texas, 2003

[8] National Institute of Building Sciences, National Building Information Model Standard, Version 1.0 – Part 1: Overview, Principles, and Methodologies, page 1.

[9] Griffis, F.H, D. Hogan and W. Li, *An Analysis of the Impacts of Using Three Dimensional Computer Models in the Management of Construction,* Research Report 106-11, Construction Industry Institute, The University of Texas at Austin, Texas, September 1995.

[10] Eastman, C. P. Teicholz, R. Sacks, and K. Liston, *BIM Handbook, A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors.,* John Wiley & Sons, Inc, Hoboken, 2008.

[11] Ibid.

[12] Griffis, Hogan and Li, op.cit.

[13] "GSA to Require Building Information Models by FY 2006" by Elaine S. Silver, 1/21/2005 http://enr.construction.com/news/informationTech/archives/050121.asp

[14] As of July 1, 2008, Polytechnic University was renamed as Polytechnic Institute of New York University (NYU) as part of the recent acquisition of Polytechnic University by NYU

[15] Glen W. Birx, AIA, *Getting Started with Building Information* Modeling, AIA Best Practices – BP 13.01.02, Revised January 2007.

[16] Ashcraft, Howard W. Jr., Esq., *Sexy, Young Technology Seeks Stable Project Delivery Method for Lasting Relationship . . . – Building Information Modeling*, Adapted from Building Information Modeling: Electronic Collaboration in Conflict with Traditional Project Delivery", Construction Litigation Reporter (Jul/Aug 2006), © 2006 Thompson/West.

[17] Ibid. p. 208

[18] Griffis, Hogan and Li, op.cit.

DEVELOPING CONSTRUCTION NETWORK-BASED INTERFACE MANAGEMENT SYSTEM

Yu-Cheng Lin[1]

ABSTRACT

It is necessary to trace and control related interface events and problems in construction management. Interface management (IM) approach play an important role in construction management. The interface events can be identified and traced in interface management for involved participants to improve the construction process and minimize deleterious change. This study proposes a new and practical methodology to track and manage interface events by using network-based maps. Using network-based maps, users can get an overview of previous and current interface events in selected project and take appropriate advanced control and manage interfaces and problems in construction building project. This study addresses application of interface management in construction/mechanical/electrical of building project and proposes a Construction Network-based Interface Management (CNIM) system for project participants. The CNIM system is will applied in selected case study of a building project in Taiwan to verify our proposed methodology and demonstrate the effectiveness of interface management. The main purpose of this study is to developing a web-based interface management system for involved engineers to increase interface event information sharing and tracing efficiency. Project managers and engineers can take advantage of interface events information flow to help managers and engineers to handle interface events and activities through CNIM system. By effectively using network-based maps and web technologies during the construction phase of a project, interface management can be enhanced and improved in build projects.

INTRODUCTION

There are many interface events and problems occurred in the construction building projects during the construction phase. The interface events include problems regarding to schedule, cost, technical area, space, and organizational interfaces caused by different participants or organizations. It is necessary to trace and control related interface events and problems for effective management during the phase. Interfaces can be characterized to the level of compatibility of the parties they separate (Healy 1997). Interfaces can be internal (within one organization) or external

[1] Assistant professor, Department of Civil Engineering, National Taipei University of Technology, No.1.Chung-Hsiao E. Rd., Sec.3, Taipei, Taiwan, E-Mail: yclinntut@gmail.com

(different organizations) (Healy 1997). Interfaces will arise because the work into parts executed by different participants or organization (Stuckenbruck 1993). The interface events can be identified and tracked in interface management involved general contractor and all participants to improve the construction process and minimize deleterious change, and promote beneficial change. This study proposes a new and practical methodology to track and manage interface events by using network-based maps and interface management (IM) approach. Using network-based maps, users can get an overview of previous and current interface events in selected project and take appropriate advanced control and manage interfaces and problems in construction building project. This research is a pilot study to develop a generic model using network-based maps for interface management in building project in Taiwan, analyzing and discussing whole processes during interface management, pertinent supplementary techniques, and IM implementation status for construction projects. This study develops construction Network-based Interface Management (CNIM) system for project participants to improve interface management in construction/mechanical/electrical of building project.

PROBLEM STATEMENT

Construction projects are characterized by extreme complexity and diversity as well as nonstandardized production. Unlike manufacturing, each project is designed and executed to meet owner needs. Thus, effectively managing interfaces is essential to construction management. Interface management is very important for construction projects particularly regarding related information gained from participants when interfaced is identified. Effective sharing information can improve construction interface management during construction phases, thus helping avoid unnecessary mistakes. France (1993) states that IM is useful shorthand to describe how companies work with each other in the design, manufacture, and construction of project. Only limited research efforts have focused on interface management issues in construction in the past. Chen (2008) presents a multiperspective approach that systematically explores comprehensive cause factors for various interface issues. Chua (2006) proposed to use the work breakdown structure (WBS) concept to improve work interface management. A multimedia and web-based educational tool is developed for civil engineering students to better understand the detailed of the planning of equipment, design, and construction of a complicated project (Golias et al. 2005).

Interface information gained enables construction teams to identify interface gray information and avoid unnecessary problems. Interface information sharing can serve as references for understand the interface working on similar projects. During the construction phase, engineers and experts usually execute their own work and do not share this interface information with others. Interface management is an information-intensive task in which available and useful information is extremely useful to related participants. However, no appropriate platforms exist to assist project managers and engineers in exchanging and sharing related interface information during construction projects. Additionally, few suitable platforms have been developed to assist project participants in sharing their interface information when needed. Therefore, sharing and using interface information in construction projects is the primary objective of this study.

RESEARCH OBJECTIVES

The main purpose for conducting this research is to develop a CNIM system for general contractors by using network-based maps, to provide interface events tracing and controlling service in the construction phase. To identify, trace, control, and manage of the construction interface events and problems are critical and necessary. The main purposes of this study include (1) developing a web simply and friendly design interface for involved engineers in interface management; (2) applying such a system that integrates web technology to increase interface event information exchanging and tracing efficiency, and (3) supporting project managers related to individual participants in dynamically monitoring and controlling the construction process. Project managers and engineers can take advantage of interface events information flow and change activities to help managers and engineers to handle interface events and activities through network-based maps. By effectively using network-based maps and web technologies during the construction phase of a project, interface management can be enhanced and improved in construction projects.

BACKGROUND RESEARCH

Interface management is the systematic control of communications supporting a process operation (Healy, 1997). Interface management is an outgrowth of the influences of system thinking on project management. IM has been proven to address project complexity and allows for a dynamic and well-coordinated construction project system (Chen et al., 2007). Despite the many articles and extensive discussion in practice and in the academic literature, construction professionals lack systematic approaches to managing interfaces during construction phase (Evans, 1997).

Morris (1983) proposed two main interface types: static interfaces and dynamic interfaces. Stuckenbruck (1983) proposed three main interface types: personal interfaces, organizational interfaces and system interfaces. Pavitt and Gibb (2003) proposed three main interface types: physical interfaces, contractual interfaces and organizational interfaces. Physical interfaces are the actual physical connections between two or more building elements or components. Contractual interfaces are the groupings of work elements into distinct work packages to suit the availability of design information. Organizational interfaces are the interactions between various participants in a construction project (Pavitt and Gibb, 2003).

Pavitt and Gibb (2003) proposed three main interface types. They are physical interfaces, contractual interfaces, and organizational interfaces. Physical interfaces are the actual, physical connections between two or more building elements or components. Contractual interface is the grouping together of work element into distinct workpackages to suit the design information availability or due to the principal contractor's program. Organizational interfaces are the interactions between various parties involved in a construction project (Pavitt and Gibb, 2003). The CNIM system mainly manages physical interfaces, contractual interfaces, and organizational interfaces (or called interface events) in the study.

Portals, a unique and sometimes complex tool introduced in the late 1990s, are websites that collect information related to specific topics and provide users with access to related services and information sources. When a portal is utilized, all project-related information in a centralized project database can be obtained only via a web interface. Thus, a portal also utilizes authentication and access control

mechanisms that enable project participants to access information based on user privileges and activity-related units. Standardized interactions via a single portal are easier to manage than numerous peer-to-peer relationships. Electronically exchanging information further reduces the incidence of errors and increases work efficiency.

Based on a review of the literature and a pilot study of interviews among various construction parties, the proposed interface management procedure includes interface finding, interface identifying, interface communicating, interface recording and interface closing. Each phase is briefly outlined in the following descriptions (see Table 1).

Table 1. Description of construction interface management phases

Phase	Description
Interface Finding	Interface finding is the checking for new or existing interface events related to projects.
Interface Identifying	Interface identifying ensures that the identified interfaces are consistent with all relational participants.
Interface Communicating	Interface communicating is the process of requesting, responding to and tracing processes among relational participants.
Interface Recording	Interface recording is all information recording processes related to the identified interface event
Interface Closing	Interface closing is the final closing action when the interface event is reconfirmed without further identification or tracing.

Concept of Network-based Maps

Like construction project management, IM is based on the concept of undertaking project planning and control activities. Interface information submitted by project participants can be identified, tracked, managed and solved in construction projects. Acquired latest interface problems and solutions from participating engineers can be shared and saved as map units in categories for efficient collection, management and finally, retrieval for reference in the current projects. The proposed network-based maps are specific approaches to interface management in the construction field. Although knowledge and concept maps are easily recognized in knowledge management, the proposed network-based maps approach is a novel concept and is specific to construction interface management. The network-based maps can be defined as a diagrammatic and graphic representation of experience linking relationships between experience and attributes of engineers. The network-based maps are designed to be easily integrated with interface events and construction activities and projects. The key reason for using network-based maps is the ease with which the combined interface information can be understood and shared. The primary advantages of network-based maps are as follows: (1) network-based maps are simply, clearly and dynamically represented interfaces in the CNIM; (2) network-based maps enhance the available interface events and activities illustration between construction projects and participants; (3) network-based maps may freely extend the interfaces relationship for both vertical and horizontal graphic representation; and (4)

network-based maps methodology helps users identify the most critical and indentified interface events and activities relevant to a particular project.

Framework of Network-based Maps

Network-based maps are defined in multiple levels, and constructed from variables which can be broken down by decomposing the activity units into smaller map units into which the identified interface is stored. Network-based maps may be comprised of several layers. The first layer generally models the project unit. The subsection unit is modelled in the second layer. The third-level layers model activity units (network illustration) or groups of activities. The lower-level layers model interface event units (event illustration). Similarly, any map unit in this lower layer can be broken down further to incorporate other components in lower layers. The map contents can be viewed as either a single point or as ranges. The structure of network-based maps enables users to access stored interface information through layers based on the attributes and types of interface problems. Interface information stored in map units of a project map includes both Interface problems and Interface solutions. Interface problems may be comprised of an interface event topic, interface event description, problems-faced descriptions and interface event attachments (documents, reports, drawing and photos). Interface solutions may include problems-faced descriptions, problems-solved explanations, solution suggestions, and solving history record explanations. Additionally, network-based maps give users an overview of available interface events map in selected project, enabling effective interface management. The interface problems and interface solutions of map-based interface management are likened to the duration and relationship of stages-based project management. Identifying the relationship between identified interface events and activities are significant for users to link related management together.

Network-based maps have components and procedures based on the construction project management. The components and procedures of network-based maps are described below. The network-based maps consist of ten components. These ten components are interface event topic, interface event date, interface event description, interface event owner, interface event relationships, interface event ID, interface event packages, interface event record, interface responds, and interface partners. Procedures are presented for constructing network-based maps based on an interface management framework. The procedures consist of the following six primary phases: interface identification; interface confirmation; interface track; interface report; interface validation; and, interface close.

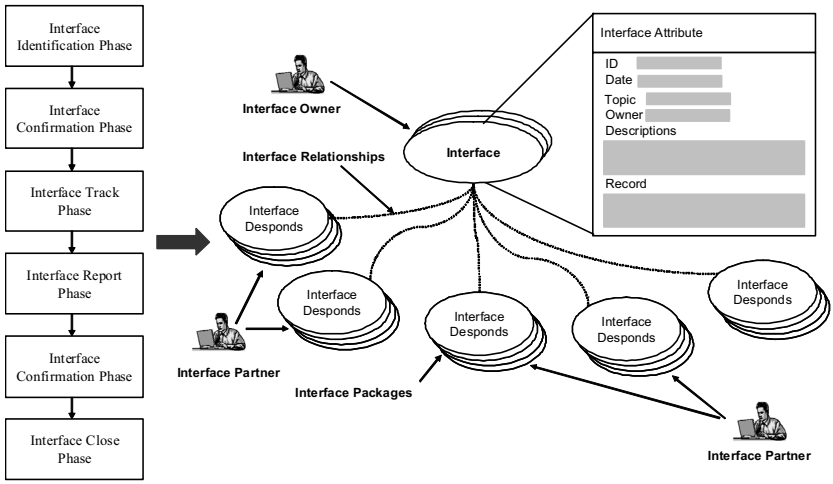


Fig. 1. The components and procedures of the network-based maps

SYSTEM DEVELOPMENT

The CNIM system is run on Microsoft Windows 2003 with an Internet Information Server (IIS) as the web server. The prototype is developed using Java Server Pages (JSPs), which are easily incorporated with HTML and JavaScript technologies to transform an Internet browser into a user-friendly interface. The CNIM system server supports four distinct layers: interface, access, application and database layers. Each layer has its own responsibilities. The interface layer defines administrative and end-user interfaces. Users can access information via web browsers such as Microsoft Internet Explorer or FireFox. Administrators control and manage information via the web browser or using a separate server interface. The access layer provides system security and restricted access, firewall services and system administration functions. The application layer defines various applications for collecting and managing information. The database layer consists of a primary Microsoft SQL Server 2003 database. A firewall and virus scanning can used to protect the system database against intrusion.

This following section demonstrates the implementation and modules of the proposed CNIM system.

Interface Authorities Management Module

The interface management module serves as an access control mechanism to prevent unauthorized users from entering and/or retrieving sensitive interface information. The CNIM system requires that all relevant project teams (subcontractors and suppliers) register. Registering as an approved system user requires companies to input a unique User ID and password for authentication

purposes. As the project-related information or reports required by different project participants vary, general contractors are allotted different access rights and authorities.

Interface Progress Monitoring Module

This progress monitoring module allows project participants to track interface events. Additionally, project participants can share the current progress or delivery condition of selected interface events. The progress monitoring module has an easy access option allowing participants to trace and record all information related to the interface events status. Additionally, project participants can share interface events information and trace all historical record regarding of interface problems and solutions.

Interface Alert Management Module

This alert management module is helps general contractors, subcontractors and suppliers observe the impact of the most recently interface events. Importantly, since the dates related to notification of interface events are recorded systematically; thus, project participants can easily establish liability related to interface events. Furthermore, this module provides a convenient access and a push-based function that helps engineers respond to certain situations in advance of tracked interface events or responded interface events.

Interface Online Communication Module

This communication management module is an interfacing event-based communication platform similar to a MSN Messenger and e-mail, and enables a ''threaded'' discussion to take place online. Related members regarding to interface events can post questions, responses, and comment thereby generating a permanent record related to a particular issue. For sensitive topics, discussion in the sensitive topics can be protected using a secure password.

Interface Document Management Module

The document management module enables users to download electronic documents directly via the CNIM system. This module has a "search" function such that required information can be found and retrieved easily. Most uploaded files are automatically converted into pdf documents by the CNIM system. This process allows participants to manage, track, and organize these files in a central location. This feature also allows participants to determine who accessed files or downloaded documents, and when the file was edited and uploaded to the system. This feature also facilitates identification and verification of individuals before they enter data or transmit information.

Interface Report Module

The interface report module is an easy-access environment in which users identify their needs and analyze interface information based on user requirements in the CNIM system. All interface results can be presented in the web environment or extracted using commercial software (e.g, Microsoft Excel). Authorized records are maintained by a contractors, subcontractors, and suppliers and can be extracted and summarized in reports.

CASE STUDY AND SYSTEM EVALUATION

The following case involves a contractor with seven years of specific experience in Taiwanese construction building projects. Furthermore, the general contractor hopes to take full advantage of interface management to avoid reworks, time wasting, adn financial loss in the project. Therefore, the contractor encouraged all participants to use the CNIM system and apply interface management to manage interface events effectively from participating engineers. The CNIM system was utilized in the Taiwanese construction building projects to verify the efficacy of the proposed methodology and demonstrate the effectiveness of sharing interface management during construction. This case study was undertaken for a 9-month construction project with a schedule that had approximately 4128 activities. Moreover, all engineers were encouraged to track and handle the interface events in the CNIM system. Figure 1 presents the interface-sharing interface in the CNIM system.

During field trials, the verification test assessed whether the CNIM system performed the tasks specified in system analysis and design. The validation test selected case participants to use the system, who then provided feedback via a questionnaire. The CNIM system was installed on a general contractor's main server during field trials. The 16 respondents included 2 project managers with 5 years of experience, 4 senior engineers with 20 years of experience, 3 engineers with 10 years of experience, 6 junior engineers with 1 year of test experience. Use of the CNIM system was demonstrated for respondents, who were then requested to express their opinions of the system via the questionnaire. A field test was performed over a 8-month period. The total number of interface events in the system was 53 with 137 interface events packages at the end of project execution

To evaluate system functions and user satisfaction with system capabilities, questionnaires were distributed. System users were asked to grade system conditions, system function and system capability on a five-point Likert scale, ranging from 1 for "not useful" to 5 for "very useful." The next section presents the detailed results of the performance evaluation and the general contractor satisfaction survey conducted during field trials.

Based on the user-satisfaction survey, participants gave an average of 89% on their satisfaction in interface event sharing that the CNIM system enabled engineers to share and track interface events to enhance interface management. Furthermore, the user-satisfaction rate of 85 %, indicating that the CNIM system provided clear and dynamic representations of interface events and effectively identified current interface events with status and situation related to the project. Participants gave an average score of 91% for their satisfaction with the easiness and convenience in tracing and managing interface.

Questionnaire results indicate that the primary advantages of network-based maps in the system are as follows. (1) Participants gave an average score of 90% for the usefulness of network-based maps in providing clear and dynamic representations of existing interface events relevant to selected projects. (2) Participants gave an average score of 88% for their satisfaction with network-based maps that clearly identified interface latest information and tracking situation. (3) Participants gave an average score of 93% for their satisfaction with the integration of network-based maps and construction interface management.

CONCLUSIONS

The application of interface management for building projects in construction phase is discussed in this paper. Also, the main purpose of this paper presents a construction Network-based Interface management (CNIM) concept and system for all project participants as an interface-sharing platform. Network-based maps shows the available interface events, problem descriptions and solutions in the interface management environment. The collection of interface events and problems for network-based map units in construction projects allows involved project managers and engineers to trace and manage most interface-related information. The content of the interface content bank in the system not only provide the specific problem-solutions, but also support all area interfaced events and information from the projects. Although effort is required to update the interface events for various problems and solutions of interface events, the developed system will benefit interface management by (1) providing an effective and efficient computerized environment to assist interface management tasks, and (2) facilitating the implementation of a web-based interface management system pertinent to these activities in the projects. With the evaluation of the case study in the Taiwan building project, the results show that a CNIM system is effective in managing interface events for building projects. The case study also highlighted the need for improvements to interface management in construction building projects. Overall, field test results indicate that the CNIM system is an effective and simple platform for construction interface management. Furthermore, observation results result show that the CNIM system significantly enhanced progress in the process and management of construction project interface events. The suggestions are made based on received feedback as follows: (1) Policy and strategy must be reworded to encourage to use the CNIM system; (2) Further effort is needed to update interface information related to various interface events in the project; (3) senior engineers and experts require substantial time and assistance to edit interface information; (4) Most senior engineers cannot edit their interface information without help; (5) the CNIM system may be integrated with web-based project management in the future.

ACKNOWLEDGMENTS

The authors would like to thank the National Science Council, Taiwan, for financially supporting this research under contract number NSC 95-2221-E-027-143-.

REFERENCES

Chan, W. T., Chen, C., Messner, J. I., and Chua, D. K. H. (2005). “Interface management for China’s build-operate-transfer projects.” J. Constr.Eng. Manage., 131 ┌ (6), 645–655.

Chen, Qian, Reichard, Georg and Beliveau, Yvan. (2008). “Multiperspective Approach to Exploring Comprehensive Cause Factors for Interface Issues.” J. Constr. Eng. Manage., 134(6), 432-441.

Chua, David K. H., and Myriam, Godinot. (2006). “Use of a WBS matrix to improve interface management in projects.” J. Constr. Eng. Manage., 132(1), 67–79.

Evans, G. N., et al. (1997). “Organizing for improved construction interfaces.” Innovation in civil and construction engineering, Civil-Comp Press, Edinburgh, U.K., 207–212.

France, G. (1993). "Building team spirit." Proc., Building, The Builder Group, London, 60.
Healy, P. ┌(1997). "Interfaces." Project management: Getting the job done on time and in budget, Butterworth-Heinemann, Port Melbourne, Vic., 267–278.
O'Connor, J. T., Rusch, S. E., and Schulz, M. J. (1987). "Constructibility concepts for engineering and procurement." J. Constr. Eng. Manage., 113(2), 235–248.
Pavitt, T. C., and Gibb, A. G. F.┌(2003). "Interface management within construction: In particular, building façade." J. Constr. Eng. Manage., 129(1), 8–15.
Stuckenbruck, L. C. ┌(1983). "Integration: The essential function of project management." Project Management Handbook, D. I. Cleland and W. R. King, eds., Van Nostrand Reinhold, New York, 37–58.

VIRTUAL SUPERVISION IN CONSTRUCTION PROJECTS

Lahiru P. Silva[1], Janaka Y. Ruwanpura[2] and Kasun N. Hewage[3]

[1]SMASCE, M.Sc. Student, Project Management Specialization, Department of Civil Engineering, Schulich School of Engineering, University of Calgary, Calgary, Alberta, T2N 1N4, PH (403) 220-6185, Fax (403) 282-7026, Email:
[2]MASCE, Canada Research Chair in Project Management Systems, Director and Associate Professor of Project Management, Department of Civil Engineering, Schulich School of Engineering, University of Calgary, Calgary, Alberta, T2N 1N4, PH (403) 220-6892, Fax (403) 282-7026, Email: janaka@ucalgary.ca
[3]Assistant Professor, University of British Columbia – Okanagan, School of Engineering, 3333 University Way, Kelowna, BC, V1V 1V7, PH (250) 807- 8176, Fax (250) 807-9850, Email: Kasun.Hewage@ubc.ca

ABSTRACT
Better utilization of supervision time is a key factor to improve communication in construction projects. Popularity of the remotely accessed cameras in construction industry has increased drastically in the last few years. The concept proposed in this paper is an information management and a supervision time optimization system called "Virtual Supervision" model. This model enables the supervisors and other stakeholders of a project to monitor construction activities remotely and address the issues by using a surveillance camera system integrated with a few other technological tools. The focus of the "Virtual Supervision" model is to improve the efficiency, communication, and worker satisfaction. The system facilitates efficient information flow between the site office, site, head office, and other relevant stakeholders.

Introduction

The construction industry faced many challenges in the beginning of the 21st century, as it was forced to change and to incorporate new advanced technologies into the construction processes, to gain a new competitive edge in the market (Abduh and Skibniewski, 2003). According to FIATECH – Fully Integrated and Automated Technologies (2004) - the construction industry lags behind manufacturing and transportation industries in terms of field-level automation and wireless and display technologies. There are many uncertainties in the use of information technology (IT) in the construction industry.

Hewage and Ruwanpura (2006b) found that the "inadequate communication" between the stakeholders in construction projects; especially at the site level leads to

productivity losses and inefficiencies. This was validated by interviewing 101 workers from four construction sites of four general contractors. A similar problem was identified by the previous researchers such as Bowden et al. (2006) and Mohamed and Stewart (2003). These researchers found that only 20% of the information passed down to the operational (worker) level in a construction site. Hewage and Ruwanpura (2006a) also proposed and pilot tested a novel concept called "Information Booth" to address communication issues in the construction site environment. "Information Booth" is an automated information outpost designed to aid lead workers and foremen during the daily tool box meeting and site operations. The key information elements stored in the 'Information Booth" were daily and weekly targets, technical specifications, 2D or 3D drawings, 3D construction details, and safety information. During the pilot testing period of the "Information Booth", extreme weather conditions forced the researchers to deploy a wireless camera for observational purposes (Hewage and Ruwanpura 2008).

Remote access cameras become increasingly popular in the construction industry during the last few years (Sitecam 2008). The "Productivity Improvement" research group at the University of Calgary recently developed a laboratory titled "construction visualization and monitoring center" to monitor construction operations in real-time (Weerasinghe and Ruwanpura, 2009). It aided the growing needs of the students and the industry to visualize the construction operations and to collect data using wireless cameras. Wireless surveillance cameras are deployed at several construction sites and monitored at the laboratory. The access of the camera views have been given to the selected stakeholders of the project including key site personnel. The system functionality includes zooming, changing direction, focusing to a certain object when required, and archiving images or video throughout the days on all work days.

Inadequate supervision and management factors are critical issues that lead to declining construction productivity (Dozzi and Abourizk, 1993). Liberda et al (2003) identified 51 factors related to the construction productivity in Alberta. Thirty five of those factors were significantly related to poor management practices in the construction industry. Site management is directly responsible for more than 50% of the time wasted due to poor management practices (Haas et al., 1999). Supervisory staff plays a key role in communicating with workers and spend significant amount of time with them during a work day (Gannoruwa and Ruwanpura, 2008). Therefore, better utilization of supervision time is a one of the critical factors for improving efficiency and productivity of construction work. Maximising the potential of the said wireless cameras by the site supervisors bring the term "Virtual Supervision". It means that the supervisor has access to the site people at any time even if the supervisor is away from the work area. The scope of this paper is to illustrate the concept of "Virtual Supervision" and to explain the rationale behind the need of the system and the challenges during implementation stage.

Research Objectives

The overall goal of this research project is to develop a system to better utilize the supervision time to improve on-site communication with the aid of remote access

wireless cameras and the "Information Booth". Following are the specific sub-objectives. This paper only discusses the sub-objectives 1, 2, 4 and 5.

1. Investigate the supervisory behaviour in construction using a time-motion study.
2. Investigate the technological capabilities and limitations of the existing on-site camera systems.
3. Investigate the psychological impacts on the workers for continuously monitoring their work through cameras.
4. Explore the physical constraints at the construction site level to implement the proposed system.
5. Develop guiding principles and a theoretical model for "Virtual Supervision."
6. Investigate the issues and concerns of the implemented "Virtual Supervision" system.
7. Test and validate the "Virtual Supervision" model.

Road Map

The research methodology is briefly stated in this section. Quantitative and qualitative tools will be utilized to fulfill the objectives of the research. These tools include interviews, questionnaire surveys, observations, statistical analysis, and cost benefit analysis. Following are the major steps.

- Conduct at least thirty interviews with office managers, site managers and foremen. Interviews will be conducted to:
  - study the existing supervision systems in the construction industry
  - identify the drawbacks of the present supervision systems
  - identify the factors affecting the better utilization of supervision time
- Observe construction operations to understand the present work practices. A detailed time motion study will be conducted with the supervisory staff and workers (at least two construction sites of the same trade). Observations will be carried out for 3 months in both sites to:
  - identify ineffective supervision times and supervisory behaviour
  - identify supervision needs and requirements of the construction workers
- Develop the "Virtual Supervision" model.
  - conceptualize the Virtual Supervision model
  - develop an implementation road map for the "Virtual Supervision" model.
- Implement the "Virtual Supervision" System.
  - implement the camera system
  - implement a new communication system by integrating both camera system and the "Information Booth."
- Conduct workshops with the workers, site and office managers, and foremen to assess the technology adoptability and the adaptability (ability to accept the technology and to make necessary changes accordingly – Hewage and Ruwanpura (2006a)) of the "Virtual Supervision". A questionnaire will be issued in these workshops.

- Assess the sustainability of the "Virtual Supervision" under two categories: economic viability and usability (economic feasibility study and ability to sustain the technology within the construction industry).
- Analyse the detailed time-motion survey conducted with the pilot sample to measure the worker efficiency and effectiveness before and after the implementation of the "Virtual Supervision".
- Questionnaire survey to assess the level of worker and supervision staff satisfaction before and after implementation of the "Virtual Supervision" model.
- Develop a set of guidelines for "Virtual Supervision" under three categories: i.e.: site supervision (supervision carried out by site staff), engineering supervision (supervision by the engineers office and construction mangers), and administration supervision (all the other supervision excluding above two categories).

Present Status in Supervision

Supervision time consists of three major components - direct work, instructions and ineffective time (Gannoruwa and Ruwanpura, 2008). Direct work is the time that supervisory staff is physically engaged in actual work. Instruction time consists of many other sub categories such as receiving instructions from senior management, communicating instructions to the workers and monitoring construction activities. Time spent on activities such as idling, walking and socializing contributes to ineffective time. Figure 1 illustrates the work time distribution of an average foreman in form work trade and ineffective time contributes to more than 30% of the workday (Gannoruwa 2008). This shows that the workers performed the work without a proper supervision for approximately 1/3rd of the day.

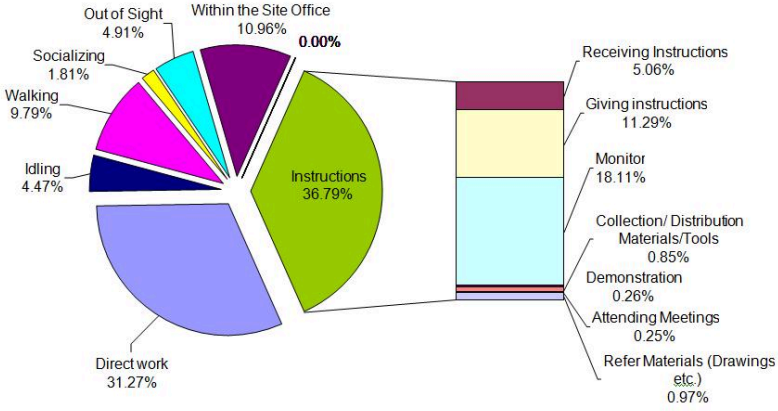


Figure 1. Total Time Distribution of a Typical Foreman (Gannoruwa 2008)

The time spent by a supervisor while at the site office and out of sight may be converted into instruction time using the concept of "Virtual Supervision." In the

construction site environment; engineering supervision and instructions are critical in improving construction productivity since work can be held up due to discrepancies, errors, and interpretations in engineering details. Typically, relevant personnel should be physically present in the job site to provide instructions to the workers. "Virtual Supervision" is a handy concept in those instances to efficiently mitigate delays and rework.

Virtual Supervision Model

"Virtual Supervision" is of one the novel concepts for construction site supervision formulated by the authors. The Construction Monitoring and Visualization Center (CMVC) serves as the nerve center of "Virtual Supervision" System. Capabilities of the center are stated in the introduction. CMVC has the capacity to store 10TB of data captured from 12 cameras throughout the day for 3 years. The concept of Virtual Supervision includes three major elements, which are, site supervision, engineering supervision and administration supervision (Figure 2).

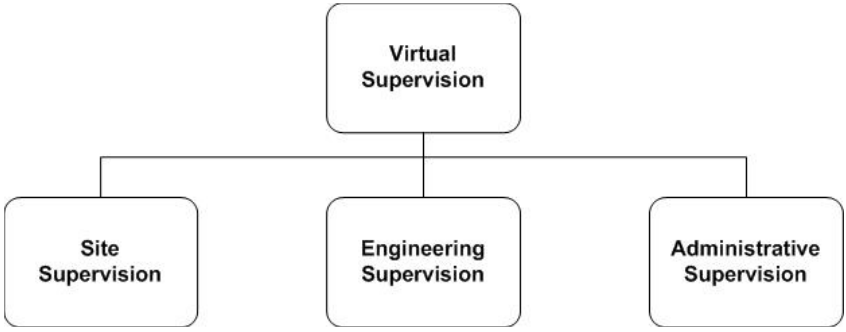


Figure 2. Virtual Supervision Model

Site Supervision

Site supervision includes labour & material management, tools & equipment management, and safety management. The site foremen, safety officers and site superintendents are responsible for the site supervision. In some instances, the amount of time spent on monitoring was less than 20% (Gannoruwa 2008). Therefore, the "Virtual Supervision" has a considerable potential to minimize ineffective time of supervisory staff.

"Virtual Supervision" model will improve the utilization of supervision time. The researchers noted that the effectiveness and efficiency of the workers change in a positive manner as soon as supervisory staff appears in the work area. The concept of "Virtual Supervision" mainly focuses on enabling supervisory staff to observe construction operations when they are away from work area through Internet. "Virtual Supervision" model is a useful tool in a job site with a large footprints and high-rise structures. Presence of a "Virtual Supervision" model may significantly improve the time utilization of supervisory staff, and as a result, the supervisory staff

can concentrate on other important planning activities. Tool time and productivity of the workers is expected to improve as a result of such continuous monitoring.

Another important feature of the proposed model is the opportunity for the supervisory staff to request archived motion images of construction operations. This could lead to a healthy discussion between the workers and the supervisory staff on the areas in need for improvement. "Virtual Supervision" is a proactive planning model than a reactive planning model as the continuous monitoring enables the supervisory staff to identify a situation and to provide real time solutions using the "audio" features of the "Information Booth" and Wi-Fi enabled handhelds (refer Silva et al. 2008 for details).

Engineering Supervision

Construction projects have three direct stakeholders: client, engineer and contractor. Although contractor is responsible for the onsite engineering supervision, the engineer or the consultant plays a vital role in this process. Site work can be held up due to a discrepancy in a detail or inability of site staff to interpret the construction details/ specification. "Virtual Supervision" provides engineers the ability to inspect the site work through cameras in addition to regular site visits. In addition, supervisory staff also possesses the ability to communicate with the engineers regarding the discrepancies in construction details. Engineers or construction managers have the ability to view, explain the details, and provide necessary answers in real time. This will considerably reduce the disruption to work and will improve the efficiency and effectiveness of the work force.

Administrative Supervision

"Virtual Supervision" offers substantial assistance for the administration arm of the contractor. Contract administrators and planners have access to archived images as well as time lapse motion pictures (Figure 3).

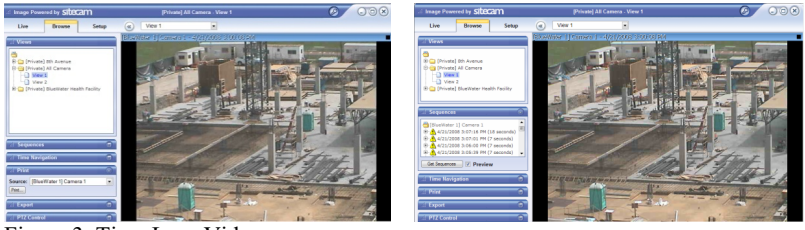


Figure 3. Time Laps Videos

The contractor gains an advantage in reducing insurance costs as the site can be viewed at any time of the day. There are many other indirect benefits. For example, clients and contractors have the capability to utilize the cameras as an advertising media to sell condominiums. The camera can be used as evidence in case of an accident or theft. Further the camera system associated with the "Virtual Supervision" model can be used to visualize the availability of materials in open space (Zhang and Ruwanpura 2008).

On Site Implementation and Case Studies

On site implementation mainly focuses on camera installation. Camera locations must be selected based on three main factors. Those factors are view, accessibility, and power source (see detailed under case studies). Based on these information and economic viability, the required number of cameras could be installed. Connectivity to the video server at the CMVC can be linked through a hard wire cable or a wireless portable internet adaptor. Connection speed and bandwidth must be determined by the frame rate and the resolution of the image. The technology provider is responsible for the programming of the camera, installation of the server, and the periodical maintenance. Details of two different case studies being implemented by the search team are given below.

Case Study I

The researchers selected Taylor Family Digital Library (TFDL) project at the University of Calgary. The TFDL building comprises of six stories and one basement. This project site is an ideal location to implement "Virtual Supervision" model because of the available infrastructure in terms of view, connectivity, and power. Presently, two cameras are sufficient to cover the entire job site. As shown in Figure 4, selected locations of the cameras are library tower (8 stories) and student center (3 stories). The supervisory staff initially did not show much interest in "Virtual Supervision." However, supervisor's attitude changed considerably after the cameras were installed as the supervisor realized the advantages of the continuous monitoring system.



Figure 4. TFDL Site Plan & Camera Images

Case Study II

A mixed development project in downtown Calgary was the second job site selected for the implementation of "Virtual Supervision" model. This project consists of three towers; 36 & 24 storey twin tower condominium and a 14 story office complex (Figure 5). Due to the nature of the project and the unavailability of adjacent structures to the project site determination of points to install cameras was practically difficult. Some of the existing buildings close to the site were not high enough to install cameras for considerable period. The only feasible solution was to fix the cameras on the tower cranes. The project team also faced the difficulties in supplying power and Internet connections. Having the camera installed on the tower crane also reduces the opportunity for periodic maintenance of cameras. Finally, the project

team and researchers decided to install both cameras on the tower crane. However, the selected camera location provided an opportunity to have a fix camera location for the entire high-rise.



Figure 5. Mix Development Site Plan and Areal View

Anticipated Problems and Intended Solutions

Many issues may be encountered during the early stages of the implementation of "Virtual Supervision". The researchers expect problems in four major categories: worker behaviour, management, technological, and external issues. The researchers carried out a brainstorming session with the project team to mitigate the impact of the following issues.

Worker Issues: Worker issues have been identified as the most influential category. When the workers realize that they are being monitored by the supervisors and other stakeholders, they may resist remote monitoring due to privacy and psychological reasons. However, many job sites in Alberta have similar type of cameras both in union and non-union environments (Sitecam 2008). Site management will have to create awareness among the workers that the camera system is deployed to ensure safety of the workers and to improve communication rather than inspecting individual worker efficiencies. Researchers have prepared a set of guidelines for supervisory staff to prevent unhealthy work environment due to worker resistance. Researcher has interviewed the project managers of the sites that have installed similar type of cameras and web cameras.

Management Issues: In general, the construction industry is known for the stiff resistance to IT based solutions (Mak, 2001). Success of the "Virtual Supervision" vastly depends upon the on-site management comfort and trust on the system. The researchers carry the prime responsibility in implementing awareness sessions with management to convince the site and office supervisory staff.

Technological Issues: Researchers encountered a few technological difficulties in one of the projects such as connectivity and power supply issues (refer case study 2). The other technological risks include force majeure issues such as lightning and heavy winds. The researches plan to keep one spare camera per site in case of an emergency. The system is programmed in such a way that the spare unit can be installed without major modifications and minimal training. The Contractors' IT managers will be trained to maintain the system under the guidance of technology provider to ensure sustainability of the system when the research team and

technology provider move out of the site. The camera could behave in an abrupt manner when more than one user attempt to operate it simultaneously (changing the view or zoom of the image). The researchers solved this by creating a ranking system in user accounts. It is also possible to temporarily allow access to users via remote desktop capability in that situation.

External Issues: Issues may also arise if the camera is used for unethical purposes. For example, it is possible to direct the camera to "peep" into adjacent property. This issue was mitigated by enforcing strict guidelines to the users of the system. Further, if the user has the ability to view the entire site by turning only 90 degrees, then black paint could be applied to the rest of the camera dome to block the view of the remaining 270 degrees. The site superintendent or the manager of CMVC has the ability to preset the camera, and the users will only have the capability of viewing the image.

Weather conditions in Alberta can be critical during winter sessions. Camera units are designed to withstand up to -35C temperature (design to military standard C-4150J). In case of unidentified problems, the researchers have been advised to follow the four step procedure to resolve them (refer Silva et al. 2008 for details).

Conclusion

"Virtual Supervision" model is a novel concept being implemented in Alberta, Canada. The main contribution expected from this model is to optimize the supervision time to enhance efficiency and effectiveness of the work force in the site environment. The authors strongly believe that the worker and supervisory staff satisfaction will be increased due to the real time visualization and improved communication. This system enables proactive planning and better supervision under engineering, construction, and administration areas. It is expected that the worker satisfaction will be increased because of the improved and real time communication between the supervisors and workers when the supervisor is away from the work area. It is noted that the sustainability of the system depends on the worker and supervisory staff satisfaction, increase in efficiency and communication, and the significant savings to project schedule and cost. There are various other research opportunities associated with the same system such as automatic tracking of workers and to measure tool time and productivity (refer Weerasinghe and Ruwanpura, 2009).

Acknowledgement

The researchers wish to acknowledge the support and funding for this research project by Canadian Foundation of Innovation, CANA, PCL, Ellis Don, Graham, Ledcor, Stuart Olson, Revay & Associates, Canadian Construction Research Board, and Calgary Construction Association, and the Natural Sciences Engineering Research Council under their Collaborative Research and Development Grant # CRDPJ 341047 – 06.

References

Abduh, M. and Skibniewski, M.J. (2003). "Electronic networking technologies in construction." J. Construction Research, 5 (1), 17-42.

Bowden, S. Dorr, A. Thorpe, T. and Anumba, C. (2006). "Mobile ICT support for construction process improvement." Automation in Construction, 15: 664-676.

Dozzi, S.P.and AbouRizk, S.M. (1993). "Productivity in construction." Institute for Research in Construction, Ottawa.

FIATECH (2004). "Capital Projects Technology Roadmap," Element 4 – Intelligent and Automated Construction Job Site (IACJS). October 2004. <http://www.fiatech.org/projects/roadmap/jobsite.html>

Gannoruwa, A. (2008). "Development of an Efficiency Model for Optimum Construction Productivity through Effective Supervision on Worker Performances." Under Review, M.Sc. Eng thesis, Univ of Calgary, 1-320

Gannoruwa, A. and Ruwanpura, J.Y. (2008). "Development of an Efficiency Model for Optimum Construction Productivity Through Effective Supervision." Proc. of the Canadian Society for Civil Engineering Annual Conference, Quebec City, Quebec, June 10- 13.

Haas, C.T. Borcherding, J. Allmon, E. and Goodrum, P.M. (1999). "U.S. construction labour productivity trends 1970-1998." Center for Construction Industry Institute, Report No. 7, March, University of Texas, Texas.

Hewage, K.N. and Ruwanpura J.Y. (2008). "A Novel Solution for Construction On-Site Communication – The Information Booth." Under Review, Canadian Journal of Civil Engineering.

Hewage, K.N. and Ruwanpura, J.Y. (2006a). "Technology adoptability and adaptability issues related to communication in Alberta commercial construction projects." 1st International Construction Specialty Conference, Canadian Society for Civil Engineering, May 23-26, Calgary, Canada.

Hewage, K.N. and Ruwanpura, J.Y. (2006b). "Carpentry worker issues and efficiencies related to construction productivity in Alberta's commercial construction projects." Canadian Journal of Civil Engineering, 33(8), 1075-1089.

Liberda, M. Ruwanpura, J.Y. and Jergeas, G. (2003). "Construction Productivity Improvement: A study of Human, Managerial and External Factors." Proc. of the ASCE Construction Research Congress, Hawaii.

Mak, S. (2001). "A model of information management for construction using information technology". Auto. in Construction, Elsevier, UK, 10 (2) 257–263.

Mohamed, S. and Stewart, R. A. (2003). "An empirical investigation of users' perceptions of web-based communication on a construction project." Automation in Construction. 12 (1), 43-53.

Silva, L.P., Hewage, K.N. and Ruwanpura, J. Y. (2008). "Total Information System Integration in Construction Projects." Proc. of the Canadian Society for Civil Engineering Annual Conference, Quebec City, Quebec, June 10- 13.

Sitecam, (2008). "Live Projects", Retrieve August 22, 2008, from <http://www.sitecam.com>

Weerasinghe, I.P.T. and Ruwanpura, J.Y. (2009). "Automated Data Acquisition System to Assess Construction Worker Performance." Under Review, Proc. of the ASCE Construction Research Congress, Seattle.

Zhang, G. and Ruwanpura, J.Y. (2008). "An efficient material management model to improve productivity" Proceedings of the CIB 2008 conference, Dubai, UAE,

3D WORK ENVIRONMENT MODELING FOR THE INTELLIGENT EXCAVATION SYSTEM (IES)

M. Chae[1], G. Lee[2], J. Park[3], J. Kim[4], and M. Cho[5]

Abstract

This paper presents a new method of real-time earth surveying using 3D laser scanner (3D imaging system) and the development of a customized software and a method for automatic data processing. Authors of this paper participate in the Intelligent Excavation System (IES) development project, which includes the development of technologies for surveying of earth environment and controlling unmanned excavator. This paper describes 3D earth work environment modelling part of the IES project. 3D laser scanner loaded on a mini-van scans the earth work area repeatedly to monitor the changes while earth work is done by excavators and loaders. Algorithm of registering (stitching) multiple scan segments into one 3D model on a common 3D coordination has been developed. Through a several experiments, important issues in 3D earth modelling have been found.

Introduction

Effectively and automatically recognizing objects and environment in construction site is an important issue in construction robot development. Computer vision technology has been widely used to recognize the surrounding environment and track objects in the field. Current most advanced vision technology delivers a viable solution that may replace human vision. It is almost possible for the computer to recognize the work environment as human does (Yoo et al. 2007). However, the vision system does not always fit well in the earth work environment which is relatively large and has a lot of noise and varying light condition.

Recently, 3D laser scanner (LiDAR or LADAR[6]) that has been used in many industries such as mechanical design, reverse engineering, 3-D modeling and 3-D CAD drawing from 3D objects is now getting attention for its possible application in outdoor environment. Long range terrestrial 3D laser scanner can be used in construction job site for 3-dimensional modeling of earth surface (Chae et al 2008). While long range 3D laser scanner is an expensive solution for its purpose of the use

[1] Ph.D. P.E., Senior Researcher, Korea Institute of Construction Technology, chae@kict.re.kr
[2] Researcher, Korea Institute of Construction Technology, gwlee@kict.re.kr
[3] Researcher, Korea Institute of Construction Technology, jwpark@kict.re.kr
[4] Researcher, Korea Institute of Construction Technology, jrkim@kict.re.kr
[5] Ph.D., Korea Institute of Construction Technology, mycho@kict.re.kr
[6] LiDAR: Light Detection and Ranging, LADAR: Laser Detection and Ranging

(3D modeling of construction job site) it might be the only solution to scan large areas of construction field with reasonable resolution, accuracy, and durability in the outdoor environment. While the industrial market of 3D laser scanner grows fast, the cost of the scanners is expected to go down in near future.

In this paper, the development of the software that controls the 3D scanner customized for earth work project, the mobile 3D imaging system, and the algorithm to stitch multiple scan data on the common coordinate is explained.

Research Scope

This study was conducted for 3D modeling of earth works environments using 3D imaging system. This study covers the software development for 3D laser scanner control and automatic data collection and arrangement of 3D data, mobile 3D imaging system development, and the algorithm of automated registration of multiple scan data. The software was simplified and automated, to which only the functions optimized to and required for earth works were added. This study was processed according to the following steps: (1) The software controlling the 3D laser scanner was developed; (2) The mobile 3D imaging system was developed; (3) the algorithm for the automated registration of multiple 3D scan data was developed; and (4) 3D work environment modeling using the actual field data was performed.

Development of the user interface

In the previous research work (Chae et al. 2008) three 3D laser scanners from major manufacturers were reviewed and ScanstationII by Leica Geosystems was chosen for earth work environment modeling. Main consideration aspects were scan distance, scan speed, and photogrammetric features. Although this does not mean that other two scanners do not fit in earth work environment, the chosen scanner was the most appropriate one to scan 100-meter long in diagonal site, which is a common working size for residential area development. Quick technical assistance availability was also considered.

Although a bundled software is provided by the scanner manufacturer, for the optimized functions and ease of use for the IES (Intelligent Excavation System), the scanner controller and mesh data builder was developed and named as Scanner Controller and Registration for IES (SCR). It has the following features: (1) controlling ScanstationII; (2) creating 3D point cloud, filtering noise, smoothing, sampling, and triangulation; (3) automatic mesh build-up; and (4) integrated 3D earth model build-up. A screenshot of the program is shown in Figure 1.

Scanned data are originally x, y, z point data. This data set is called point cloud. Before mesh data is build, point data are filtered to remove all the ineffective points. Usually, earth work job site is larger than the scanner's range, so multiple scans are required to cover the site. Once the multiple scan data are obtained, it is required to register on a common coordination using known points from different data files.

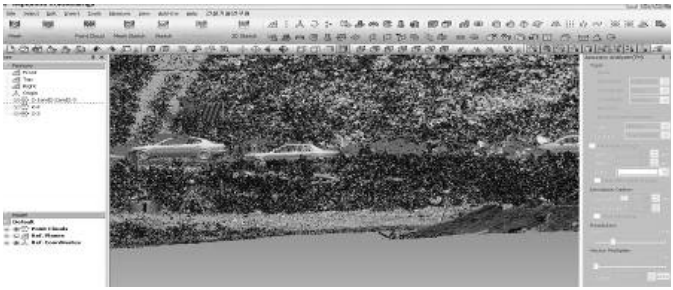


Figure1. Scanner Controller and Registration for IES (SCR)

Development of Mobile 3D Imaging System

The work flow of the Intelligent Excavation System (IES) has three phases: (1) Work environment modeling using 3D laser scanner; (2) Task planning system that controls the work order; and (3) giving order to the remote controlled excavator. Before the excavation starts, an initial scanning is performed and the scanning process is done repeatedly during the excavation process. Repetitive scan updates the shape of earth and the job task planning is also updated accordingly. In order to have the multiple scans periodically, the mobile 3D Imaging System has been developed in this research. The mobile system has 3D laser scanner, wireless modem, laptop computer with SCR (Scan Controller and Registration) software, power generator and inverter, and the hydraulic cylinder that holds the 3D scanner equipped on a mini-van with sun roof (Figure 2).



Figure2. Mobile 3D Imaging System

Development of an Automatic Registration Module

Scan data obtained from the mobile 3-D imaging system have relative x, y and z coordinates in 3-D space corresponding to the scanner position. Accordingly, the coordinates of objects in the same space may differ depending on the scanner's position. Therefore, a registration (stitching) process that unifies 3-D data into a single coordinate system in space is required. The image registration methods currently being the subject of several studies supported by mathematical techniques use: the range-image (Roth, 1999); the depth (Z-buffer) information drawn on the geo-sphere (Benjemaa et al, 1997); the image showing the relative distance from the

normal vector against a specific point in a form of a spin image (Johnson, 1999); and the volume metric (Curless, 1996). Of these diverse registration methods, one that automatically minimizes the differences in the distance between scan data using the sphere target was employed in this study, and a 3-D automatic registration module was designed to automatically perform all registration processes for the measured scan data. The 3-D automatic registration module is processed using the cluster analysis technique, and every step is processed using the software. Figure 3 shows the flow chart.

The first step is to uniformly distribute several sphere targets at arbitrary points in the earth work site as shown in Figure 4. To register a multitude of scan data, a minimum of three targets with identical scan section must be shared. About 10 targets are required when some targets are not scanned correctly in case of hidden behind hills, too far to be scanned correctly, lost or hit by trucks or other field equipment, etc. It would be preferable to have the sphere targets installed as far from the site as possible toward the outside to avoid influencing the work of the IES excavator. Moreover, absolute fixation is required to keep the position of the

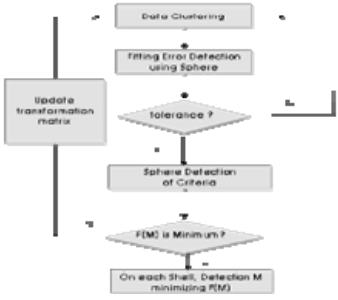


Figure 3. Flow Chart for Auto Registration

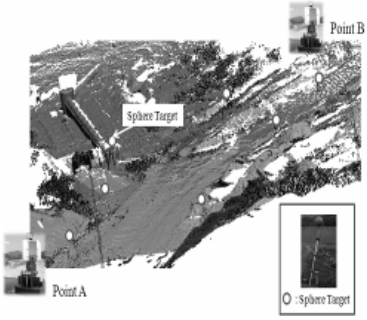


Figure 4. Sphere Target

target constant during the scan. The second step is to make the scanned data segments into a total of *n* clusters as shown in Figure 5, and calculate the fitting accuracy using the sphere target. If the fitting accuracy falls within the allowable range, the sphere target belongings to the boundary of two clusters can be detected.

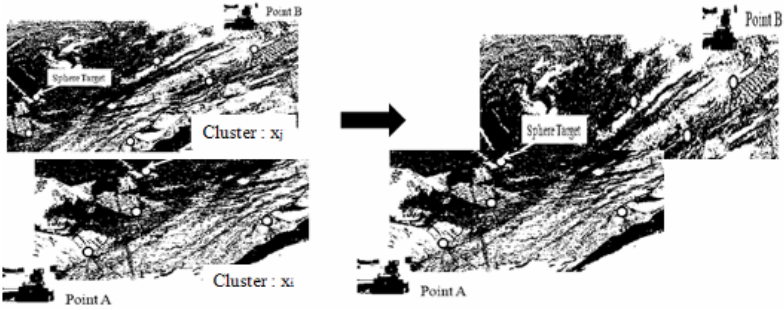


Figure 5. Registration by Clustering

The final step is to calculate the similarity matrix M between two clusters, and repeat it until an M that makes the least F(M), the objective function of Eq. (1), is found.

$$F(M) = \sum_{n=1}^{n} (Dev_1(M) + Dev_2(M) \ldots\ldots Dev_n(M)) \quad (1)$$

Where, $[M]_{ij} = n\ (x_i, x_j)$: similarity matrix

Dev_n: *Deviation between clusters, when transformed with M*

Thus, the registration is completed by finally finding the cluster that has the minimum similarity matrix.

Field Experiment of the Mobile 3-D Imaging System

A field test using the 3-D imaging system was conducted in an actual earth work site (Eunpyeong New Town residential area development earth work site by Youngshin Construction) to create a global model for the intelligent excavation system (IES). The residential area site development field is divided into about 100m x 100m segments for work. The subject field was 80x80m in size, where an excavator could be easily operated, and suitable for the work environment modeling for the intelligent excavation system (IES). The experiment was conducted by the automatic registration method using the target. The sequence was: scanning, polygon triangulation, automatic registration, merging.

This experiment's major purpose was to measure the time required for the 3-D modeling of the entire work field using the mobile 3-D imaging system, and evaluate the data processing performance using the SCR, the software developed in this study.

Condition and Method of the Experiment

The input values for the scanner were determined as shown in Table 1. As shown in Figure 6, the IES working area was first scanned using the mobile 3-D imaging system at point A, and the same working area was scanned after moving to point B. The back of a hill cannot be measured in front straight from the scanner due to the inherent characteristic of the 3-D laser scanner. Therefore, the scanning must be performed at two or more positions. The registration and merging of two sets of data scanned from different directions were conducted using the SCR software, and the optimal condition for 3-D modeling of the earth work site, the time spent in the merging of scan data, and the sizes of scan data were measured.

Table 1. Scanning Option

Scanner measurement position	2m (above ground)
Scanning range	Probe : 50m
Sample spacing	1cm × 1cm (Hori × Vert)
Number of points	<Point A> Vertical : 7360 points Horizontal : 2067 points
	<Point B> Vertical : 4840 Horizontal : 2695

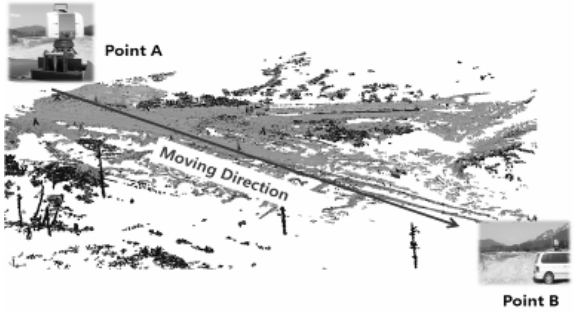


Figure 6. Site drawing

At first, scan data form point clouds. Each point has 3-D coordinates of x, y and z from the scanner, and the point cloud is converted into a triangle mesh as shown in Figure 7. The mesh data are automatically registered using a common sphere target as shown in Figure 8.

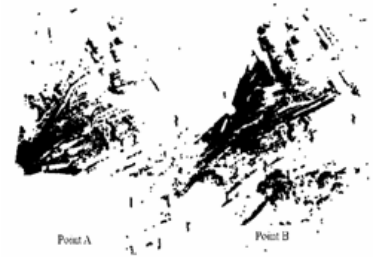


Figure 7. Mesh Data

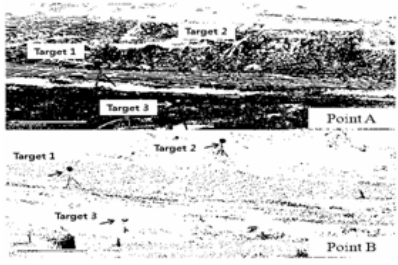


Figure 8. 3D Auto Registration

The last process is the merging of the registered scan data into one data file as shown in Figure 9. The first work environment modeling for the intelligent excavation system is completed when the merging process is finally completed. With

continuous measurements of the changes in the earth work by repeated scanning and processing, the earth work volume can be calculated, the properness of the progress compared with the plan can be determined, and the work progress can be automatically updated for the IES.

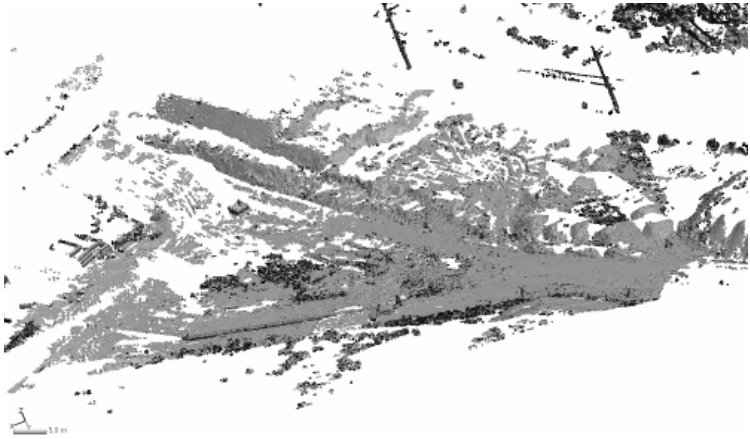


Figure 9. Merged Scan Data

Experiment Results

Total time spent in scanning

Realizing a 3-D model for an 80x80m earth work site using the mobile 3-D imaging system developed in this study took about 130 minutes. About 50 minutes was spent in one scan, providing that the work was conducted at the best resolution setting of the Scanstation II (sample spacing: 1x1 cm). It seems that the actual earth work planning and excavation required a slightly lower resolution, and the time required for a single scan may be significantly reduced. After the completion of the first scan, it took about 10 minutes to lower the scanner, close the sun roof, open the sun roof again and raise the scanner. Finally, automatic registration and merging took 20 minutes. If the scanning is conducted at a maximum of four points based on these experimental results, one full work environment modeling will take a maximum of 250 minutes, and about five scans can be conducted a day. It seems that this work may be significantly reduced through the resolution optimization.

Scan Data Size

The data size of the 3-D work environment modeling data for earth work is a very critical issue. Data resulting from the 3-D work environment modeling are necessary in developing the working sequence and control the excavator, and therefore, excellent communication is required to quickly update the working sequence and create the excavator's route. An excessive file size may increase the risk of delay in the transfer and processing of data. In this study, the point cloud was saved in the

ASCII file format to ensure data compatibility, taking up about 50Mb for one scan shot. The probe distance was 50 m and the sample spacing was 1cm (H)×1cm (V). If the scanning had been conducted at 1×1mm, which is the highest density available for the 3-D laser scanner (Scanstation II), a larger file would have been created. The optimal resolution for the intelligent excavation system was not considered in this study, but the current ASCII data will be converted later into a much smaller binary file.

Transferring a large file wirelessly requires the consideration of data latency, and the optimal file size combination will be adjusted later through scanning experiments, automatic excavator operation experiments and wireless telecommunication experiments, etc., considering the level of resolution and wireless telecommunication latency required for the intelligent excavation system.

Slenderness of mesh data

3D scan data are initially collected as point clouds and converted into polygons, in other words, mesh data. Good mesh data means that most of triangle polygons are almost equilateral triangles. However, as shown in Figure 10, when the scanner scans the area far from the scanner's location, 3D points on vertical direction is much further apart than horizontal direction. Thus, the maximum distance of laser scanning is not dependent on the scanner's scan distance but dependent on the height of the scanning position.

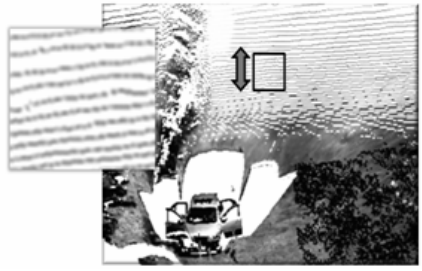


Figure10. Slenderness problem of scan data

Summary and Conclusions

This research is a part of Intelligent Excavation System (IES) project, which includes the development of new technologies for surveying of earth environment and controlling unmanned excavator. This paper describes 3D modelling of earth environment. It introduces the design of a mobile 3D imaging system optimized for earth work automation. The mobile system is to scan the earth work area repeatedly to measure the changes while earth work is done. The mobile system has a laptop computer, a wireless transceiver, a 3D laser scanner, and a hydraulic cylinder to push the scanner through the sun roof of the van. The method of registering multiple scan data is presented in this paper.

Through experiments, the performance of the mobile scanners and the software has been reviewed and the time for scanning and data processing has been found and possible scan frequency for the automated excavation process has been provided. It has been found that the reducing the data size is an important issue. In order to find the optimum data file size while maintaining required resolution, data transfer rate over wireless modem and 3D data post-processing time should be considered. In addition, reasonable selection of scanning position should be treated importantly to reduce the slenderness of mesh data.

Acknowledgement
This research is funded by KICTTEP Project No. 06-C4TF-C01.

References

Benjemaa, R., Schmitt, F, (1997) "Fast Global Registration of 3D Sampled Surfaces Using a Multi-Z-Buffer Technique", *Proceedings of IEEE International Conference on Recent Advances in 3D Digital Imaging and Modeling* (3DIM '97), Ottawa, Canada, May 1997.

Chae, M., Yoo, H., Kim, J., Cho, M., Jang, J., Jang, D., (2008) "3D Imaging System for the Intelligent Excavation System (IES)", *International Symposium for Automation and Robotics in Construction (ISARC) 2008*, IAARC, June 26-29, 2008, Vilnius, Lithuania, pp. 286-291

Curless, B., Levoy, M., (1996) "A Volumetric Method for Building Complex Models from Range Images", *Proceedings of ACM SIGGRAPH 96*, 1996, pp 303-312

Johnson, A., Hebert, M., (1999) "Using spin images for efficient object recognition in cluttered 3D scenes", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol.21, no.5, May, 1999, pp 433-449

Roth, G., (1999) "Registering two overlapping range images", *Proceedings of the Second International Conference on 3-D Digital Imaging and Modeling (3DIM'99)*, pp 191-200

Yoo, H., Chae, M., Kim, J., Cho, M. (2007) "A Study on Development of the 3D Modeling System for Earthwork Environment", *Proceedings of Korea Institute of Construction Engineering and Management*, Busan, Korea, Nov. 2007, pp 977-982

QUERYING IFC-BASED BUILDING INFORMATION MODELS TO SUPPORT CONSTRUCTION MANAGEMENT FUNCTIONS

M. P. Nepal[1], J. Zhang[2], A. Webster[3], S. Staub-French[4], R. Pottinger[5], and M. Lawrence[6]

[1] Department of Civil Engineering, University of British Columbia, 6250 Applied Science Lane, Vancouver, BC, Canada, V6T 1Z4; PH (604) 822-2739; FAX (604) 822-6901; email: mpnepal@civil.ubc.ca

[2] Department of Computer Science, University of British Columbia, 201-2366 Main Mall, Vancouver, BC, Canada, V6T 1Z4; PH (604) 827-3984; FAX (604) 822-5485; email: jiemin@cs.ubc.ca

[3] Department of Computer Science, University of British Columbia, 201-2366 Main Mall, Vancouver, BC, Canada, V6T 1Z4; PH (604) 827-3984; FAX (604) 822-5485; email: awebster@cs.ubc.ca

[4] Department of Civil Engineering, University of British Columbia , 6250 Applied Science Lane, Vancouver, BC, Canada V6T 1Z4; PH (604) 827-5118; FAX (604) 822-6901; email: ssf@civil.ubc.ca

[5] Department of Computer Science, University of British Columbia, 201-2366 Main Mall, Vancouver, BC, Canada, V6T 1Z4; PH (604) 822-0436; FAX (604) 822-5485; email: rap@cs.ubc.ca

[6] Department of Computer Science, University of British Columbia, 201-2366 Main Mall, Vancouver, BC, Canada, V6T 1Z4; PH (604) 822-0436; FAX (604) 822-5485; email: mklawren@cs.ubc.ca

Abstract

The design and construction community has shown increasing interest in adopting Building Information Models (BIM). While the richness of design information offered by BIM is evident, there are still tremendous challenges in getting construction-specific information out of BIM, particularly from IFC-based product models. This paper describes our approach for querying construction-specific design conditions from an IFC-based model. The approach involves: (1) the formalization of construction-specific design conditions as an ontology of product features, (2) the automated generation of feature-based product models for a particular construction domain and function, and (3) a formal specification that supports user-driven queries of the feature-based model. This approach allows practitioners to answer a broad range of user-customizable queries in support of different construction management functions. It also transforms designer-focused IFC-based models into construction-focused, feature-based models.

Introduction

The design and construction community has shown increasing interest in adopting building information models (BIM) to support various aspects of the architectural, engineering, construction and facility management (AEC/FM) industry. The continuing development of the Industry Foundation Classes (IFC) and the richness of design information offered by these models are evident. However, BIM and IFC do not explicitly represent many of the *design conditions* that are important for construction. Moreover, there are tremendous challenges in getting construction-specific information out of BIM, particularly from IFC-based models, limiting the usability of these models for construction and other downstream processes. As a result, construction professionals spend significant amounts of time and effort browsing, analyzing and interpreting design information to identify these design conditions. This process is ad-hoc, inefficient, and inconsistent. There is a need for computer support to help practitioners query a BIM model to identify the design conditions that are important for a particular construction domain.

Many have recognized the various design conditions that affect different construction domains and functions. These include the horizontal and vertical layout of elements, spacing between elements, size, shape, type, clearances, tolerances, modularity, repetition, similarity, uniformity, and use of standard sizes (Thomas and Zavrski 1999; Fischer and Tatum 1997; Hanna and Sanvido 1990). Many design conditions re-occur frequently from project to project and are critical to a variety of downstream disciplines (e.g., construction and facility maintenance), domains (e.g., buildings and bridges), and functions (e.g., productivity analysis and method selection). Automated approaches to identify these design conditions have been limited: focusing on a narrow set of design conditions (e.g., Haymaker et al. 2004); requiring extensive user input (e.g., Nguyen and Oloufa 2002); querying only certain design conditions (e.g., Chen et al. 2005); or lacking user customizability (e.g., Fischer 1991). Current software applications (e.g., Solibri Model Checker™ and NavisWorks™) also provide limited support for practitioners to identify construction-specific design conditions from a given BIM or IFC model.

In this paper we describe an approach to query an IFC-based BIM model for a variety of design conditions. Our approach facilitates the automatic identification of construction-specific features from a given IFC-based model, browsing and navigating features, and formulating a variety of user defined queries. This process transforms designer-focused IFC-based models into construction-focused, feature-based models. This research contributes to sustainable construction and industry IT efforts, such as *buildingSmart,* by making BIM models more accessible to the construction user.

Motivation

This section describes a case study of the recently constructed 123,000 square foot Chemical & Biological Engineering (Chem-Bio) building at the University of British Columbia (Figure 1). In this case study, we identified a variety of design conditions that are explicit and implicit in the design, and that impact a variety of construction management functions (e.g., cost estimating, productivity analysis, and method selection) and building components (e.g., walls, columns, beams and slabs).

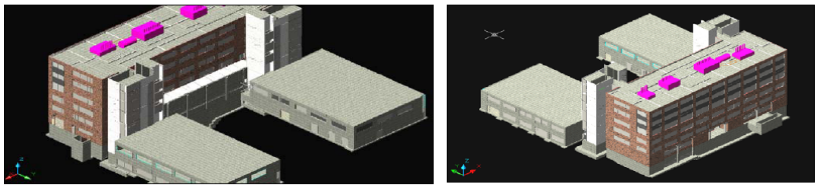


Figure 1: 3D model of the Chem-Bio building

A variety of design conditions impact the construction of walls. Figure 2 shows the configuration of walls on the fifth floor of the Chem-Bio building. Notice the variety and distribution of different wall *types* on this floor, which is not uncommon. Practitioners consider a variety of factors for characterizing walls. They associate *functional* (e.g., shear wall, partition wall), *material* (e.g., brick masonry wall), *spatial* (office partition), *location* (atrium wall assembly) attributes, and many other pieces of information to distinguish their types. Practitioners also distinguish walls based on their *properties* (e.g., height), *property values* (e.g., 2-hour fire-rating), and constituent *elements* or parts (e.g., metal studs). For example, wall types W1A and W1B are both masonry walls, and differ only in terms of the size of metal studs used; wall types P5A and P5B both are interior hollow concrete masonry wall partitions but the former is not fire-rated while the latter has 1-hour fire-rating.

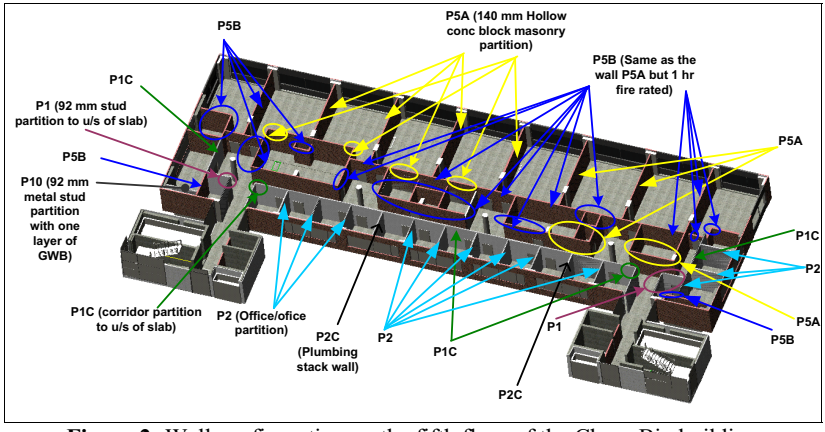


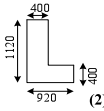
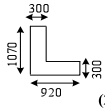
Figure 2: Wall configuration on the fifth floor of the Chem-Bio building

All of these design characteristics impact wall construction. The spatial distribution of different wall types impacts productivity because crews have to continually switch materials as they progress linearly through the floor. Different equipment is needed for different ranges of wall heights (e.g., use scaffolding for wall heights between 9 and 13 feet). Different productivity rates are assigned to different wall thicknesses (e.g., 8, 12 and 15 inch walls), ranges of wall heights (e.g., wall heights between 8 and 16 feet), and types of wall shapes (e.g., clipped or curved

walls). For example, consider the case of a brick veneer wall: RS Means states that if it is battered, 30% labor cost is added to the normal cost; if it is a curved wall, an extra 30% is added; and if the wall has corbels, an extra 75% labor cost is added (RS Means 2004). Understanding these design conditions, therefore, is essential to assess productivity, method selection, constructability, and ultimately construction cost.

Table 1 shows a summary of the different shapes, sizes and configuration of columns in each floor of the Chem-Bio building. There is remarkable *variation* in the location, orientation, and the size or shape of columns on a single floor and from floor to floor. For example, two columns A-4 and A-9 (column type '7') sized as 550x500 mm in the basement change to round columns (550 mm diameter) in the ground floor, and then take the size of 300x1100 mm in the remaining floors. The change in *shape*, *location, size* and *orientation* of columns introduces a number of other design conditions that prevent the use of the most economical forming methods, such as non-uniform spacing and column bay sizes, misalignment of columns, among others. Understanding these design conditions is difficult in current applications; the user must process them by hand. Our work makes this kind of processing far easier and results in more efficient understanding of the design.

Table 1: The distribution of columns on each floor of the Chem-Bio building

Column Type	Column Sizes in Floor						
	Basement	**1**	**2**	**3**	**4**	**5**	**6**
1	450x1200 **(4)**	400x1200 **(4)**	400x1200 **(4)**	400x1200 **(4)**	N/A	N/A	N/A
2	Do **(2)**	Do **(2)**	400x900 **(2)**	400x860 **(2)**	N/A	N/A	N/A
3	Do **(2)**	750 Φ **(2)**	400x1200 **(2)**	400x1200 **(2)**	N/A	N/A	N/A
4	350x2000 **(6)**	500 Φ **(12)**	500 Φ **(12)**	300x1500 **(6)**	300x1110 **(6)**	300x1110 **(6)**	300x1110 **(6)**
5	 **(2)**	Same as in the basement floor **(2)**	 **(2)**	Same as in the 2nd floor **(2)**	Same as in the 2nd floor **(2)**	Same as in the 2nd floor **(2)**	Same as in the 2nd floor **(2)**
6	300x1200 **(4)**	300x1200 **(4)**	300x1110 **(4)**	300x1110 **(4)**	300x1110 **(4)**	300x1110 **(4)**	300x1110 **(4)**
7	550x550 **(2)**	550 Φ **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**
8	750x750 **(2)**	750 Φ **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**
9	500x900 **(4)**	N/A	N/A	N/A	N/A	N/A	N/A
10	600x900 **(1)**	N/A	N/A	N/A	N/A	N/A	N/A
11	300x1100 **(2)**	300x1100 **(2)**	300x1100 **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**	300x1110 **(2)**
12	N/A	N/A	N/A	N/A	450x900 **(8)**	450x900 **(2)**	450x900 **(2)**
13	N/A	N/A	N/A	N/A	450x750 **(4)**	450x750 **(4)**	450x750 **(4)**
14	N/A	N/A	N/A	N/A	450x750 **(4)**	600 Φ **(4)**	600 Φ **(4)**
15	500x500 **(1)**	500x500 **(1)**	500x500 **(1)**	N/A	N/A	N/A	N/A
16	N/A	500x500 **(5)**	500x500 **(5)**	N/A	N/A	N/A	N/A
No. of columns	**(32)**	**(38)**	**(38)**	**(26)**	**(34)**	**(34)**	**(34)**
No. of sizes used	**9**	**8**	**6**	**5**	**4**	**5**	**5**

Apart from components and their properties, other design conditions, such as openings, penetrations, and other types of component intersections, also impact construction. Various aspects of these features are of interest to practitioners, such as the size, spacing and location of openings and penetrations, the relative dimension of intersecting components. These conditions create a number of construction requirements that practitioners must comply with. For example, pipe penetrations through fire-rated walls and slabs have to be fire stopped; all service penetrations

through P3 acoustic wall types and through block walls between labs have to be packed and caulked.

Construction practitioners look for the aforementioned design conditions (and others) in every building project because they are critical for assessing construction methods, productivity, constructability, costs, etc. They *filter* and *group* design conditions based on specific attributes, and *quantify* different types of quantitative information. For example, identifying all walls that are between 8 and 16 feet high; identifying interior stud walls that have duct penetrations; grouping walls with similar thicknesses; identifying the location of different column sizes used on a floor. These design conditions often need to be calculated or derived, such as identifying the total length and surface area of fire-rated and curved walls.

Although BIM models are becoming more available to practitioners, there is limited computer support for construction practitioners to represent their perspective explicitly in the design, and to automatically query a given design for the design conditions that are important for their domain and function. As such, they spend an enormous amount of time and effort manually analyzing and interpreting the design for each project. In the section that follows, we describe our vision for representing knowledge about construction-specific design conditions, and our approach for automatically querying these conditions from a given IFC-based model.

Research Approach

Figure 3 illustrates our overall research for querying a given IFC-based model. First, construction users define the features of interest for a particular domain based on the feature ontology. Second, the ontology is instantiated with data from a specific project to automatically create a Feature-based Model (FBM). Finally, the FBM is queried to help the user identify and understand the design conditions. The three major steps are described in detail below.

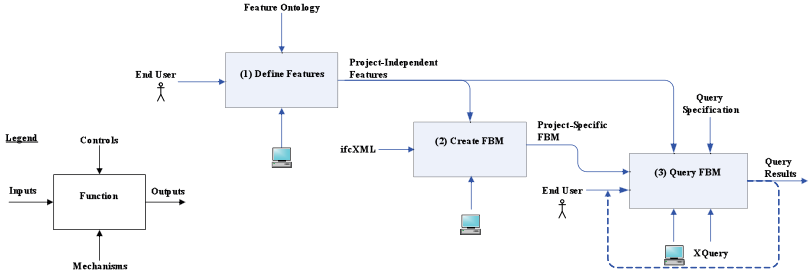


Figure 3: Our approach for querying an IFC-based BIM model

1. Define Features

We use *features* to represent construction-specific design conditions in a formal, general, and computer-interpretable way. Features have been used extensively in the manufacturing domain to refer to "a set of information related to a part's description" (Shah and Rogers 1988). Users define the features that are important for a particular domain based on the feature ontology we formalized. The user is generally an expert

in the domain and defines these features from a specific viewpoint and for a specific purpose, such as cost estimating. In our approach, the feature ontology provides a vocabulary for describing construction-specific design conditions. We modeled our feature ontology in Protégé, a free, open-source, ontology development platform. Nepal et al. (2008) have described the feature ontology in more detail. Essentially the feature ontology helps users to specify the design conditions they want the system to identify automatically and represent explicitly. For the Chem-Bio building project, this would include a variety of design conditions, such as wall curvature, shape, openings, and penetrations. In some cases, these features are explicit in an IFC model, such as openings, but in many cases, this information is not typically explicit and requires further analysis of the IFC data. The output of this process is a project-independent set of features that are important to a particular practitioner. These features are input once and represented generically so that they can be reused from project to project.

2. Create FBM

The Feature-based Model (FBM) is automatically created by the system which takes as input a feature ontology and a building design model in ifcXML format. The system instantiates feature instances and property values by directly extracting explicitly-defined components and by analyzing the geometry and topological relationships between objects in the IFC model to derive implicitly-defined features. This process, therefore, transforms the designer-focused IFC-based model into a construction-focused, feature-based model. The output of this process is the instantiated project-specific FBM tailored for a particular construction domain and function. It is this model that users can interactively browse, navigate and query in the system.

The user interface for browsing the FBM is presented in Figure 4. The left side shows a hierarchical view of the instantiated features which are organized by level and then by the hierarchy specified in the feature ontology. The user can navigate feature instances in the left panel. These features include building components, as well as other features defined by the user, such as openings and penetrations. The associated properties or relationships of a feature selected in the left panel are displayed in the right panel. Notice the explicit representation of wall curvature ('is_curved') and shape ('is_clipped'), which extends the property information typically represented by the IFC's. Also notice the explicit representation of all component intersections. These intersections are not always explicit in a given 3D model and resultant IFC export. Another useful navigational feature of the interface is the ability to select any feature presented in the right panel and have this feature's attributes displayed in the pop-up window as demonstrated in the inset of Figure 4. In this way, users can trace the relationships between features, such as related walls or ducts.

The flexibility and expressivity of the FBM browser is one of its key strengths. Not only does it promote a better understanding of the design features present in the given BIM model, but it also provides guidance to the user in the formulation of queries. The FBM browser enhances and complements existing technologies, such as IFC viewers, by providing additional support for navigating design features that are important to construction practitioners. Ideally, the FBM

browser would be an information visualization tool that would allow the user to view the design features both in data and graphical (not implemented yet) views.

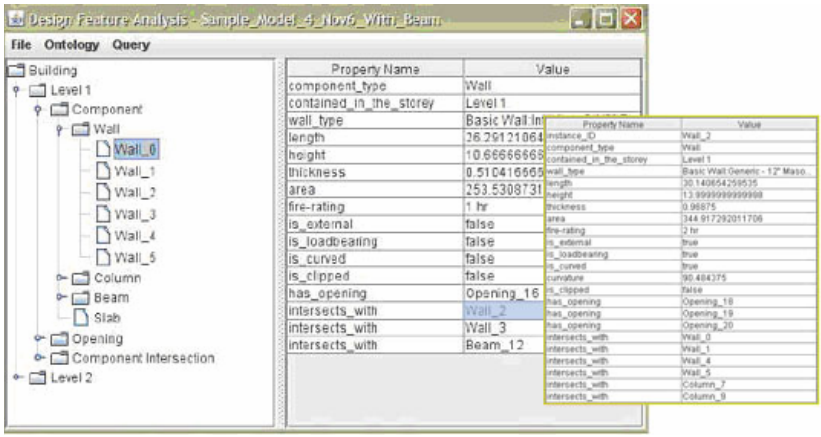
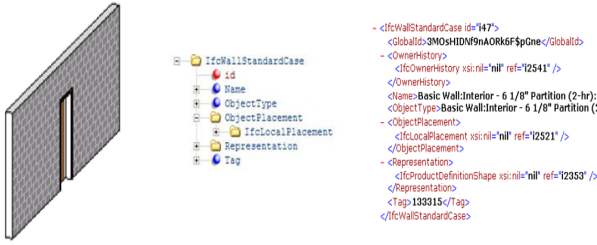


Figure 4: User interface for browsing construction-specific features in the FBM

The input data is in ifcXML format, an XML representation of IFC data. This format was chosen among four candidate standards which are supported by Revit (Microsoft Access, ifcXML, gbXML and DWF-content XML) as it offers the most comprehensive coverage of the relevant features – and hence the features represented in the feature ontology. As such, building design data must be converted into an ifcXML file. In our case, we exported the Revit 3D model to an IFC file using Revit's export mechanism and then the IFC file was converted to an ifcXML file, using a convertor based on the IFC2x2/ifcXML2x2 specifications. Figure 5 (a) to (c) shows the different representations of a 3D wall at each step in this process.



(a) 3D Model of a wall in Autodesk Revit

(b) ifc hierarchical representation of a wall in IFC Viewer

(c) ifcXML representation of a wall

Figure 5: A wall with the portion of corresponding IFC and ifcXML representations

While ifcXML is the best choice given the standards considered in this study due to its higher expressivity, the trade-off is a much more complex schema and

significantly larger file sizes that result. In particular, the properties of an element are often not directly attached to it as sub-elements or attributes (as is generally the case with highly-related XML data) but indirectly by references. This convoluted structure is demonstrated in Figure 5(c). The element "IfcWallStandardCase" has a very limited amount of information explicitly attached to it: only the name and the history of the object are directly represented; all other related design conditions must be determined by navigating a complex sequence of references. Nepal et al. (2008) have described these and other challenges of working with ifcXML data.

3. Query FBM

Once the FBM is generated, the user can formulate queries on the information in the FBM. The user interface for query formulation starts with the FBM window as shown in Figure 4. The user can choose to open a new model or load an existing model. The system will then automatically generate a FBM for the model in the back end. In addition to browsing or navigating the FBM, there are three other ways to query the model. The user can choose to create a new query, customize an existing query or, alternatively, run a previously defined query that was saved to the query library; this allows easy access to the user's commonly needed design features. In formulating a new query or customizing a saved query, the user can filter the design data by feature type, properties or relationships, and quantify and group the filtered data. Figure 6 demonstrates the creation of a query in which the component "walls" are filtered with the property 'height' between 8 and 16 ft. This filtered data is then aggregated by total length and grouped by height and the property "thickness". The results of this query are shown in the 'Results' panel. Users can also save the newly created or customized query to the query library for future reuse.

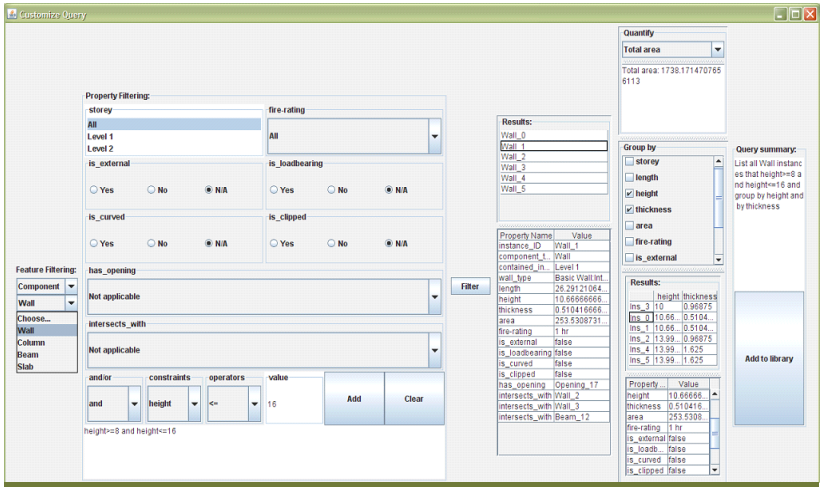


Figure 6: User Interface for formulating a query of wall components

The user interface and most of the functionality it provides was written in Java. A small subset of functions as well as the IFC converter was written in C++; these components are called by the Java program. The Java program translates the user-created or library queries into XQuery – the standard query language for XML and SQL's counterpart for XML data. Due to the complicated query paths, extracting features/properties from the original ifcXML is quite time consuming. The performance would be a major issue if the system queried the original ifcXML for each and every query posed by the user. To circumvent this problem, we created a simpler, more compact intermediate schema in XML to store information that is extracted from ifcXML. Since this intermediate XML represents an FBM, we call it fbmXML. Figure 7 illustrates a sample of fbmXML describing a wall instance where all of its properties are directly attached to it as sub-elements, rather than requiring the user to ferret out the information as in the ifcXML representation shown in Figure 5(c). When the user loads an IFC file into the system, the system automatically converts the file to ifcXML (as described above) and then to fbmXML. All user queries are performed on the fbmXML representation of the design data that is significantly less complicated and much faster than querying the original ifcXML.

```
−<model>
  −<feature type="Component" id="0" ifcid="i46" ifctitle="IfcWallStandardCase">
      <component_type>Wall</component_type>
      <contained_in_the_storey>Level 1</contained_in_the_storey>
      <wall_type>Basic Wall:Interior - 6 1/8" Partition (2-hr)</wall_type>
      <length>26.291210643103</length>
      <height>8</height>
      <thickness>0.510416666666667</thickness>
      <area>185.981488186518</area>
      <fire-rating>1 hr</fire-rating>
      <is_external>false</is_external>
      <is_loadbearing>false</is_loadbearing>
      <is_curved>false</is_curved>
      <is_clipped>false</is_clipped>
      <has_opening ref="13"/>
      <intersects_with ref="2"/>
      <intersects_with ref="3"/>
```

Figure 7: Portion of an fbmXML file generated to create the FBM

Conclusions

In this paper, we described our approach for querying design conditions from an IFC-based model. Our implementation analyzes the component geometry and topological relationships between components in a BIM model represented in ifcXML format to create a feature-based model tailored to a particular construction domain and function. It is this model that users can interactively browse, navigate and query in the system. This work demonstrates both the power and challenge of working with IFC-based BIM models. While the flexible nature of ifcXML provides a platform that can better express the domain knowledge encoded in the feature ontology, it also results in a much more complex schema which presents a number of challenges that have not yet been solved. It is this complexity that is responsible, in part, for the

difficulty in fully extracting the information expressed in the feature ontology from the input ifcXML files. This is particularly true for spatial information. The complex nature and large size of ifcXML data, in combination with the weakness of XQuery, leads to poor performance in the process of querying an ifcXML file to create the equivalent fbmXML file. The on-going work will focus on extending the breadth and depth of queries, scaling up the application, and enhancing the system performance and user interface.

References

Chen, P.-H., Cui, L., Wan, C., Yang, Q., Ting, S. K., and Tiong, R. L. K. (2005). "Implementation of IFC-based web server for collaborative building design between architects and structural engineers." Automation in Con., 14, 115-128.

Fischer, M. (1991). "Constructability input to preliminary design of reinforced concrete structures." Technical Report, Center for Integrated Facility Eng., Stanford University, Calif.

Fischer, M. and Tatum, C. B. (1997). "Characteristics of design-relevant constructability knowledge." J. Cons. Eng. and Mgmt, 123(3), 253-260.

Hanna, A. S., and Sanvido, V. E. (1990). "Interactive vertical formwork selection." Concrete Int. Design and Cons., 12(4), 26-32.

Haymaker, J., Kunz, J., Suter, B., and Fischer, M. (2004). "Perspectors: composable, reusable reasoning modules to construct an engineering view from other engineering views." Advanced Eng. Informatics, 18 (1), 49-67

Nepal, M. P., Staub-French, S., Zhang, J., Lawrence, M. and Pottinger, R. (2008). "Deriving construction features from an IFC model." Proc., CSCE 2008 Annual Congress, Quebec City, Canada, 11 pages.

Nguyen, T., and Oloufa, A. A. (2002). "Spatial information: classification and applications in building design." Computer-Aided Civil and Infrastructure Eng., 17, 246-255.

R.S. Means. (2004). "RSMeans building construction data." 62nd annual edition, R. S. Means Co., Inc, Kingston, MA.

Shah, J. J., and Rogers, M. T. (1988). "Functional requirements and conceptual design of the feature-based modeling system." Computer-Aided Eng. J., 9-15.

Thomas, H. R., and Zavrski, I. (1999). "Construction baseline productivity: theory and practice." J. Cons. Eng. and Mgmt., 125(5), 295-303.

ADVANCED QUALITY CONTROL METHODS FOR ROAD PAVING CONSTRUCTION BY UTILIZING SENSORY DEVICES

Yong K. Cho[1], Thaddaeus Bode[2], and Yong-Rak Kim[3]

[1]Assistant Professor (corresponding author), Construction Engineering and Management Division, Charles Durham School of Architectural Engineering and Construction, College of Engineering, University of Nebraska-Lincoln, 1110 S. 67th St. Peter Kiewit Institute (PKI) 104C, Omaha, NE 69182; PH(402)554-3277;FAX (402)554- 3850; email: ycho2@unl.edu
[2]Graduate Research Assistant; Construction Engineering and Management Division, Charles Durham School of Architectural Engineering and Construction, College of Engineering, University of Nebraska-Lincoln, 1110 S. 67th St. Peter Kiewit Institute (PKI) 118A, Omaha, NE 69182; PH(402)554-3277;FAX (402)554- 3850; email: tbode@mail.unomaha.edu
[3]Assistant Professor, W351 Nebraska Hall, Department of Civil Engineering, University of Nebraska-Lincoln,Lincoln NE 68588-053, PH(402)472-1727,FAX (402) 472-89341, email: ykim3@unl.edu

ABSTRACT

This study is currently being conducted to produce a more realistic picture of how variables are created and dealt with from hot mix asphalt (HMA) paving construction in the State of Nebraska. Several paving projects across Nebraska have been visited where sensory devices are being used to test how density, moisture content within the asphalt, material surface temperature, internal temperature, wind speed, haul time, and equipment type, contribute to temperature differentials. Areas of high temperature differentials are identified using an infrared camera, and confirmed with a penetrating thermometer. A non-nuclear density device is also used to record how the lower temperature asphalt density compares to the more consistent hot area. After all variables are recorded, the location is recorded via a handheld global positioning system(GPS) to aid in locating points of interest in future site revisits to verify the research findings. Initial data collection suggests that most variables having the largest impact on quality can be controlled with adequate planning, and proper lay down procedures.

1 INTRODUCTION

Generally, hot-mix asphalt pavements are designed to last 15 or more years. However, many have been failing early due to cracks, potholes, raveling and other problems, thus not servicing up to its original design expectations (Phillips, 2008). About 90% of the highways and roads in the U.S. are paved by hot mix asphalt (HMA). In 1988, Transportation Research Board (TRB) launched $150 million

Strategic Highway Research Program to reduce premature failure of roads resulting from poor construction methods. In 1993, SuperPave® (SUperior PERforming Asphalt PAVEments) was developed from the TRB program as a set of optimized mix designs and analysis methods and standards. Even after adoption of the SuperPave®, premature failure of hot-mix asphalt (HMA) pavement still persisted (Phillips et al. 2003). The expected life of a segregated pavement could be less than half of its expected 15 years. The various causes of these premature failures are numerous and lead to the wasting of state allocated roadway funds.

In a series of thermographic research studies performed by the University of Washington and Clemson University (Willoughby, 2003; Amirkhanian, 2006), it was found that excessive thermal differentials during pavement construction cause density differentials to develop, which leads to lower durability of pavements than the designed durability. The cause was the surface and boundary cooling of hot-mix asphalt during transportation from a batch plant to a construction site and it contributes to a problem called 'cyclic segregation'. Cyclic segregation is a cyclic occurrence of low-density pavement areas. During the transport of HMA, several areas of the material are prone to more rapid cooling. When the material is unloaded, it is often not remixed thoroughly and portions are therefore stiffer and more resistant to compaction. These areas become relatively porous, less dense, and less resistant to wear and degradation from traffic and the weather environment.

From a further study by the University of Washington, it has been detailed that the cooler areas of hot-mix with a temperature differential greater than 25°F exhibited significantly lower densities after compaction. It was also found that asphalt that is cooler than 175°F is relatively stiff, and resists compaction, which results in a lower density than hotter areas after compaction, and is therefore prone to premature failure (Willoughby, 2003).

One of major conclusions formulated by previous research projects was that some type of remixing must be performed immediately prior to unloading the mix to achieve a uniform temperature. The most common remixing method is the use of a material transfer vehicle (MTV). An MTV easily breaks up the large chunks of cooler material and remixes all of HMA, resulting in a smooth mix with a consistent temperature profile (Willoughby, 2003; Gilbert, 2005). However, a careful and detailed cost-benefit analysis should be considered before involving the added cost of incorporating an MTV as a solution. In addition, there has been no proven test results revealed thus far that all MTVs will eliminate temperature segregation to a desirable level; while it is considered that most of the MTVs improve overall mat quality. For these reasons, Nebraska has not regulated the use of MTV for paving construction yet. Thus**, the main goal** of this research is to identify problem areas causing temperature segregation during pavement construction, and provide recommendations to minimize or eliminate the problems from the construction processes including HMA truck delivery process, dumping and rolling practices, contractor's workmanship, and environmental working conditions rather than simply adopting a costly MTV. This

paper presents how to utilize various sensor devices to control HMA pavement quality during paving construction.

2 RESEARCH OBJECTIVES AND APPROACHES

The main objective is to identify and measure variables which have a significant effect on HMA mix temperature segregation during roadway construction in the State of Nebraska using various portable non-destructive testing sensor devices. The approaches to accomplish the objective are as follows: (1) evaluate the possible reasons for the occurrence of thermal differentials during HMA construction process, (2) develop a practical and economical method of preventing and managing HMA thermal differentials, (3) validate the effectiveness of infrared thermal images as a test modality for assessing thermal differentials in HMA, and (4) validate the effectiveness of other sensor devices as a test modality for assessing HMA densities.

This research requires very close collaborations with contractors because the results will help the contractors mitigate the HMA temperature segregation and consistently obtain a high density (%) of random samples which need to be reported to the Nebraska Department of Road (NDOR). It is also expected that the research previously performed by other states with suitable information brings significant benefits to this research. Due to different environments, construction methods, and regulations in different states, however, the outcome of applying the technology might vary. Also, the long-term implications are worth further investigation to confirm the benefits and to find a means of practical application. For example, relating thermographic data with exact location data would be worth implementing to strengthen the findings by revisiting the site for refinement.

3 SENSOR DEVICES USED IN THIS STUDY

In this study, an infrared camera, a non-nuclear density gauge, a nuclear density gauge, a windmeter, and a handheld GPS are mainly used to measure various conditions at sites. More details about sensor devices are as follows.

3.1 Verification and calibration of infrared thermal camera

When thermal image data on the surface of HMA pavement is collected by an infrared camera, surface and internal temperatures on the same spots are measured by using an asphalt thermometer to compare two different data sets. This is done initially to ensure the infrared camera used in the study provides an accurate representation of temperature differentials. The accuracy of infrared cameras in general has already been proven in HMA applications from the University of Washington study; noting that both temperature probes and infrared cameras are adequate tools for proving temperature differentials (TD) (Willoughby, 2001). Figure 1 shows an infrared camera used in this research. Figure 2 shows infrared images taken from paving sites.



Figure 1. Infrared Camera (Infrared Solutions Inc.)

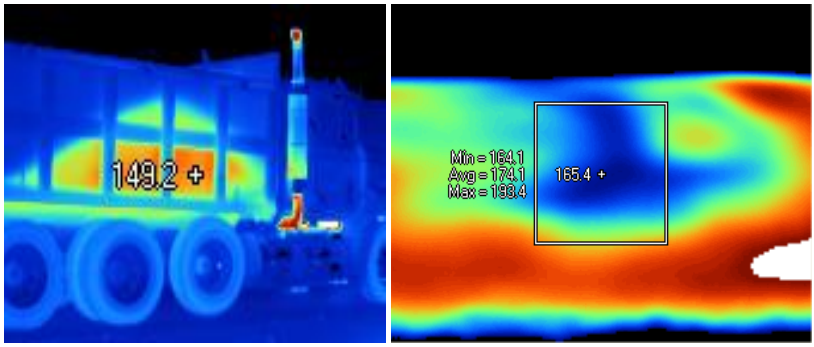


Figure 2. Heat loss from a truck (left) and temperature differ from a HMA mat (right)

3.2 Verification and calibration of non-nuclear density gauge

For the past several decades, density of freshly laid HMA mats has been measured by contractors using nuclear density gauges. However, use of these devices requires the user to maintain an inordinate amount of records on the use of equipment. These requirements include calibration and recalibration records, certification records of the operators, recodes of radiation badges, and periodic testing of the operator's badges for radiation exposure. In addition, there is always the concern about possible accidents with the gauges that might expose the radiation source to the operators or other bystanders (Schmitt, 2006; Sargand, 2005). Due to these issues and concerns associated with using the nuclear gauges, this study adopted a non-nuclear density measurement method for paving quality control. After thorough literature reviews, this study chose the Pavement Quality Indicator ™(PQI) 301 developed by TransTech Systems *Inc*.(TransTech, 2008). The validation and effectiveness of PQI has been tested in several states with positive results including Texas (Sebesta et al. 2003), Kentucky (Allen et al. 2003), New York (Rondinaro, 2003), Utah (Romero, 2002), Ohio (Sargand, 2005), and Nebraska (Hilderbrand, 2008). The PQI uses electrical waves to measure dielectric constant using a toroidal electrical sensing field established by the sensing plate. The electronics in the PQI convert the field signals into material density. Once calibrated, direct density readings can be consistently obtained (TransTech, 2008). In this study, the PQI is calibrated by comparing PQI's density measurements with the ones of core samples (a.k.a, Gmb) at each site. A Maximum Theoretical Density (MTD) value (a.k.a., RICE or Gmm) is required for this process which can be provided from the asphalt mix designer. Then, the offset is adjusted after PQI readings have been taken (Figure 3) and cores have been obtained from those reading areas (Figure 4). As an alternative method, a calibrated nuclear gauge is used to offset the PQI's measurement as well. Especially when a paving progress is on the fast track to quickly open the road to public traffic, a nuclear density gauge is used rather than core samples. Using a nuclear gauge to calibrate the PQI has been validated by the Wisconsin DOT (Schmitt, 2006).



Figure 3. PQI Density measurement



Figure 4. Core sampling for calibration

3.3 Field Data Acquisition

During the paving season in 2007-2008, the research team has visited ten HMA paving sites to collect data. The data contains variables which are considered to cause thermal differentials within HMA pavement. The targeted variables at sites include: location, time of the day, air temperature, mat temperature, ground temperature, humidity, wind speed, equipment type (paver, compactor), mix type, haul time, and contractor's workmanship, thermographic image data, and HMA density data after compaction. A paving specialist from the NDOR joined and assisted the research team to investigate field construction practices in the state.

3.4 Positioning the spots on the pavement where density is measured

To verify the analyzed data compared to the real-world results, this research plans to revisit the previously investigated sites to collect the visual images to see any premature failures and density changes after public use of the investigated roads. This activity requires exact spot information on the pavement where suspicious density and thermal images are measured. As an economical method, this research uses specially designed pavement marking nails similar to surveyor's mark (see Figure 5). Approximate location for each mark within about 10ft diameter is measured by a handheld GPS shown in Figure 6.



Figure 5. Surveyor's marking nail on pavement

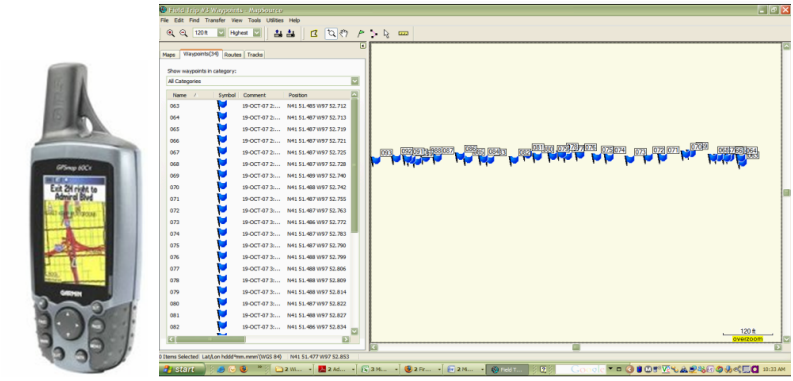


Figure 6. Handheld Garmin™ GPS(left) and data location map (right)

4 DATA ANALYSIS

As an on-going research, this study plans to collect the data until spring 2009. Most of the collected data at the present time has been analyzed using the Least Square Method (LSM) to find any correlations between thermal differential and variables. In this analysis, correlations between thermal differential and each of variables are studied rather than using the multi-regression analysis to identify the key variables which have significant impacts on thermal differential problems.

4.1 Temperature Differential (TD) with respect to Density

The collected data shows that there is no significant relationship between temperature differential (TD) and density (r^2=0.08) when all data sets are considered. Here, r^2 is called the coefficient of determination and it tells how well the sample regression line fits the data (Gujarati, 1995). The coefficient of determination ranges between 0 and 1.

As shown in Figure 7, it is noticed that most of the data points whose correlations are not explained well are scattered below the regression line. Thus, the data sets are regrouped as TD from 1ºF or higher through 30ºF or higher to see the relationship (r^2) between TD and density as shown in Table 1. Their relationship is calculated as r^2 = 0.9624 (Figure 8). It explains that the mat with a higher temperature differential has higher probability to get lower density. For example, based on the data collected so far, if temperature differential is over 10°F, there is about 50% of probability that the cold spot on the mat would have lower density than the surrounded area.

From Figure 7, it is noticed that two extreme data points with 120°F and 90°F temperature differential respectively are included in this analysis. They are not statistically determined to be outliers, but treated as valid measurement because they are explained well from the analysis shown in Figure 8. Also more data with high

temperature differential is being collected for further analysis with the two data. If an observation is statistically determined to be an outlier, it is suggested that an explanation should be provided for this outlier before its exclusion from further analysis. If an explanation cannot be found, then the observation should be treated as an extreme but valid measurement and it should be in further analysis (EPA, 1992).

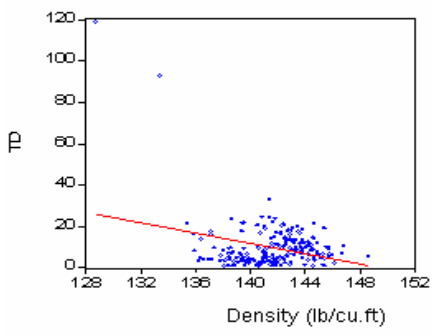


Figure 7. TD vs. density (all data)

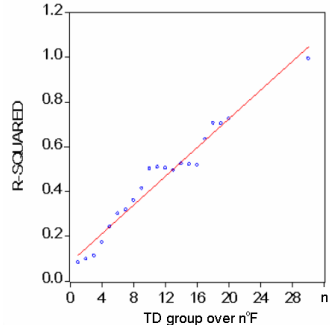


Figure 8. r^2 vs. group of TD over n °F

Table 1. R^2 for TD groups based on

TD group	No. of data	R^2	TD group	No. of data	R^2
1 ºF over	208	0.084	12 ºF over	59	0.505
2 ºF over	190	0.099	13 ºF over	55	0.496
3 ºF over	172	0.144	14 ºF over	43	0.526
4 ºF over	153	0.174	15 ºF over	38	0.522
5 ºF over	135	0.245	16 ºF over	37	0.52
6 ºF over	120	0.303	17 ºF over	30	0.634
7 ºF over	107	0.032	18 ºF over	24	0.706
8 ºF over	99	0.362	19 ºF over	20	0.705
9 ºF over	89	0.415	20 ºF over	18	0.726
10 ºF over	77	0.503	30 ºF over	3	0.995
11 ºF over	67	0.50			

4.2 Temperature Differential vs. Equipment Types

There are two types of material feeding process from a delivery truck to a paver in Nebraska. Either trucks directly dump delivered HMA to the hopper of paver (Figure 9) or when the trucks lay a windrow of HMA, a pickup machine scoops up the HMA from the windrow and deposited it in the hopper of a paving machine as it was laying a new surface (Figure 10). Unlike a material transfer vehicle (MTV) such as RoadTec Inc.'s Shuttle Buggy MTV, the pick-up machine does not have special remixing auger or chute.



Figure 9. Direct dump between truck and paver



Figure 10. Pick-up machine with Paver

The Figure 11 shows the temperature differential variation for each material feeding process. When a pick-up machine is used between a truck and a paver, the completed mat shows more consistent temperature (standard deviation=3.45°F) than when a truck directly dumps HMA material to a paver (standard deviation=13.06°F). It means a pickup machine is a very effective solution to reduce temperature differential of delivered HMA without using an expensive MTV.

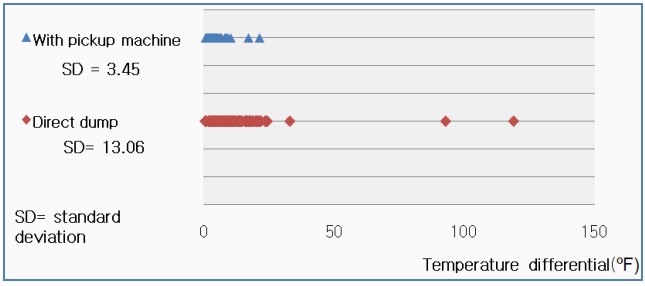


Figure 11. Temperature Differential based on feeding types

4.3 Temperature Differential with respect to other variables

Other variables have been investigated including truck haul time, wind, air temperature, density differential between hot and cold spots in measured area, and moisture in the mat. As an on-going project, not enough data has been collected to explain TD with these variables. For example, truck haul time measured from 5 minutes to 45 minutes does not show significant impact on TD (r^2=0.01). Also, TD with respect to haul time is not well explained when a pickup machine is used. For example, a long truck hauling time still gives a low temperature differential when a pickup machine is used.

4.4 Workmanship

Workmanship is also an important factor which significantly affects the quality of HMA pavement. This research plans to observe the construction process to find preventable defects from contractor's workmanship such as truck bed insulation and top-cover conditions, HMA loading method to a truck from a batch plant, length of break time, crew shifting time, paver wings' dumping time, amount of material in paver hopper while waiting for truck delivery, types of compactor, and path and timing of compaction. Finally, recommendations to improve contractor's current workmanship will be made.

5 CONCLUSIONS AND RESEARCH IMPACTS

This paper introduces the newly developed paving quality control and evaluation method using portable sensor devices including an affordable infrared camera, non-destructive density measurement devices, wind meter, and GPS. The current data analysis results show that the mat with higher temperature differentials has higher probability of having a lower density. Also, this study recommends a pickup machine to reduce temperature differential if a MTV is not affordable.

The research expects to contribute on major cost savings through improvement in quality of HMA pavements, more consistent physical characteristics, a longer service life, lower maintenance costs, and increased safety to the traveling public. This study also provides a foundation of geographical pavement management database system which can be further implemented to the state road construction and maintenance geographical information system (GIS).

ACKNOWLEDGEMENT

This article is based on the research funded by the Nebraska Department of Road (NDOR) (Grant no. MPM-11)). The authors gratefully acknowledge their financial support and encouragement throughout this study.

REFERENCES

Allen, D.L, D.B. Schultz, and D.A. Willett (2003), "Evaluation of Non-Nuclear Density Gauges," Report No. KTC 03-24/FR-115-01-1F, Kentucky Transportation Center, Lexington KY, August 2003

Amirkhanian, Serji N., Bradley J. Putman, Bradley J. (2006). " Laboratory and Field Investigation of Temperature Differential in HMA Mixtures Using an Infrared Camera." Clemson University. Report No. FHWA-SC-06-06. Clemson, SC.

Environmental Protection Agency (1992)."*Statistical Training Course for Ground-Water Monitoring Data Analysis*," EPA/530-R-93-003, Office of Solid Waste, Washington, DC

Gilbert, Kim. (2005). "Thermal Segregation." Colorado Department of Transportation Research. Report No. CODT-DTD-R-2005-16.

Gujarati, D. (1995). Basic Econometrics- 3rd Edition, McGraw-Hill Press.

Hilderbrand, S (2009). "Pavement Quality Indicator Test," Nebraska Department of Road (NDOR) Project: F-385-3 (1009), <http://www.transtechsys.com>(August 29,2008).

Philips, L. (2008). "Infreared thermography Revolutionizes Asphalt Paving-Significant Cost Saving for States and Municipalities," FLIR in Focus, Cost Justification Series

Rondinaro. J., (2003). "Non-nuclear density gauge data collection for Hot Mix Asphalt," Materials Procedure No.: NY 03-001, New York State of Transportation, Materials Bureau, Alabany, NY.

Sargand, M. Shad. (2005). "Non-Nuclear Density Gauge Comparative Study." Ohio Research Institute for Transportation and the Environment. Report No. FHWA/OH-2005

Schmitt, Robert. (2006). "Non-Nuclear Density Testing Devices and Systems to Evaluate In Place Asphalt Pavement Density." Wisconsin Highway Research Program. Report No. 0092-05-10

Sebesta, S., M., Zeig, and T. Scullion (2003). "Evaluation of Non-Nuclear Density Gauges for HMAC: Year 1 Report." Texas Transportation Institute, Report No. 0-4577-1, College Station, TX, October 2003.

TransTech Systems Inc. (2009). Pavement Quality Indicator (PQI). < http://www.transtechsys.com> (Augutst 29, 2008).

Willoughby, Kim. (August 2003) "Construction-Related Variability in Mat Density Due to Temperature Differentials." Washington State Department of Transportation

EMBODIED ENERGY OF CDW RECYCLING AND TECHNICAL METABOLISM DUE TO REGIONAL DIFFERENCES AND BUILDING DESIGNS

Christopher Hermreck[1] and Wai K. (Oswald) Chong[2]

[1]J.E. Dunn Construction Inc., Phoenix, Arizona, U.S.A.
[2]University of Kansas, Dept. of Civil Engineering, Lawrence, Kansas, U.S.A

Abstract
Energy and resource efficiencies are both critical to achieve building design and construction sustainability. Embodied energy measures the energy needed to produce, install and maintain materials while technical metabolism enhances building design recyclability. Although the concepts of embodied energy and technical metabolism have been around for many years now, the measurement systems for embodied energy and recyclability are still unreliable. Four projects were selected and the energy use the recycled materials from these projects were thoroughly examined. Past researches were also investigated. The study found that the embodied energy and recyclability were affected by several critical factors, such as, distances between project site and the locations of recycling facilities, regional variables and conditions, social preferences, and design complexities. The study also concluded several critical imperfections in the existing sustainability tools, such as the calculation of embodied energy, and the implementation of technical metabolism. The authors propose a framework to capture accurate information on embodied energy and resource efficiency to better reflect the "true" sustainability and greenness of building designs and construction. However, the authors also acknowledge that more works need to be done in this area to allow engineers better understand and acknowledge the real energy and resource consumptions of their designs.

Introduction

Our social and environmental problems cannot easily be solved until we know the extensiveness of the problems by measuring them. The goal of sustainability is to meet the needs of the current generation without compromising the ability of future generations to meet their needs (WCED, 1986). "Human footprint," "carbon footprint," "energy efficiency," and "cradle to cradle" are some of the commonly-used terms to reflect the compromises between current and future generations.

Beyond that simple definition, it is very difficult to define sustainability and determine what practices would compromise the living standard of current and future generations, since the scope and scale of sustainability is driven by society and community (Ofori, 1998). Level of income, regional climate, geographical location, cultures, and political environment are some of the variables that create the gaps of sustainability needs between different countries. A third world country has different sustainability needs from a developed country, while the needs of a less urbanized area are different from a rural area. Because the developing and third world economies consume only a fraction of materials as compared to the developed world, increasing energy and resource efficiency and improving material life cycle may not appear to these economies as sustainable as it does to the developed world.

Implementing sustainability in building design and construction has reduced the impact of building on the environment (Horvath and Hendrickson, 2000). Alternative studies found that current "sustainable" procurement processes could regenerate more waste, result in changes, cause delays, and instigate overproduction if not implemented properly during construction (Lapinski et al, 2006). Inefficiency and waste in sustainable construction can be linked to the limited understanding of project stakeholders, and the supply chain networks that encompass construction projects. Research has also highlighted that many contractors have found that requiring workers to salvage materials or to minimize wastage compromises workers' productivity, while vigorous attempts to protect the relatively inexpensive materials can increase construction costs significantly (Chong, 2008). Sustainable building projects require increased collaboration, innovative and complex design analysis, detailed material and process selection far ahead of the project delivery phase (Lapinski et al, 2006). This is a problem because often times this level of definition is not available during the early development phases (Graedel,1998).

Greenwashing is often used by companies to expand their consumers' base by asserting their claims to something more morally and socially responsible even when their products may not actually be. Several scientists have developed theories and concepts to produce cleaner coal by capturing these environmental polluting by-products (Edwards and Chapman 2005, O'Neill, 2007, and Wood, 2007). But why is coal allowed to label itself "clean" even when the concept of clean coal exists only in theory? In fact, some stakeholders continuing to doubt the practicality of green practices.

Differences in the maturity of recycling markets and facilities, availability of education and information, presence of legislatures, and the comprehensiveness of recycling supply chain cause the recycling rate gap between the cities in the Midwest and in both East and West Coasts (Warren et al, 2007). There are few questions that have not yet been effectively answered: How "regional" is sustainability? Can a green practice be sustainability in one location but not in another? If this is true, how do we know?

Research Objectives, Scopes and Case Studies

This paper is to present some preliminary results from an on-going research project at the University of Kansas. This paper will discuss: (1) the energy use and technical metabolism of recycled Construction and Demolition Wastes (CDW); (2)

the sustainability of recycling and the use of highly renewable materials; and (3) the hindrances towards design recyclability. The four projects selected in this paper will be limited to two geographical locations, two projects in the Midwest and two projects in the West Coast.

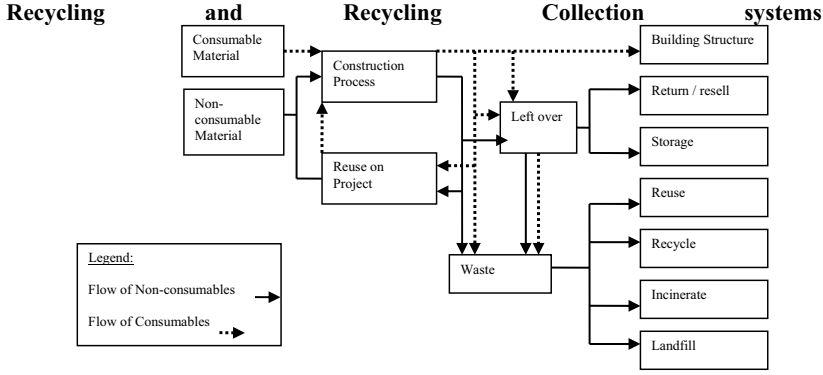


Figure 1: Generic flow pattern of Construction Material on site (Gavilan et al, 1994)

The below figure suggests, there is a pattern on how materials flow in a construction process. The main goal of eco-efficiency is to eliminate the last two processes of wastes and left-over from the construction activities. The concept of technical metabolism goes further by minimizing recycling activities whenever possible.

Eco-Efficiency and Technical Metabolism

The features of eco-efficiency include: 1) Material and energy intensity reduction of goods and services; 2) Reduced dispersion of toxic materials; 3) Recyclability; 4) Use of renewable resources; 5) Greater durability; and 6) Increase service intensity of goods and services (WBCSD, 2000). Technical metabolism is a concept that duplicates the biological metabolism. The biological metabolism is made up of natural processes that circulate the pool of materials or nutrients that support life on Earth. The technical metabolism, designed to mirror natural nutrient cycles, is a closed loop system in which valuable, high-tech synthetics and mineral resources circulate in an endless cycle of production, recovery and reuse. In technical metabolism, materials or products will be treated as nutrients and the nutrients will go back into the system to feed the manufacturing process of other products in the concept of technical metabolism. Each component within a product needs to be separated by a system so that it can be reused and upcycled. On the other hand, the product can be designed in such a way that it can be reused with minimal reprocessing. For example, an entire door can be reused with minimal reprocessing. During the design of a product, designers need to reduce the complexity of the recycling process of the product and determine appropriate use after the product end-of-life. The concept calls for the change of the design process in order to make

recycling easier, reduce the commingling of different materials within a product, to reduce the types of materials used in a product, and to better understand what should be the next use of the disposed products

Preliminary Data Analyses

Data are collected from over four projects (two in the Midwest and two on the west coast). These projects are located on the metropolitan areas, and are LEED certified and obtained LEED credits for recycling and the use of highly renewable materials. The projects located in the Midwest are labeled MW 1 and MW 2, and the projects in the West Coasts are labeled WC 1 and WC 2.

Recycled CDW Traveling Distances and Energy Use

a. MW 1 required additional 1,788 liters of diesel per ton to recycle the CDW: (1) 98 liters of diesel per metric ton were wasted due to poor recycling management (wastes rejected at the recycling centers and have to sent to landfills); (2) 273 liters of diesel per metric ton were needed to send all the wastes immediately to landfills; and (3) over 3,500 liters of diesel per ton needed to recycle internationally versus over 1,200 liters of diesel used per ton needed to recycle nationally.

b. MW 2 required additional 1,574 liters of diesel per ton to recycle the CDW: (1) 105.5 liters of diesel per metric ton were wasted due to poor recycling management; (2) 106.4 liters of diesel per metric ton needed to send all the wastes immediately to landfills; and (3) 3,345 liters of diesel per ton needed to recycle internationally versus 502 liters of diesel used per ton needed to recycle nationally.

c. WC 1 required over 900 liters of diesel per ton to recycle the CDW: (1) 143 liters of diesel per metric ton were wasted due to poor recycling management; (2) 373 liters of diesel per metric ton were needed to send all the wastes immediately to landfills; and (3) 2,327 liters of diesel per ton needed to recycle internationally versus 398 liters of diesel used per ton needed to recycle nationally.

d. WC 2 required slightly over 372 liters of diesel per ton to recycle the CDW: (1) 377 liters of diesel per metric ton were wasted due to poor recycling management; (2) 451 liters of diesel per metric ton were needed to send all the wastes immediately to landfills; and (3) 1,438 liters of diesel per ton needed to recycle internationally versus 245 liters of diesel used per ton needed to recycle nationally.

Energy Use for Sorting and Treatment

The recycling facilities and transfer centers adopt different practices and approaches for recycling, handling, treatment, and sorting techniques and the energy used for sorting and treatment depends heavily on their pratices and approaches. For example, one recycler uses a crasher to crash and haul the recycled wastes, while another uses a small truck to haul instead of using the crasher. Recyclers on the coast are more reliant on manual labors while the recyclers in the Midwest rely heavily on heavy equipments. The study found that the energy used by the equipments is insignificant compared with the energy needed to transport the CDW. For example, a crasher or backhoe uses a full tank of diesel (between 20 and 120 gallon fuel tank) between 1.5 and 7 days, depending on the weight of load, type of work, operation efficiency, working hours, productivity, and operation effectiveness. Managers from

the recycling facilities and transfer centers highlighted that their crasher or backhoe uses about 25-30 gallons or 94.64-113.56 liters of diesel for two full 8-hour day work, handling mainly heavy equipment. Each machine can handle about 4-7 tons of CDW during those periods of time, though the actual weight varies as the types of CDW vary. Data analysis suggested that about 100 liters of diesel could handle 5 tons of CDW. Thus, it is safe to assume that so each ton needs between 10 and 20 liters of diesel for handling, 5 and 15 liters of diesel for sorting and treatment.

Demand and Supply of Recycled CDW

The supply and demand of recycled construction materials is more inconsistent compared to the supply and demand of new construction materials. The supply of recycled construction materials depends on the supply of CDW from demolition and renovation projects, the locations which the materials are extracted, and the presence of transportation to deliver those materials to another site. In some cases, the supply of recycled material is also affected by the quality from the supply source

The demand for the reused/recycled materials does not match the supply of the materials for WC1. Even though WC 1 diverted 96% of its CDW from the landfills initially, the diverted materials still found their way to the landfills after Habitat for Humanity could not find buyers for them. More energy was required to divert the materials to a recycling facility before they were shipped back to the landfills. In MW 1, there was leakage in the accounting system as more energy was needed to divert wastes to the recycling facilities that were sometimes located more than 200 km away. In both MW 1 and MW 2, there were limited number of recycling facilities that could handle construction waste, and many site personnel did not have sufficient knowledge to reuse the waste. The cities were thus unable to "metabolize" these wastes (Chong, 2008).

Over 35% of the recycled CDW from WC 1 and WC 2 had to send to overseas for recycling, while less than 20% could be reused and 45% were recycled locally. 27% of the recycled CDW from MW 1 and 52% from MW 2 had to be sent to overseas for recycling. These clearly indicate that: (1) there are insufficient demands for the recycled CDW; (2) the recycling capacities in most regions in the United States are still limited; and (3) the energy footprint of transportation CDW is still significant.

MW 1 diverted 194 tons or 4,217 m3 of CDW (or about 78%), but only managed to recycle 64% of the CDW. MW 2 diverted 372 tons or 7,665 m3 of CDW (71%), but managed to recycle 67%, WC 1 diverted 133 tons or 4,134 m3 (92%) but only recycled 69%, and WC 2 diverted 147 tons or 3,449 m3 (98%) but only recycled 64%. The amount of recycled CDW (and not diverted CDW) becomes the supply of recycled materials that replaces new materials. The supply of recycled CDW is extremely inconsistent even among the projects that require high amount of

The study shows that design recyclability depends on: (1) the economical and feasible use for every CDW; (2) the reduction of the environmental footprints from the recycling process (mainly the transportation energy as indicated above); (3) the regional capacities of reuse and recycling; and (4) the regional and global ability to generate sufficient demand for and supply of CDWs.

Data Analyses

Many studies and research can easily claim that reuse and recycling of CDW will reduce the demand for new raw materials, and landfills (quote). However, the claim that recycling CDW actually reduces energy consumption is a difficult one to assert, as indicated in the earlier discussion. There are contrasting reports highlighting both the benefits and drawbacks of recycling. Eads (2003) mentioned two contrasting examples of international municipal solid-waste (MSW) recycling ideologies. Japanese Government in 2002 began implementing "*The Basic Plan for Establishing a Recycling-Based Society*" and claimed huge benefits, while the Swedish Finance Department in 1999 published a report titled "*Recycling: Not worth the effort*" that clearly indicated recycling is wasting energy and efforts, and the disadvantages far surpass the benefits. Japanese manufacturing and business culture has been driven by the lack of raw materials and resources, while Sweden has a lower population density. Are we able to model these benefits at the design stage so that designers can maximize the benefits of recycling?

Regional Capabilities and Energy Use of CDW Recycling

The analyses clearly indicate that the distances between project site and the locations of recycling facilities and landfills, regional recycling capacities, market conditions for CDW, social preferences, and design complexities drive the rate of recycling, and the energy use to recycle. The study also found that there are too many assumptions embedded in the calculation of embodied energy, and the implementation of technical metabolism. The authors propose a framework to capture accurate information on embodied energy and resource efficiency to better reflect the "true" sustainability and greenness of building designs and construction.

The CDW diversion rate and the real recycling rates are lower for MW1 and MW2, compared to WC1 and WC2. There are more governmental supports and market interventions for recycling on the coastal cities than in the Midwest, and thus recycling businesses tend to be more profitable. The profitable situation has also allowed the businesses to develop more competitive approach to recycle CDW, such as the capability to recycle commingled wastes. The distances between MW1 and MW2 to a recycling facility is much further than to a landfill. In some cases, the distance to a landfill facility can be as far as 1,800 km. Transporting CDW to such a long distance will leave behind a huge environmental footprint. The average distances between recycling facilities and WC1 and WC2 are 300 km and 278 km, while the average distances of MW1 and MW2 are 900 km and 1,025 km. The differences in the embodied energy to recycle are too large to be ignored, and relying on standardized embodied energy does not yield accurate result. In fact, the benefits of recycling can be overstated, as in the case of both MW1 and MW2 projects. This result confirms the analysis in Warren et al (2007) why a recyclable design from New York City may not be recyclable in Kansas City.

The study further indicates the level of digestability of designs differ between regions. The digestability of a design (i.e. the ability of society to accept recycled CDW) depends heavily on the demand of such wastes (i.e. how the society reuses and recycles the CDW regionally). Habitate for Humanity is able to resell over 20% of the CDW from WC1 or WC2 but can only resell less than 10% from MW1 or MW2.

In addition, between 30% and 60% of the wastes still ended up in landfills. This clearly indicates that the regional communities and global communities do not demand the CDW. The rate of reuse indicates the regional digestability, while the rate of recycling indicates global digestability.

International perspective of Technical Metabolism and Energy Use of Recycling

In Europe**,** the "Thematic Strategy on the Prevention and Recycling of Waste", adopted on May 2003 is a long-term strategy to help Europe become a recycling society. Institute for Public Policy Research (IPPR) for 2003-04, reports that the total waste recycling rate within the European Union (EU) varies from 3% (Portugal) to 65% (the Netherlands). The United Kingdom (UK) has trebled its recycling since 1997 but need much better to avoid huge fines for breaking EU landfill limits. Recycled materials are generally less expensive and recycling in Germany, Holland and Denmark is cheaper than disposal. In the EU, the estimated annual generation of C&D waste is 200 to 300 million tons. An EU study calculated that an average of 28% of all C&D waste was recycled in the late 1990s. In the Netherlands 95% and Denmark 90% of all C&D waste is recycled. Most EU members have set goals for 50% to 90% C&D waste recycling (Lauritzen, 2006).

In the US, it recycled 32% of its waste, a rate that has almost doubled during the past 15 years. 50% of all paper, 34% of plastic soft drink bottles, 45% of aluminum beer and soft drink cans, 63% of steel packaging, and 67% of major appliances are now recycled. CDW in the US is 250 to 300 million tons per year (2002 figures) (Lauritzen, 2006). CDW makes up 25% to 45% of the waste that goes to landfills (Leigh, 2004). The demolition industry, encompassing demolition and renovation projects, produced more than 140 million tons of waste in 2000. This equated to 90% of the CDW generated. There is a 16% increase in C&D waste production over the four-year period from 1996 to 2000 in the US (Chini, 2005). The average CDW composition in the US is Wood-27.4%, Asphalt/Concrete/Bricks/Dirt-23.3%, Drywall-13.4%, Roofing-12%, Miscellaneous mixed-11.9%, Metal-8.8%, Paper-2.7%, and Plastics-0.5% represent the average composition of CDW in the US. In decreasing order of recycling rates, Metals, Concrete, Wood, Asphalt Shingles and Drywall are the most frequently recycled C&D waste in the US (Davis, 2001).

Europe recycling market is mailny driven by governmental interventions while recycling in the United States is mainly driven by the private market (though with some assistance from the government). Does that mean public policies can improve the rate of metabolism and recycling? If there are more facilities to recycle, does that mean less energy will be needed to recycle?

The Similarities and Conflicts between Eco-Efficiency and Technical Metabolism of Building Designs

Eco-efficiency calls for the reduction of resource-intensity of a product, and to increase the durability of materials, reduce use of toxic materials, and increase in service intensity. While reducing toxic materials and reduction of resource-intensity are inline with the concept of technical metabolism, increasing durability and service intensity may not be what technical metabolism is all about. The life expectancy of a product may have nothing to do with how long it will survive, but how long a

consumer needs them. A bathtub may still be functional but too often homeowners replace them long before these tubs come to their end in life. If engineers are unable to predict a reliable lifespan of the product/material, how can we accurately determine the recyclability, renewability, durability, and service intensity of many of the building products? Thus, there is a need to align eco-efficiency and technical metabolism, since it is impossible to abandon one for the other.

Building Design Impact on CDW Recycling

The study clearly indicates that recyclable design depends not just on the use of renewable or recyclable materials. The recyclability of design is also affected by the regional recycling capabilities, distances between facilities and projects, the size of the reuse and recycled CDW market, the energy use to recycle, social acceptance of CDW, the intensity of recycling practices, and government policies.

Other Lessons

1. Procurement and Financing Options

Photocopying equipment had one of the highest rates of reused and recycling among all of the manufactured products. The key reason is that the leasing option allows the manufacturer to recollect the used equipment and reused the components. This helps to centralize the recycling system and thus disconnect the recycling from the central facilities. Centralize recycling facilities may not be able to handle many types of recycled materials and most materials have to go to the landfill. As such, designers may want to take a look at the leasing options as a recycling method.

2. City-wide thrash and recyclables collection systems

The ability to recycle materials depend a lot of the availability of the recycling system within the city. Most California cities offer commingle recycling facilities which then make recycling simpler for the building contractors and designers. Alternatively, most mid-western cities do have many commingle recycling facilities and the cost of landfills is relatively lower. The shortage of commingled waste recycling facilities will deter contractors to recycle due to the difficulty of sorting. The cost of cheaper landfills will also deter many from recycling.

Conclusion and Future Research

The study concludes the followings: (1) Embodied energy of the CDW recycling process may be higher than intially thought; (2) Energy use for transporting CDW may be so high that such energy could represent a huge portion of the embodied energy; (3) Embodied energy of recycled materials may be driven by the regional recycling capabilities, and the distances between projects, transfer centers, and recycling facilities; (4) The energy use to treat and sort the recycled CDW may be quite insignificant compared to the energy used for transportation; (5) The technical metabolism of CDW depends on the regional recycling capabilities, the energy used to transport the materials, and the demand and supply of such materials; (6) The

technical metabolism depends heavily on the size of the market, i.e. regional, national or global (reusing CDW can only be applied to regional market, while recycling opens up the market to the whole world); (7) Reusing and recycling CDW is thus not wholly an economic and technical challenge, but it is also a social challenge; and (8) Government policies can have significant contributions to overcome many of the economic and social challenges of increasing the rate of CDW recycling. Table 1 summarizes the preliminary study of embodied energy, metabolism and building designs of CDW recycling.

Table 1. Embodied Energy, Metabolism and Building Designs of Recycling CDW

CDW Components and Treatments	**Embodied Energy**	**Metabolism**	**Impacts on Building Designs**
Building Structure Reuse	Minimal to no energy use	Building capacities and structural strength should remain the same (less than 5% of all CDW)	The ability to retain structural components (similar or lower strength and aesthetic requirements)
Return/Resell unused materials	Significant amount of energy use for transportation, and insignificant for treatment	Regional demand and supply (Within 500 km to be economically feasible) (About 20% of all CDW)	The presense of a return/ resale markets for unused materials, estimate the amount of wastes generated during construction (regionally), and the energy use for transportation
Storage of unused or recycled materials	Insignificant amount of energy use	Regional and global capacities to store materials, and regional and global demand for such materials	Understand the regional and global capacities for recycling and storage, and the energy use for transportation and handling
Reuse	Insignificant amount of energy use for treatment and handling	Regional demand and supply (Within continental U.S.), and	Understand the regional and national resale

		treatment/sorting capabilities (About 20% of all CDW)	market for CDW, the treatment and sorting capabilities and technologies, the reusing of CDW, and the energy use for transportation and handling
Recycle	Significant amount of energy use to transport, and not as significant amount to recycle	Global demand and supply, and technology (About 40% of all CDW)	Knowledge of recycling technology, and energy use of transportation and handling, and remanufacturing globally
Landfills	Significant amount of energy in areas where landfills run out, but not as significant in areas where landfills are plenty	Indigestable CDW will have to be disposed off (unusable, or have no second use) (About 40% of all CDW)	The knowledge of exactly which materials and under what conditions they cannot be recycled

Future research by the team will concentrate on establishing the theories, concepts, embodied energy of recyclable design and technical metabolism of buildings, when more data becomes available.

References

Chong, W. K. (2008), Technical Metabolism and Building Designs, Proceeding of the International Waste Engineering and Management, 28 – 30th May 2008, Hong Kong, China, pp C-11 – C-17

Davis, A. (2001). *Recycling Construction Debris*. Architectural week, Environment. (Source dated 10/10/2006).

Edwards, Steven, and Chapman, Rich (2005), "IGCC Technology: A Promising – and Complex – Solution" *World Energy Magazine* Vol. 8 No. 3, pp 48 - 50

Gavilan, R. M. and Bernold, L. E. (1994). *Source Evaluation of Solid Waste in Building Construction*. ASCE Journal of Construction Engineering and management. Vol.120, No. 3, pp. 536-552.

Gavilan, R. M. and Bernold, L. E. (1994). *Source Evaluation of Solid Waste in Building Construction*. ASCE Journal of Construction Engineering and management. Vol.120, No. 3, pp. 536-552.

Graedel, Thomas E. (1998): *Streamlined Life-Cycle Assessment*. NJ: Prentice Hall.

Horvath, Arpad and Hendrickson, Chris (1998): Steel versus Steel-Reinforced Concrete Bridges: Environmental Assessment. *Journal of Infrastructure Systems*, Vol. 4, No. 3, 111-117.

Lapinski, Anthony R., Horman, Michael J. and Riley, David R. (2006): Lean Processes for Sustainable Project Delivery. *Journal of Construction Engineering and Management*, Vol. 132, No. 10, 1083-1091.

Lauritzen, E. K.. (2004). *Recycling of Concrete – an overview of Development and Challenges.* International RILEM Conference on the Use of Recycled Materials in Building and Structures. RILEM publications SARL. pp 297-305.

Leigh, N.G. and Patterson, L.M. (2004). *Construction and Demolition Debris Recycling for Environmental Protection and Economic Development, Practice Guide # 7*. Southeast Regional Environmental Finance Center, University of Louisville.

O'Neill, Mark (2005), Australian Coal Association, "Clean Coal: The Path to Major Reductions in Greenhouse Emissions" *World Energy Mag* Vol. 8 No. 2, 126 - 129

Ofori, George (1998), Sustainable Construction: Principles and a Framework for Attainment – Comment, Journal of Construction Management and Economics, Vol. 16 No. 2, 1998, pp 141 - 145

Warren, Joshua A. Chong, Wai Kiong, and Kim, Changwan (2007), *Examine the Opportunities of a Recycling Program of C&D Waste for Highway Projects in Kansas City Metropolitan Area*, Transportation Research Record of the National Academy, Volume 2011, pg 193-200

WBCSD (2000) Eco-Efficiency: Creating more value with less impact, World Business Council for Sustainable Development. ISBN 2-94-024017-5.

WCED (1987). *Our Common Future*, World Commission on Environment and Development, Oxford University press, oxford, U.K.

Wood, Ron (2004) Black & Veatch, "The Comeback of Coal-Fired Power" *World Energy Magazine* Vol. 7 No. 4, pp 98 - 106

A PROPOSED ECO-LABELING METHOD FOR BUILDING DESIGN

Rendall, Joseph[1], and Chong, Wai K. (Oswald) Chong[2]

Abstract
Buildings consume nearly 40% of all energy use and building construction and demolition generate huge amount of pollutants and wastes. Consequently, buildings and building products need to be more eco-friendly in order to minimize the impact to the environment. Eco-efficiency is one of the many concepts that designers can apply to reduce the environmental impact of designs. Several public agencies and private companies also offer a variety of ecolabels that validate the ecoefficiency of project, company, system or material. The research team integrates the concept of ecoefficiency with food labeling technique to develop a new ecolabeling concept that could potentially improve the communication of building eco-efficiency information at the design stage. The paper also discusses the potential hindrances and conflicts of the proposed ecolabel. The intention of this ecolabel is to convey the information of building design and product eco-efficiency accurately to the designers so that they could reduce the impact of their designs on the environment.

Introduction

The knowledge needed to achieve sustainability can be extensive, as the scope of sustainability seems to be all-inclusive. Sustainable development calls for the preservation of our environment and social values for future generations without sacrificing our own economy while doing so. As such, implementing sustainability on a project can be complicated if stakeholders do not know what they really want. Most ecolabeling techniques provide sufficient environmental information but do not address the uniqueness of individual products, and the production locations and methods. Transportation and production method embodied most of the energy of a material or product.

The United States Green Building Council's (USGBC) Leadership in Energy and Environment Design (LEED) has incorporated a series of sustainable standards for building design and construction (LEED, 2007). The National Institute of Standard and Technology's (NIST) Building for Economic and Environmental Sustainability (BEES)

[1] Undergraduate Research Assistant, University of Kansas, Department of Civil, Environmental and Architectural Engineering, 1530 W. 15th St., 2150 Learned Hall, Lawrence, KS 66045
[2] Assistant Professor, University of Kansas, Department of Civil, Environmental and Architectural Engineering, 1530 W. 15th St., 2150 Learned Hall, Lawrence, KS 66045, email: oswald@ku.edu, phone: 785-864-2891

allows designers to make better environmental and economic decisions on materials (NIST, 2007). The Forestry Stewardship Certified (FSC) program and the Envirodesic Certification Program also identify the environmentally responsible products.

These sustainable systems, however, do not address the different environmental impact of the same materials or products manufactured in different locations or by different production processes. Technological breakthrough and escalating awareness of the environmental problems will propel some companies to adopt environmentally friendly manufacturing approaches, but most companies will continue to rely on lower cost but more polluting production approaches. Materials made in a country with sloppy environmental regulation enforcement may produce more pollutants than the same materials made in a country that enforces its environmental regulations. The current method that assumes a material produced by different production process and in different locations generates the same amount of pollutants, and uses the same amount of (embodied) energy may be oversimplified.

RESEARCH OBJECTIVES

The purposes of this paper are to: (1) discuss existing ecolabeling and the shortcomings; and (2) propose a new ecolabel methodology. The paper will investigate various ecolabels that are used by the construction industry, categorize the ecolabels, discuss the shortfalls of these ecolabels, and introduce their new approach of ecolabeling, and finally, conclude the paper by discussing some potential obstacles of the new ecolabeling methodology.

ECOLABELING AND SUSTAINABILITY

The attributes of eco-efficiency include: 1) Material and energy intensity reduction of goods and services; 2) Reduced dispersion of toxic materials; 3) Recyclability; 4) Use of renewable resources; 5) Greater durability; and 6) Increase service intensity of goods and services (WBCSD, 2000). Eco-efficiency aims at reducing material, toxic elements, and energy used and the attributes may conflict one another. For example, recycling may increase the energy use to regenerate a material while toxic materials may improve the durability of a material, and procurement of a highly renewable material from a distance location may require longer transportation distance (Warren et al, 2007, and Lapinski et al, 2006). Current ecolabels do not emphasize the conflicts and assume that the products or materials they certify comply with all the attributes.

1. MATERIALS AND PRODUCTS LABELING

Material and product labeling is a very commonly used technique to label the ecoefficiency of a product or material. BEES incorporates 12 environmental variables and two economic variables. The 12 environmental variables include, global warming (carbon dioxide, methane, and nitrous oxide), acidification, eutrophication, fossil fuel depletion, indoor air quality, habitat alteration, water intake, criteria air pollutions, human health, smog, ozone depletion, and ecological toxicity. The BEES model also incorporates the measurement of initial and future costs. BEES only measures the impacts of materials on the environment, and the associated costs, but does not measure the softer social costs (NIST, 2008).

Building Owners and Managers Association (BOMA) of Canada measures the

multiple environmental attributes for other portions (Facilities) of the product's life cycle (BOMA, 2008). China ecolabeling provides ecoefficiency measurement of decoration products for buildings, office equipment, recycled products, food packaging products and wares, water treatment equipment, waste treatment equipment, air purifying products and cleaning services (China ecolabeling, 2008). EcoLogo sets specific standards to certify products in more than 120 categories (Ecologo, 2008). Catalonia provides consumers and users with more reliable information on ecoefficiency, and promotes the design, production, marketing, use and consumption of products and services that fulfill certain environmental quality requirements beyond those established as compulsory under current regulations (Catalonia, 2008).

Other similar product certifications include the Good Environmental Choice (Good Environmental, 2008), Green Seal (Green Seal, 2008), Greenstar (Greenstar, 2008), Hong Kong Green Label (Hong Kong Green Label, 2008), IBO (IBO, 2008), Natureplus, (Natureplus, 2008), SCS Sustainable Choice (SCS Sustainable Choice, 2008), and SmaRT Consensus Sustainable Product Standards (SmaRT, 2008). Some labels are more products' specific. Emicore labels the emissions of flooring installation materials and attempts to minimize indoor air pollution (Emicore, 2008). Other materials-specific labels include Green Label Plus for Carpet (Green Label, 2008, and SCAS, 2008), Rugmark (Rugmark, 2008).

2. PROJECT LABELING

Project labeling provides a simple method to ascertain the eco-efficiency of a completed project. Most labels tend to incorporate standards and measurement methods from other established agencies. Although green building standards are not the only facet of sustainable construction, construction stakeholders often associate green building standards with Sustainable Construction. Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is one of the premier green building programs in this country but LEED does not develop its own standards. LEED™ follows a scorecard methodology with the capability of achieving four levels of certification for the completion of various tasks in the categories of Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, and Indoor Environmental Quality. LEED credits and prerequisites adopt standards from other agencies (USGBC, 2007). A LEED label represents the achievement of green standards by a building.

There are other project ecolabels similar to LEED. Argue TQ is an Austrian system that measures Resource Consumption, Environmental Loadings, Indoor Environmental Quality, Durability, Safety and Security, Quality of the design, process, Quality of the construction process, and Quality of amenities and site. It also measures the environmental performance of the whole life cycle of products (TQ, 2008). Building Research Establishments (BRE) Environmental Profile, Building Research Establishment Environmental Assessment Method (BREEAM) is a popular project ecolabel in the United Kingdom. Earth Advantage is an ecolabel that certifies new and remodeled homes on energy efficiency, indoor air quality, resource efficiency and environmental responsibility (Earth Advantage, 2008). Other project ecolabels include LEED-Home, EcoSchool and R-2000 (R-2000, 2008, EcoSchool, 2008).

3. ENERGY EFFICIENCY LABELING

Energy efficiency labeling measures the energy consumption of a completed project, product or system. Its intention is to minimize energy consumption during occupancy. EnerGuide for New Houses highlights information on one's home energy use and helps new homebuilders plan and build energy efficient, cost-effective homes. The scoring system rates homes from zero (lowest) to 100 (highest) (EnerGuide, 2008). Minergie is a label for new and refurbished buildings that level comfort level and energy use of commercial buildings (Minergie, 2008). European Union also runs the Energy Performance Certification program that measures the energy consumption of buildings (EPC, 2008). Energy Star certifies energy efficiency of electrical equipment in the United States.

4. COMMUNITY LABELING

Community labelings, like LEED Community Development and Green Globe Community, provide key measurements for community's eco-efficiency, and guidelines and tools to address water and energy conservation, waste reduction, social inclusion and economic sustainability (LEED, 2008, and Green Globe Community, 2008).

5. COMPANY AND OPERATING FACILITIES ECO-EFFICIENCY

Although the Dow Jones Sustainability Index is a better-known sustainability index among corporations, the construction industry also has its specific ecolabels that targets designers, contractors and owners. The Cleaner and Greener Certification uses market forces to reduce the environmental pollutions and improve energy efficiency of corporations' operations (CGC, 2008). The Envirodesic Certification Program provides licensing to qualified builders, manufacturers, and service providers that meet strict environmental standards (Envirodesic, 2008). Green Globe Company Standards measures companies' environmental and social responsibility (GGCS, 2008). IPM Star or Integrated Pest Management (IPM) Star Certification Program certifies IPM practitioners who meet a high standard for IPM in schools, childcare centers and school-age programs (IPM, 2008). Environmental Production Declaration follows the principles of environmental declarations based on the ISO 14025 TR standards to determine whether a company is practicing environmental sustainability or not.

6. INDOOR AND WORKING ENVIRONMENTAL QUALITY

GreenGuard (2008) establishes acceptable indoor air quality standards for indoor products, environments, and buildings and is a third-party certification programs. SCS Indoor Advantage (2008) is a certification program that measures the concentrations of individual VOCs in classrooms and offices using established procedures developed by the Environmental Protection Agency. It also measures the Indoor air quality and VOC emission criteria, using the Chronic Reference Exposure Level (CREL) threshold standards. TCO Development (2008) certifies office equipment's ergonomics, emissions, energy use and ecological impacts.

7. WATER EFFICIENCY

Drinkable water is becoming scarcer globally. The Water Efficiency Rating & Standard of Australia (WERS, 2008) provides water efficiency information for water-consuming household products and is mandatory in Australia. Water Sense (2008) measures the level of water use efficiency of products that consume water during production. Waterwise Marque (2008) awards products that reduce water wastage or raise awareness of water efficiency. In China, the Water Conservation Certification (CWCC, 2008) labels water conservation program for 62 different product categories.

SHORTCOMINGS WITH THE EXISTING ECOLABELING LABELS

EcoLabeling is a necessary process to differentiate eco-efficient products, projects, companies, and systems from those that are not. Most of the labels adopt a simplified approach of issuing a label when a product, project, company or system complies with the requirements. Such method is very similar to the organic food approach, where an "organic" label on a food product highlights that it is grown under qualified conditions. The one label approach seems to assume that all consumers have the same values and needs. In addition, unless one truly understands the certification process or recognizes what an organic label truly means, the label simply represents the condition where a food is grown, and the label may not fit into everyone's definition for "organic". Consumers have only two choices in the one label approach and they cannot make a choice base on their values, benefits and ideals. The proposed labeling approach could address the differences in the values and ideals of individual consumer. For example, food labels allow consumers to choose the kinds of nutrients they wish to consume and those they wish to avoid. Promoting such awareness is the key towards achieving the true goal of sustainability. There are also many shortcomings in many existing ecolabels.

- First, most of the certification processes adopt a fixed set of standards regardless of their relevance. For example, USGBC LEED gives credit to LEED certified buildings that provide sufficient bicycle facilities, even if the buildings are located in bicycle-unfriendly cities, and when the building occupants are unlikely to use these facilities.
- Second, the environmental impact generated by the production process of the same product or material in various regions can be significantly different from one another. A product certified eco-efficient in China may not be eco-efficient in the United States. The production technique in China may be significantly different as their industry relies on manual labors while production in the United States uses more machinery due to higher labor cost. Increasing use of machinery escalates energy consumption and carbon dioxide production. Additionally, a toxic material may be recyclable in one region but not in another. The ability to recycle toxic materials may make a product (that contains a recyclable toxic material) more ecoefficient. Besides, many ecolabels do not address labor exploitation in developing countries even though labor exploitation is an important component of product sustainability.
- Third, existing labels do not present clear information to the designers, contractors and consumers. Users of these labels are unable to identify the exact amount of environmental pollutions the products generate and thus unable to control the impacts

of their choices. Users are also unable to make effective and informed decisions on energy and resource savings. Users may end up buying something that can be less ecoefficient.

- Fourth, most labels do not illustrate the different level of achievable product ecoefficiency operating under different conditions and maintenance level. A product will not yield the best level of ecoefficiency if it does not operate at the optimum level.
- Fifth, multiple labels can overcome regional differences can be overcome. However, this would make ecolabeling non-economical. As such, the solution is to make a label as generic as possible, and broad enough to cover different variables in any region.
- Sixth, an ecolabel has to effectively address its intention and communicate any environmental information accurately and effectively to the product users. The eco-stamp approach, such as the Green Seal and LEED certified, tends to limit consumer choice and competition between products.

MEASURING AND LABELING ECOEFFICIENCY: A NEW APPROACH

A successful ecolabel has to reflect the critical eco-efficient features of a product accurately. The proposed label focuses on answering the two questions that consumers often ask before they buy anything: What am I paying for? What are the benefits of this product? Consumers buy a product for its intended functions and the benefits that accompany it (Pine et al, 2007). A consumer pays more for a luxurious car that achieves the intended function for transportation and the benefits to enjoy more comfort while driving. Both the functions and benefits are the "ingredient" of a product.

Food labeling has been quite successful, as it often serves people with different needs by listing the ingredients on a food product label. People who have high cholesterol can avoid food with high cholesterol, while those who have high blood pressure can avoid food with high sugar content, just by reading the label. The ecolabels for building products, projects, companies or systems should allow address illustrate the ingredients within. The eco-efficient needs of one community may not be the same for another. For examples, (1) a new LEED certified building constructed in St. Louis provides bike racks for its occupants and earns a LEED point but a survey found that no one ever uses those racks; (2) a project in Kansas City installs waterless urinals in order to earn two LEED points from the projected water saving, but a recent survey on the building showed that nearly 90% of the occupants avoided these urinals and used those that have flushes; and (3) a project in Kansas City earns two points from importing highly renewable materials from overseas and avoided using higher quality substitutes that are available locally, the higher energy use to deliver the products, and the impact on the local economies made that decision less "green".

Ecolabeling should consider the impacts to the global ecological community just like how a food label allows one to consider the impact of different food ingredients in a body (Hinman, 2006). An ecolabel should specifically measure the impact of a project, product, system and company on the environment. A quantitative set of information through an ecolabel should provide an individual building consumer and owner the choice for choosing what they really need base on their financial status. The ingredients listed on a label have to be measurable, and easy to read and understand. The ingredients should adopt measurements and units from established sources. Some of

these suggested ingredients include:

1. Material and energy intensity of goods and services:

The ingredients for this requirement include the energy, materials/resources, and water use for production, transportation, manufacturing, extraction, storage, operate, installation, disposal, recycling, reusing, and remanufacturing processes. In addition, the label should also include energy and resource use information at the operation stage. For example, an airconditioner should state the amount of energy use per hour under specific load, and the amount of resources needed for an average annual maintenance.

2. Dispersion of toxic materials:

The ingredients for this requirement include: (1) Air pollutants generated by production, transportation, manufacturing, extraction, storage, operate, installation, disposal, recycling, reusing, and remanufacturing processes; (2) Toxic and pollutants generated by production, transportation, manufacturing, extraction, storage, operation, installation, disposal, recycling, reusing, and remanufacturing processes; (3) Toxic and pollutants that may be generated during the operation and maintenance processes; and (4) The recapturing of toxic and pollutants and diversion from landfills and incinerators.

3. Recyclability:

Recyclability of a product is extremely difficult to quantify. Chong (2008) and Warren et al (2007) listed some of the options that can help overcome the problems associated with quantification: (1) The use of highly renewable materials; (2) Availability of recycling facilities in the region (or the nearest facilities); (3) The potential rate of recycling of the materials; and (4) Procurement or buy back options offered by suppliers or manufacturers for reuse and recycling. It is possible to quantify the amount of materials that are renewable or recyclable; it is not possible to quantify recycling facilities, procurement/buy back options, and the potential rate of recycling of the materials. For example, a label can state the procurement/buy back option such as how and where to send the products for recycling or back to the manufacturer. The label can also list the kind of facilities needed to recycle the products.

4. Use of renewable resources:

The ingredients for this requirement include the amount of renewable energy and renewable resources used to produce, transport, manufacture, extract, store, operate, install, dispose, recycle, reuse, and remanufacture the products.

5. Durability:

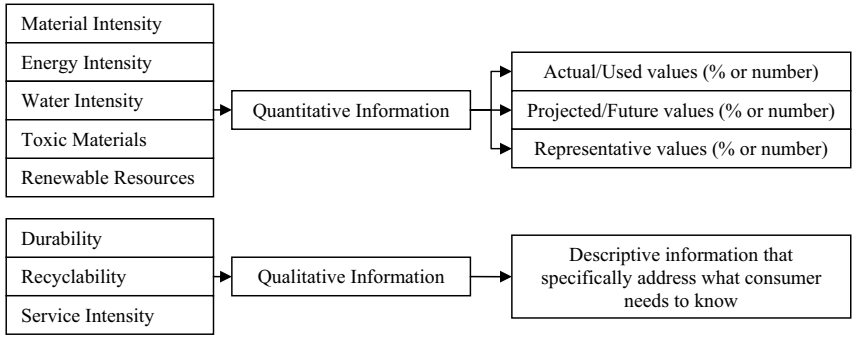
The ingredients for this requirement include: (1) expected life span of products; (2) expected replacement life of components and parts in products; and (3) maintenance information of products and parts. Consumers and designers can use this information to compare the durability between products, and make decisions whether to buy a more durable product or a less durable one. In addition, the life cycle of a completed building is determined by the life cycle of the products and materials it uses. Such information will offer critical knowledge needed to predict the life cycle of a building.

6. Service intensity of goods and services:

Similar to recyclability, the ingredients for service intensity is extremely difficult to quantify. Service intensity depends on how individual consumer consumes a product. A refrigerator uses the same amount of energy whether it is half-full or totally empty, and a heater designed to heat a space efficiently when the outdoor temperature is below

20˚F heats inefficiently when the outdoor temperature is 0˚F. Labels should provide such information the consumers so that they can better understand the most efficient operating conditions. This should be qualitative information.

Figure 1 Measurements and Information on EcoLabel



TESTRUNS OF ECOLABELS ON INFRASTRUCTURE

The authors are in process of developing a preliminary ecolabeling methodology that addresses the above for green buildings. The project team will carry out tests on three buildings, two LEED certified buildings and one non-LEED certified building. This allows the project team to understand the difficulties of implementing the labels in both LEED and non-LEED certified buildings. LEED certified buildings follow a set of green standards while non-LEED certified buildings do not, and ecolabels may be more difficult to implement in the latter. Initial test runs showed that there are several potential obstacles and conflicts to overcome, and it is more difficult to implement on the non-LEED certified building.

POTENTIAL OBSTACLES OF PROPOSED ECOLABEL: AN EXAMPLE OF WATER

This section discusses one of the many obstacles that the proposed ecolabels need to address.

The measurement of water resources is a huge challenge. The sources of water are just as important as reducing water consumption. The embodied energy of treated water from seawater is much higher than of treated water from groundwater and unpolluted rivers. Desalinate seawater needs more energy than making water from underground aquifers and rivers.In addition, desalinated seawater will generate more toxic wastes than underground water and water from the rivers. The quality of river water is significantly lower in many developing countries due to the lack of governmental regulation and control. In addition, the over-extraction of groundwater from undisrupted local wells will create large cone of depression due to the lowering of water table. Such overuse can negatively affect water quality in local wells and landuse patterns (Strobel, 2008). As a result, the environmental impact of producing potable water in different regions and from different sources is different.

It is also difficult to monitor the environmental impact due to different regions and production methods. The key challenge is how to address such differences in a label that will reflect the energy use to treat, extract, and transport water. How can the label reflect the impact on land use? How should the label address the waste products from desalination, such as salt concentrations, chemicals used during defouling of plant equipment and pre-treatment and toxic metals? Desalination plants also produce a small amount of solid waste (like the old filters and solid particles filtered out in pretreatment) (California, 2008). Should the label reflect the wastes generated by desalination? The reason for counting the amount of polluted mass within the water is to acknowledge the mass of the pollutants can cause water to become undrinkable. However, the presence of certain pollutants may not cause water to become undrinkable. For example, the level of nitrates in water has to be high enough to increase the potential of cancer when human consumes it, but nitrates in water are not a pollutant or toxic.

References

BOMA (2008), [Online] Building Owners and Managers Association, http://www.bomagogreen.com/, July 12, 2008.

California (2008), [Online] Seawater Desalination in California, http://www.coastal.ca.gov/desalrpt/dchap1.html, July, 2008

Catalonia (2008) [Online] http://mediambient.gencat.net/eng//empreses/ecoproductes_i_ecoserveis/introduccio_distintiu.jsp April, 2008.

CGC (2008), [Online] Cleaner and Greener Certification, http://www.cleanerandgreener.org/certification/index.htm, April, 2008

China Ecolabeling (2008), [Online] China ecolabeling, http://www.cecp.org.cn/ , Apri, 2008

Chong, W. K. (2008), Technical Metabolism and Building Designs, Proceeding of the International Waste Engineering and Management, 28 – 30th May 2008, Hong Kong, China, pp C-11 – C-17

CWCC (2008), [Online] China Standard Certification Center, http://www.cecp.org.cn/, April, 2008

Earth Advantage (2008), [Online] Earth Advantage, http://www.earthadvantage.com/ April, 2008

EcoLogo (2008), [Online] Eco-logo, http://www.ecologo.org/, April, 2008

EcoSchool (2008), [Online] Eco-School, http://www.eco-schools.org/, April, 2008

ECP (2008), [Online] Envirodesic Certification Program, http://www.envirodesic.com/, April, 2008

Emicore (2008), [Online] Emicore, http://www.emicode.com/, April, 2008

EnerGuide (2008), [Online] Energy Guide for Homes, http://oee.nrcan.gc.ca/residential/personal/new-homes/upgrade-packages/label.cfm?attr=4, April, 2008

EPC (2008), [Online] Energy Performance Certificate, http://www.buildingsplatform.eu/cms/index.php?id=7&no_cache=1,April, 2008

EPD, (2008), [Online] Environmental Production Declaration, http://www.environdec.com/pageId.asp, April, 2008

GEC (2008), [Online] Good Environmental Choice (Australia), http://www.geca.org.au/, April, 2008
GGCS (2008), [Online] Green Global Community Standards, http://www.ec3global.com/products-programs/green-globe/for-communities/programme/, April, 2008
GLGLP (2008), [Online] Green Label & Green Label Plus (Carpet), http://www.carpet-rug.org/, April, 2008
Green Seal (2008), [Online] Green Seal, http://www.greenseal.org/, April, 2008
GreenGuard (2008), [Online] Green Guard, http://www.greenguard.org/, April, 2008
Greenstar Certified (2008), [Online] Green Star Certification Program, http://www.greenstarcertified.org/, April, 2008
Hinman, L. M. (2006), Contemporary Moral Issues: Diversity and Consensus, Prentice Hall, USA
HKGL (2008), [Online] Hong Kong Green Label, http://www.greencouncil.org/eng/greenlabel/intro.asp, April, 2008
http://www.bfrl.nist.gov/oae/software/bees/bees.html
IBO (2008), [Online] Institut für Baubiologie und Bauökologie , http://www.ibo.at/de/index.htm, April, 2008
Indoor Advantage (2008), [Online] SCS Indoor Advantage, http://www.scscertified.com/ecoproducts/indoorairquality/indooradvantage.html, April, 2008
IPM Star (2008), [Online] Verified IPM Performance, http://www.ipminstitute.org/ipmstar.htm, April, 2008
Landfill, (2008), [Online] Landfill 101, http://www.scdhec.gov/environment/lwm/recycle/pubs/landfill_101.pdf, July, 2008.
Lapinski, A.R., Horman, M.J., and Riley, D.R. (2006). Lean Processes for
LEED (2007), [Online] United States Green Building Council's Leadership in Energy and Environment Designs, www.usgbc.org, July, 2007
Minergie (2008), [Online] Minergie Certification, http://www.minergie.com/, April, 2008
Natureplus (2008), [Online] Herzlich willkommen bei natureplus, http://www.natureplus.org/, April, 2008
NIST (2008), [Online] Building and Fire Research Laboratory, *Building for Environmental and Economic Sustainability.* (2008). August, 2008
Parrott, K., J. Woodard, B. R. (2008), [Online] Household Water Quality: Nitrates in Household Water, http://www.ext.vt.edu/pubs/housing/356-484/356-484.html, July, 2008
Pine, I. I., Gilmore J. H. and Joseph, B. (2007) Authenticity: What Consumers Really Want, Harvard Business School Press, Harvard, USA
R-2000 (2008), [Online] New Housing Resource Center, http://www2.nrcan.gc.ca/oee/nh-mn/f-t/index.cfm?fuseaction=s.ssf&language=eng, April, 2008
Rugmark (2008), [Online] Rugmark Foundation, http://www.rugmark.org/home.php, April, 2008

SCAS (2008), [Online] The Public Health and Safety Company: Sustainable Carpet Assessment Standard, http://www.nsf.org/, April, 2008
SCS (2008), [Online] Applying the Declaration: SCS Sustainable Choice, http://www.scscertified.com/ecoproducts/epd/sustainablechoice.html, April, 2008
SCS (2008), [Online] SCS Indoor Advantage, http://www.scscertified.com/ecoproducts/indoorairquality/indooradvantage.html, April, 2008

A DECISION-MAKING FRAMEWORK TO ASSESS STAKEHOLDER VALUE IN ADOPTION OF SUSTAINABLE PRACTICES IN CONSTRUCTION

Amlan Mukherjee [1] and Helen Muga[2]

[1]Assistant Professor, Department of Civil and Environmental Engineering, Michigan Tech, Houghton, MI 49931; email: amukherj@mtu.edu
[2] PhD Candidate, Department of Civil and Environmental Engineering, Michigan Tech, Houghton, MI 49931; email: hemuga@mtu.edu

Abstract:

The significant environmental impact of the construction industry, its critical role in the economy, and the urgent need to respond to global climate change has created economic and environmental challenges that the architecture, engineering and construction (AEC) industry is increasingly encountering. The diversity of priorities and differing perceptions of risk about the adoption of green building practices among industry stakeholders is critically shaping the adoption of green technology, and the rate at which the industry is shifting towards more sustainable practices. In this paper, we develop an integrated framework that uses a probabilistic definition of value to integrate reductionist methods of sustainable decision-making, within a complex adaptive systems definition of the context within which such decisions are made. It is founded in probabilistic risk assessment and system dynamics, and is used to aid individual adoption of sustainable technology and study its diffusion through professional networks in the AEC industry.

Introduction

Sustainability in and of the built environment poses the challenge of redefining the boundaries of the problem at hand in order to include the context within which it is situated. Fenner et al. (2006) explains that sustainable design and engineering requires a paradigm shift in thinking from Newtonian science, to a holistic approach founded in complexity science. While traditional engineering approaches to problem solving are rooted in reductionist analysis methods that are mechanistic and exact, the need to understand the context of the problems requires inclusion of socio-economic-environmental concerns as best characterized using complex adaptive systems. This has promoted the adoption of a life-cycle approach to design – considering not only the current economic viability of a design alternative but also measuring the long term economic, environmental and social impacts of it.

Defining and studying such systemic relationships – while critical to designing sustainable alternatives – is a challenge, because some of them are difficult to quantify and estimate. At the same time, reductionist approaches provide the methodology of quantifying specific elements within the system. This has resulted in the study of sustainability in the built environment taking fragmented approach to solving a systemic problem (estimating environmental impacts, long-term economic values of alternative designs, and the use of alternative building materials through the design, construction and operation life cycle phases) (Cicas et al. 2007). At hand is the "fundamental dilemma" (Fenner 2006): on the one hand it is necessary to use the systems paradigm to frame problems, while on the other hand it is necessary to employ reductionist approaches to study specific elements of it. This places the responsibility in the hands of decision-makers, and their role in the re-integrating individual problem components and making decisions, that adopt sustainable practices and alternative designs, with the "bigger picture" in mind.

In response, researchers have developed decision-making frameworks that aid stakeholders in the built environment. For example, designers and industry practitioners can use the Construction Environmental Decision Support Tool to make informed decisions based on quantifying energy use, emissions, and waste generation rates due to the construction phase of commercial buildings (Guggemos and Horvath 2006). Such decision-support tools place the decision-maker in a "top-down" decision-making scope, in which they are capable of objectively monitoring the design selection process using data that accurately describes long-term aggregate system behavior. While they do indeed aid in the selection of sustainable alternatives, they reduce the problem of decision-making to one of informed rational choice, ignoring any regional or social factors that drive the context of practice and can significantly bias a decision.

A comprehensive study of sustainable decision-making must also include an investigation of the "bottom-up" decision-making scope. In this, decision-makers are part of the system that dynamically organizes itself, due to complex interactions between individual stakeholders, their contexts and the constraints driving their decisions. Some of these interactions cannot be easily quantified, unless the problem is framed within the semantics of a complex adaptive system. The contribution of this paper, we develop an integrated framework that uses a reductionist method to aid "top-down" decision-making, while defining the context of such decisions using complex adaptive systems. This definition allows the study of "bottom-up" decision-making. Specifically, the framework uses probabilistic risk assessment, system dynamics and social networks to investigate the value incentive that individual stakeholders have in adopting sustainable alternatives, and studying how individual perceptions of risk and incentive drives its diffusion across professional networks.

Background: Adoption in the Built Environment

Commercial and residential buildings are one of the major consumers of raw materials and energy, accounting for around 40% of global raw materials, consumed per year (U.S Green Building Council 2005). In addition, commercial and residential buildings in the U.S consume 36% of energy and 65% of electricity. While awareness regarding sustainability has grown at a steady rate (83% of new projects use green technology, with an expected growth of 87% in the next few years) in the United

States (Turner Construction 2005, McGraw Hill 2005), its diffusion and adoption into industry has been slower than expected (Cryer et al., 2006). High initial costs, lack of education on long-term benefits, and lack of government incentives, are some of the reasons impeding the adoption of green technology. In spite of industry efforts such as, the Leadership in Energy and Environmental Design (LEED) championed by the US Green Building Council, studies by McGraw Hill (2005) and Turner Construction (2005) show that green-building projects in the U.S have steadily grown from less than five projects in 2000 to 95 projects in 2005 with the most growth experienced in the Pacific and Northeast regions. This trend shows an unevenly distributed embrace of green technology by the AEC industry.

There has been limited research investigating how individual stakeholders, such as owners, architects, engineers, contractors, public agencies and material suppliers perceive value of green technology, and how such individual perception drives the acceptance and adoption of innovation across social networks in the industry. We define the social network within the AEC industry as a map of "who does business and interacts with whom." Henceforth such networks are referred to as *professional networks*. We believe that the differential rates of green technology adoption in different parts of North America (greater adoption in the North East and Pacific coast); reflect differences in stakeholder perceptions of value that are often deeply rooted in local contexts (such as material availability and market demands) within which they are situated. This defines the topology of the professional networks, which in turn, drives technology adoption by individuals. These mutually reinforcing (or balancing) forces ultimately drive the organization of the stakeholder professional network and the adoption of green technology in the AEC industry.

The Framework

The first part of the framework uses a "top-down" perspective - that of the individual stakeholder in the AEC industry. It aids in decision-making (individual level) by providing comparisons between alternative designs. It develops a definition of value that can aid individual stakeholders to *adopt* sustainable alternatives. The second perspective is "bottom-up" and its focus is systemic. It investigates how individual adoption of green technology drives diffusion of green thinking (systems level) through different industry sectors, and stakeholder groups. The first approach is supported by probabilistic risk analysis that estimates economic and environmental value; and the second approach is supported by a system dynamics definition, which study the diffusion of technology using the analogy of the infectious diseases spreading through susceptible populations.

Adoption at the Individual Level: At the individual level the assumption of the framework is that the individual stakeholder has the opportunity to assess the *value* of alternative designs and decide to adopt a technology. We define value as the probability of a project being *successful* multiplied by the *consequences* of success. We define success generally in terms of (i) achieving lower life-cycle environmental emissions, and (ii) lower life cycle costs (which reflects increased energy efficiency). The probability of success is considered to reflect regional differences and external factors – such as construction quality – that impact the performance of alternative designs. It is critical to consider actual long-term performance as it can vary

significantly from expected performance. The consequence measures the expected improvements both from an environmental and economic standpoint.

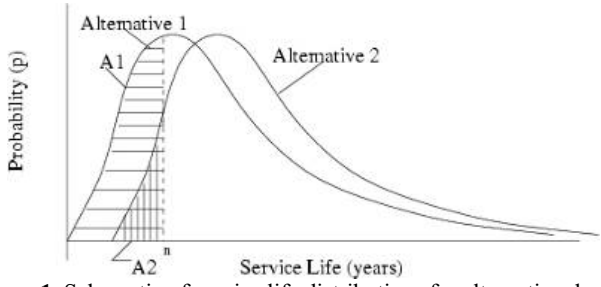


Figure 1. Schematic of service life distributions for alternative designs

For example, it is well understood that when cement is replaced by fly ash or slag in concrete pavements, their environmental viability improves – though the long-term performance of concrete pavements that use fly-ash/slag substitutions are not yet well documented. Similarly, continuously reinforced concrete pavements (CRCP) may prove to be more sustainable than jointed plain concrete pavements (JPCP), even though they use more steel, because of their longer lives and lower maintenance requirements in high traffic areas (Mukherjee et al. 2006). However, if not constructed carefully CRCP is likely to fail easily and prove to be very expensive, and have a very high impact on the environment. In this case, the *consequence* for using a CRCP section measures the reduced emissions and costs due to fewer maintenance requirements, associated reduction in user costs due to lowered construction costs to public agencies, and fewer traffic delays to road users (especially if the traffic involved is urban, high volume, heavy truck). The consequences associated with JPCP include the reduced emissions during the material acquisition phase due to lesser usage of steel. Advances in existing life cycle assessment and analysis software (EIO-LCA) can be used to assess the consequences, and can be easily measured using a typical metric such as currency ($). Let us say for a service life expectancy of n years, we denote the consequences associated with CRCP and JPCP respectively as $c_{CRCP}(n)$ and $c_{JPCP}(n)$.

The probability of success of achieving the consequences, for both CRCP and JPCP, is based on a distribution developed from historical performance of each pavement alternatives in different climate zones. Figure 1, illustrates a schematic of the service life distributions of a pavement for two alternative designs. Hence, the area under the curve for alternative 1, A_1 (horizontal hatch) – say JPCP in this example, is the probability of the pavement failing in less than or equal to n years. Hence the probability of the pavement not failing in less than n years, or success is $(1\text{-}A_1)$. Therefore the expected value (EV_{JPCP}) for a decision to adopt JPCP and the expected value (EV_{CRCP}) for a decision to adopt to CRCP (in this case alternative 2) is as follows:

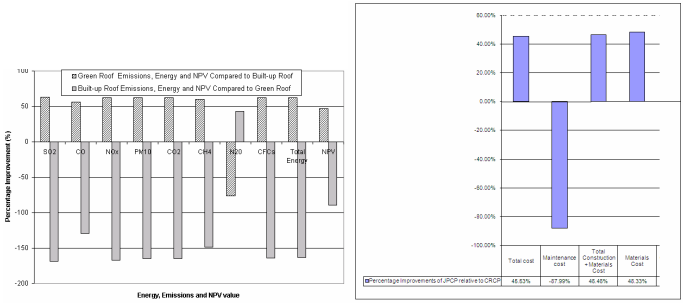
$$EV_{CRCP} = (1\text{-}A_2) \,.\, c_{CRCP}(n) \qquad (1)$$

$$EV_{JPCP} = (1\text{-}A_1) \,.\, c_{JPCP}(n) \qquad (2)$$

For an expected life of *n* years the individual decision-maker will compare the expected values delivered by the alternative designs. This probabilistic approach aims at selecting a decision that has a higher value associated with it. For this particular example, service life distributions are considered – but depending on the technology at hand, the distribution could be of unit cost (as we will see in the next example) or any other suitable performance metric.

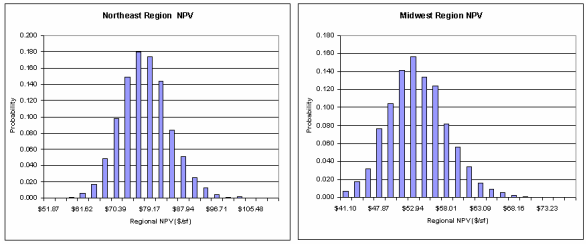
It is worth noting that this method of calculating expected value brings together two things: (i) The ability to use existing studies in the literature comparing life cycle emissions and costs of alternative technologies. Figure 2, illustrates the life cycle emissions and costs of two alternative designs for two components of the built environment (alternative roof systems and alternative pavement designs) as calculated using EIO-LCA and life cycle costing methods. (ii) The ability to incorporate information about the actual performance of a particular design and thereby provide decision-makers the opportunity to develop long term strategies that deliver the most value. The primary challenge of this approach is that it will require the development of the performance distributions for alternatives in the built environment. Development of such distributions is not difficult in domains where the data is easily accessible or alternatively, easy to estimate. For example, in a comparison of energy efficiency of green roof systems and built-up roof systems (Muga et al. 2008) a net present value (NPV) distribution for cost per square-footage was developed based on construction estimates and national energy usage patterns from the U.S. Department of Energy (Figure 3). Similarly, long-term performance data for alternative pavement designs can be accessed (if, with some difficulty) from state and national highway administrations, and can be used to develop distributions, as discussed, to compute value. Incorporating long-term performance data of alternative designs within the built environment into the discussion of sustainability is a critical direction for further research.

The next question is how can individual stakeholders within different delivery systems consider the expected value measure in their decision-making process. Muga et al. (2008) have in detail described how this method can be used to assess value to stakeholders in the construction industry, within the design-bid-build delivery system. The case study compared the value assessed for two alternative roofing systems – a traditional built-up roof and a green roof - from the point of view of different stakeholders. Figure 3, shows the distributions of net present value cost per square foot for built-up roofing systems in the northeast and the mid-western regions of the United States. The costs reflect expenditures due to energy usage of the building and long-term construction and maintenance costs. From the point of view of the contractor, the ability to use an alternative technology to bid at a cost lower than the average cost of the distribution, provides an advantage in two ways: (i) It increases the probability of them being the most price competitive bid (ii) It also allows them to be the most responsible bid, as they lower their cost through the adoption of a sustainable technology instead of compromising on quality. The gain in value for the owner is due to the long-term savings in energy and maintenance needs.



(a) (b)

Figure 2. Improvements in emissions, energy, and NPV values for (a) alternative roof systems (Muga et al. 2008) and (b) for JPCP and CRCP pavements for the initial material acquisition phase, and use and maintenance phase.



(a) (b)

Figure 3. NPV distributions across the different regions of the U.S. (a) Northeast regional NPV distribution, (b) Midwest regional NPV distribution (Muga et al. 2008)

Analysis showed (Muga et al. 2008) that in the mid-western region, the average of the distribution was $53/square-foot. The cost of a traditional built-up roof, from a case study in the same region, was $66.90/square-foot, while the cost of using an alternative green roof was $35.30/square-foot. This indicates a savings over the lifetime of the roof of ($66.90 - $35.30 =) $31.60/square-foot for the specific case study, and ($53.00 - $35.30 =) $17.70/square-foot over the average performance. The differences in cost, translates to value to the contractor, the owner and other stakeholders in the construction industry. At this point the performance distribution for green roof systems have not been developed due to limited regional adoption. This framework can be suitably ported to different delivery systems, as they provide a win-win situation for all stakeholders concerned. It is most suited to design-build-operate delivery systems that have been previously identified as conducive to sustainable design and construction.

Diffusion at the Collective Level: The second part of the framework is founded in the idea of infectious diseases diffusing through a susceptible population. The "infection" we study is the spread of alternative sustainable technologies through the AEC industry. The professional network defining the industry provides the terrain, through which the infection spreads in a community. The topology of such

networks is driven by project delivery systems, the nature of the project (public or private) and the way industry stakeholders select projects to design, bid and build. The infection represents a shift in the practices within a professional network.

Siegler (2006) concluded that adoption of green building technology is less dependent on economic market forces and more so on human social dynamics. Individuals adopt new ideas, when their peers, role models and competitors influence them. Each adoption in turn causes the idea to diffuse through the community. Diffusion is defined as the spread of demand over space and time (Rogers 1995, Stewart and Nihei 1987) – in this case, it is the spread of green engineering practices. The space through which the idea diffuses is the professional networks that the underlying industry structure creates. The topology of such networks critically influences the rate at which green thinking diffuses into the industry and leads to individuals adopting green technology – who in turn influence their networks and encourage further diffusion.

The first step is to conceptualize stakeholder involvement in the construction industry. Each stakeholder can use the framework described in the previous section to rationally assess the value associated with his or her decisions to adopt a sustainable design or practice. However, it is very likely that individual stakeholders and agencies may have completely different perceptions of value. The differences may arise from the limitations of proposed value calculation to include regional practices and allegiances. Greater availability of a particular construction material locally may also contribute to contractors having a different perception of value. Finally, market forces, regional demand and interactions between stakeholders may play a significant role in differences between the rational value and the perceived value. It is important to understand the reasons driving the gap between the stakeholder perception of value and the rational calculated value, as it will help in two ways: (i) introduce training methods and improve awareness among stakeholders to encourage adoption of sustainable technologies (ii) identify local and regional realities (resource availability, transportation needs, social preferences) that should inform the proposed value calculation method to more effectively reflect the social and regional components of sustainability.

In this section, we propose a theoretical model founded in system dynamics and agent based modeling (ABM) that can be used to simulate different scenarios in which the rational value and the perception of value differ. It can also be used to investigate relationships (if any) between professional networks in the AEC industry and the spatial distribution of individual perceptions of value driving adoption of technology Over time, do individuals with similar perceptions of value and practice, start doing business with each other? If so, how does such clustering of individuals and consolidation of ideas within cliques impede or encourage the diffusion within the entire community?

The model is founded in Bass' (1969) model to study diffusion of infectious diseases. The important parameters in the spread of the disease are infection rate (R), contact rate or the frequency of interaction between individual stakeholders (c), the infectious population (I), susceptible population (S), and total population (N). The infection rate (R) determines the spread of disease within a population. It is a function of the variables c, I, S, N, and infectivity (i). I, S, and N, characterize the size and

composition of attitudes within the professional network. The infectivity (*i*), contact rate *(c*), and probability of interaction (*p*) characterize the nature of interactions between the stakeholders and the topology of the network that defines the context within which decisions are made. Stakeholders who have adopted sustainable alternatives are considered infected and ones that are willing to adopt are considered susceptible. Construction contractors (individual stakeholder) who tend to work often on highway construction and maintenance projects, and the state Department of Transportation (agency stakeholder) are strongly connected in the network and will have high values of contact rate, and infectivity.

In the network, stakeholders interact at a certain contact rate, measured as contacts per person per time-period, or 1/time period. The infection rate, (*R*), can be calculated as the total number of encounters within the network, *S* times *c*, multiplied by the probability that any of those encounters is with an infectious individual, *I*/*N*, multiplied by the probability that an encounter with an infectious individual results in infection:

$$R = (ciS)(I/N) \quad (3)$$

Keeping the total population fixed, i.e. no new stakeholders entering the market (this is an assumption to simplify the model), we get the constraint:

$$S + I = N \quad (4)$$

The infection rate equation then becomes:

$$R = (ciI)(1-I/N) \quad (5)$$

The dynamics within this system continuously changes with stakeholders moving from the susceptible category to the infectious category, and vice versa if the stakeholders "recover" and move back to the susceptible category. While an infection denotes the adoption of a green technology, recovery denotes an unsuccessful adoption – resulting in the stakeholder rejecting a technology that they had considered sustainable. The contact rate (*c*) is directly proportional to infectivity, and the infection rate within the network. If individuals remain infectious indefinitely (i.e. there is no recovery), then the dynamics of the spread of disease follows an S-shaped growth curve, provided there are no significant delays in the negative depletion loop that constrain the population. If however the infectious individual recovers and returns to the susceptible category, then dynamics shows a bell-shaped curve. The 'tipping' point on an S-shaped or bell-shaped curve is the point where the positive loop dominates the negative loop. We will calculate the parameters from the collected data and calculate the infection rate at any point of time.

The above model was used to develop a simulation of a professional network using ABM. Each node represented an individual autonomous agent situated within a network of other agents or stakeholders. The nodes were weighted by a number, which reflected the probability of infection and contact rate between any two agents. Simple interactions rules between the stakeholder agents are used in which, any two agents only interact and influence each other if their perceptions of value are similar and they repel each other if their perceptions are radically different. The simulation generated the population dynamics of a random network that is uniformly distributed with agents that are "susceptible" – willing to adopt, "infected" – already adopted and "uninfected" – against adoption. Figure 4, shows the dynamics of how the infection proceeds within a simulation of the dynamics of change within a professional

network. The simulation represents stakeholders who are infected, susceptible and uninfected as nodes on a graph. The edges connecting the nodes reflect stakeholder relationships that define the topology of the professional network. The average edge weights show the strength of interactions within the network. The spread of infection within the network is dependent on how much influence individual stakeholders have on each other (quantified by c and i), which is directly a function of the edge strengths (Eq. 5.). Figure 5, illustrates the dynamics of change in the stakeholder population. It validates the behavior predicted by the system dynamic model. This is important because, the ABM does not directly program in any of the feedback loops in the system dynamics model. The simple interaction rule set however produces the behavior expected from the Bass model, showing that it can be used to study the diffusion of green technology within professional networks.

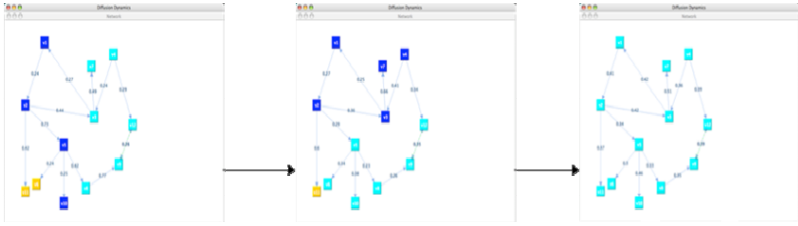


Figure 4. Dynamics of "infection" within a hypothetical professional network

This model is currently theoretical and the next step in this research is to conduct a field study of how perceptions of value vary within professional networks and use them to calibrate the simulation and study differences between fates of networks that have the actual stakeholder perceptions and one that is informed by rational calculations of value. Future results from this research can be used to identify specific factors within the construction industry that when interfaced with policy can significantly improve the adoption of technologies sustainable to professional networks.

Conclusions

In this paper we have presented a combined "top-down" and "bottom-up" approach to study decision-making driving the individual adoption of sustainable technology and its diffusion in the AEC industry. The paper uses a reductionist approach to calculating value associated with individual decisions, while framing the problem of diffusion of sustainable practices using a complex systems framework. The primary challenge of future work will be to address further development of performance distributions of different building elements to aid in calculating value associated with sustainable decision-making. In addition, field data collection regarding practices in the AEC industry will help define professional networks and quantify parameters such as contact rate and infectivity to study diffusion of sustainable practices in the AEC industry.

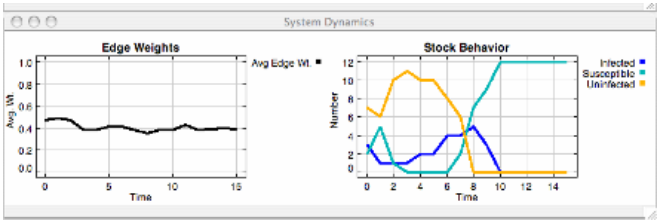


Figure 5. Population dynamics within the simulation

References:

Bass, F. (1969) "A new product growth model for consumer durables." Management Science 15, 215-227.

Cicas, G., Hendrickson, C. T., Horvath, A., and Matthews, H. S. (2007), "A Regional Version of a U.S. Economic Input-Output Life-cycle Assessment Model." Int. J. of Life Cycle Assessment, 12(6), pp. 365-372.

Cryer, B., Felder, J., Matthews, R., Pettigrew, M., Okrent, B. (2006). Evaluating the Diffusion of Green Building Practices. UCLA Anderson School of Management. Applied Management Research Project. Fall 2005/Winter 2006.

Fenner, R., Ainger, C., Cruickshank, H. and Guthrie, P. (2006) "Widening engineering horizons: addressing the complexity of sustainable development." Engineering Sustainability, 159 (ES4), pp. 145-154

Guggemos, A., and Horvath, A. (2006), "Decision-Support Tool for Assessing the Environmental Effects of Constructing Commercial Buildings." J. of Architectural Engineering, ASCE, 12(4), pp. 187-195.

McGraw Hill Construction. (2005). Green Building Smart Market Report. 2006 Green Building Issue. New McGraw Hill Construction.

Mukherjee, A., Muga, H. & Van Dam, T. (2006) "Towards Building Sustainable Concrete Pavements." In the Proceedings of the 1st. International Construction Speciality Conference, Canadian Society of Civil Engineering (CSCE), May 23-26, 2006, Calgary Canada, 2006

Muga, H., Mukherjee, A. & Mihelcic, J. (2008) "An Integrated Assessment of the Sustainability of Green and Built-up Roofs," Journal of Green Building, Vol. 3(2), pp 106-127.

Rogers, E.M. (1995). Diffusion of Innovation. 5th Edition. The Press, New York

Siegler, D. R. (2006). Green Roofs for Austin: Toward a More Progressive Model of Technology Transfer. Thesis. University of Texas at Austin.

Stewart, Charles T., and Yasumitsu Nihei. (1987). Technology Transfer and Human Factors. Lexington, Mass.:Lexington Books.

Turner Construction Company. (2005). "Green Building Market Barometer." Available from Turner Construction website. <http://www.turnerconstruction.com/greenbuildings/content.asp?d=2199>, accessed January 2008.

U. S. Green Building Council (2005) "An introduction to the U.S. Green Building Council and the LEED Green Building Rating System." USGBC, Washington DC.

KEY ATTRIBUTES OF A LONGITUDINAL STUDY OF GREEN PROJECT DELIVERY

Sinem Korkmaz[1], Michael Horman[2], David Riley[3]

[1] Assistant Professor, Michigan State University, 201D Human Ecology, East Lansing, MI 48824; PH: (517) 353-3252; e-mail: korkmaz@msu.edu
[2] Associate Professor, The Pennsylvania State University, 104 Engineering Unit A, University Park, PA 16802; PH: (814) 863- 2080; e-mail: mjhorman@psu.edu.
[3] Associate Professor, The Pennsylvania State University, 104 Engineering Unit A, University Park, PA 16802; PH: (814) 863-207; e-mail: drr107@psu.edu

Abstract
If green buildings are to continue to reduce the environmental impact of buildings and improve the operating performance of facilities, it is now more important than ever that a study of key project delivery practices, like teaming strategies, contracting approaches, and incentives, be established for these projects. When the performance outcomes of these projects, like sustainable rating, final cost, project schedule and operating performance, are statistically correlated to the project delivery practices, tremendous insight is gained for owners on how to establish their team so that their performance objectives are maximized on their green project. Initial exploratory research reported in this paper confirms how scientifically challenging such a study is to pursue with rigor. There are so many potential variables that may impact sustainable performance outcomes that a quality study needs a sample size in the thousands. By necessity a large study must occur over many years and thus the design of the study is crucial due to the time that lapses between implementation and results. This type of study, often referenced as a longitudinal study, is common in more mature disciplines of anthropology and medicine, especially, epidemiology. The contributions of the paper include a set of preliminary project delivery attributes to focus on for green building projects and data collection and analysis methods for large study of green building project delivery.

Introduction
The terms “sustainability” and “green” have gained recognition in the architecture, engineering, and construction (AEC) industry within the past decade, as the world has become more sensitive to the issues of the environment and global climate change. Globally, buildings contribute to substantial resource and energy consumption, ecosystem changes and global warming. As an example, in the U.S. buildings

consume approximately 40% of all energy, 72% of all electricity, and produce 39% of primary greenhouse gas emissions (DOE 2007). Research findings also showed that operating and personnel costs (totaling up to 99% of the business expenses related to building and personnel costs) over the life-cycle of a building considerably exceed the design and construction costs (DOE, 2003).

The potential green buildings offer to reduce operation and maintenance costs and improve well-being of its occupants, coupled with the above presented research findings, justify the importance and timeliness of more aggressively engaging the AEC industry in efforts toward sustainability. As a result, recognized by owners, public, and governments, the green building market is expanding in the U.S. with an expected value of green building construction starts is between $10-20 billion through 2010 (MCH, 2007). This growth represents a large share of the U.S. construction industry where the total construction in 2006 was $ 1.2 trillion (USCB, 2006).

Existing green building guidelines are mostly product based (e.g. Leadership in Energy & Environmental Design -LEED®- and Green Globes™) and lack the process component. Therefore, owners and project teams are not guided on "how" to manage these projects. As a result, projects may end up with less than optimum performance with potentially higher costs. There is a need for a project delivery research in the green building market that can guide owners and project teams in their practices to maximize project performance such as cost, schedule, operating, and sustainability performance.

Background and Research Need

Project delivery and contracting strategies define how project teams form, their working relationships and levels of involvement during project timelines, and incentives to encourage contribution to the project. The design of project processes is critical to success or failure of projects (Sanvido and Konchar, 1997).

Extensive research in the literature has attempted to understand the effects of project delivery attributes on project performance outcomes. Molenaar and Songer (1998) examined the correlations between possible process indicators (project, owner, market, relationship variables) and potential performance metrics (e.g., compatibility of budget and schedule variance with user satisfaction and expectations) in public sector design-build project selection and found all defined process indicators to be significant for project success; however, the owner was the most important variable in their prediction models. Chan et al. (2002) studied design-build projects in Hong Kong and identified project team commitment, client's and contractor's competencies as significant predictors for successful project outcomes. Thomas et al. (2002) observed better project outcomes in design-build projects in regards to cost, schedule, safety, changes, rework, and practice use compared to the impacts of design-bid-build projects. Ling et al. (2004) defined a wide range of variables and examined the correlations between eleven possible useful project performance metrics and 59 possible process indicators for projects using design-build and design-bid-build project delivery systems. Bennett et al. (1996) compared the relative effects of design-build, design-bid-build project delivery methods on performance outcomes with regards to cost, schedule, and quality using statistical techniques. Konchar and Sanvido (1998) used a similar approach with a larger data set, adding construction

management at risk project delivery system in to the comparisons. Both studies not only provided significant results related to project delivery systems (e.g. indicating design-build as the best performing project delivery system), but also showed that other critical project delivery attributes can affect project performance.

Different from traditional building projects, green buildings require additional considerations in their delivery processes to achieve expected performance goals (Riley et al., 2004). Early involvement of "green" concepts in projects and owner's commitment to sustainability (Lapinski et al. 2006; Beheiry et al., 2006), integrated design process (NIBS, 2005), team experience (GSA, 2004), early involvement of key project participants (Riley and Horman, 2005), and utilization of energy strategy and simulation tools in the early stages of the design process (Horman et al., 2006) are key components that lead to superior outcomes in green building projects. Therefore, there is a need to define project delivery evaluation metrics, understand the affects of project delivery systems on performance outcomes, and more importantly study project delivery practices for green building projects as they differ from traditional projects with their processes and outcomes. The green project delivery research in the literature completed up to date is either case study based (Lapinski et al. 2006) or exploratory in nature (Bilec and Ries 2007) due to the extensive number of potential variables to be examined in green building project delivery and the limited sample size in the field.

A recent research (Korkmaz 2007) conducted at Penn State employed mixed methods to study the associations between project delivery attributes and project performance outcomes for green buildings. The study expanded the knowledge regarding green project delivery through important insights about important project delivery attributes. However, it also suffered the challenges affecting the significancy of study results. The insights gained from this study points to a need for an innovative research design in this field to reach rigorous results. The lessons learned from this research along with the key attributes of the proposed research design are explained in detail in this paper.

Summary of Initial Green Project Delivery Research Results

The initial extensive green building project delivery research (Korkmaz 2007) utilized a "QUAN- Qual approach" (Gay and Airasian 2005). Data analysis began with a quantitative analysis to select the meaningful evaluation metrics needed to define green building project delivery through statistical examination (using univariate and multivariate analyses) of the collected project data. The data analysis then was followed by the qualitative approach to support the findings of the quantitative analysis, and to learn additional lessons from case study analyses and exemplary projects.

This research: (1) defined evaluation metrics for green building project delivery; (2) developed tools/methods to collect green building project delivery data; and (3) illustrated data analysis methods for green building project delivery research. The evaluation metrics defined in this research included project delivery attributes (i.e. process indicators and control variables) and project performance as summarized below in Table 1.

This exploratory research examined the potential associations between project delivery attributes and project performance using a 40 green office building sample

and concluded that the defined evaluation metrics are useful in understanding green building project delivery. More specifically the study found that:

Table 1: Summary of defined green building delivery evaluation metrics

PROJECT DELIVERY ATTRIBUTES	
Process Indicators	**Control Variables**
Owner commitment Project delivery system Project team procurement Contract conditions Design integration Project team characteristics Construction process	Project type Onerous contract clauses Building use Building system characteristics Building size Building green features Location Completion rate of CDs Project complexity Pool of qualified contractors Regulations/ Legal constraints
PROJECT PERFORMANCE	
Performance Metrics	
Schedule performance Quality performance Cost performance Safety (OSHA measures) Levels of high performance green (HPG)	

- Timing of contractor's involvement in projects (i.e. design integration) and using envelope mock-ups before construction (i.e. construction process) are the strong process indicators affecting most of the performance outcomes;
- Potential relations exist between: owner's way of procuring the project teams and cost/schedule outcomes; contractual relations and project schedule; construction process and quality and high performance green (HPG) performance; and team members' experience and project schedule and cost performance;
- The following variables under related process indicators have the potential to positively influence project performance outcomes:
  - Using negotiation for team selection process, contractual relations between owners and project participants, and including "green" in contracts (Contract conditions);
  - Accepting the role as driving force for building "green" and introducing "green" early in the process (Owner commitment);
  - Key project participants' early involvement in the process and use of energy and lighting simulations beginning early in the process (Integrated Design);
  - Construction management and design-build systems outperforming design-bid-build (Project Delivery);
- "Size" and "completion rate of construction documents at the time of construction" appear to be the control variables to affect performance outcomes;
- The exemplary projects exhibit a greater number of process indicators that align with the expected research outcomes.

The study also included contributions in data collection and analysis areas:

- The developed data collection tool was found to be useful in collecting meaningful green project delivery data;
- Use of an online data collection tool, which also was utilized for this study, is valuable for collecting meaningful green building project delivery process data that can describe reliable metrics to affect project performance outcomes due to the tool's ease of reaching different project participants for a single project at the same time;
- The quantitative analysis approach assisted development of insights into performance metrics as well as screening the defined metrics;
- The qualitative analysis helped define additional process indicators such as: inclusion of green specifications in the request for proposals for project team procurement; need for working with suppliers when preparing specifications to ensure reliable construction estimates; emphasis on importance of design-build mechanical and electrical subcontractors to enable better performance at lower cost; involvement of designers and builders in the post-occupancy phase of buildings to assure the building operates at maximum performance.

Research Challenges

The findings of the presented research provide important insights to owners in establishing their project teams to maximize their project performance. Especially, the quantitative analyses that examine the correlations of project delivery practices with green project outcomes provides a better understanding of the practices to be followed for successful green project delivery. However, the significance level for most of the research outcomes was low with small number of observations at various levels for the examined variables.

The challenges of this research effort were due to several limitations that other green project delivery research would also suffer. The most important of these challenges is the limited sample size. The project based nature of this research requires large sample sizes due to the variability in the population pertinent to project size, complexity, and type. With the number of potential variables to examine in green project delivery research (that exceed a hundred in the presented study) and the number of categories for each variable, the sample size needed for a rigorous research effort reaches up to a thousand. As illustrated in the power and sample size graph below (Figure 1) developed based on the findings of the presented research effort, larger sample sizes yield the desired levels of statistical power in green building project delivery research. However, the green building market still being in its infancy and the restricted size of green buildings in the market restraint the findings of this research.

Additionally, field researchers face project delivery data collection challenges due to: (1) unwillingness of the project actors to share project data; (2) the need to collect project delivery data from a variety of project actors (e.g. project manager, green design consultant, owner, and designer); (3) the limited timeline to collect meaningful project delivery data without the guidance of any project and team databases.

Moreover, the immaturity of the learning curve for the evolution of green design and building practices, the lack of a system to record project data, and project teams failing to pass their lessons learned on green projects to other project teams and

researchers present the other constraints that limit the potential for lessons to be passed to owners and project teams regarding green building project delivery.

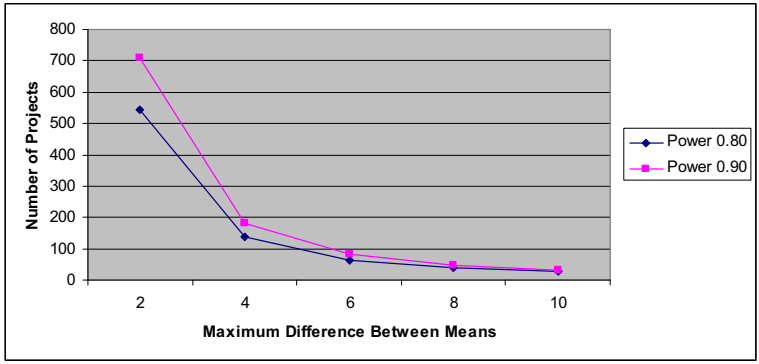


Figure 1: Sample size for cost growth vs. contract with green design coordinator

Key Attributes of a Longitudinal Study

The presented green project delivery research provides insights to owners to achieve their expected project performance goals. However, rigorous research outcomes are needed in this area to validate the preliminary study findings and to guide owners and project teams in their green building project practices. The limitations listed above in this research point to the need for a large sample size that can only be reached through a longitudinal study over several years. The main objectives in such research are to: (1) reach the desired sample size as the market expands; (2) capture the knowledge base in the evolving green market over time; (3) produce rigorous results to guide owners in green building project delivery for maximized project performance.

Longitudinal studies mostly have been undertaken in research fields, such as social sciences, medical sciences and anthropology that involve change in human development. This capacity to follow events through time, cross reference them and observe changes influenced by wider contexts and in turn influencing those contexts themselves – gives longitudinal studies a major role in understanding change. Considering the constant evolution unless the studies are done over a period of time the loss of knowledge base is imperative. Thus, longitudinal studies need to be conducted as the knowledge base itself changes in time until a desired sample size is reached and the knowledge based gets saturated. An analogy can be drawn from a case study that was conducted in the field of prostate-specific antigen. Until this study was conducted only five other papers were available on the topic due to the lack of sample size. The author agrees that even though the results of these papers have a lot of variability they provided a basis to his study when there was enough sample size (Inoue, 2004).

In 2006, the U.S. Green Building Council (USGBC), reported 775 million sq. ft. commercial space registered under their LEED® green building rating system (MCH 2007). With more green projects getting certified, the sample size is continually increasing, also increasing the industries know how in the field. But this

knowledge is not being recorded and is passing from generation to generation verbally, getting distorted with each communication. Similarly in the construction industry, we cannot wait for the sample size to increase to the require point, as by then fine details of projects would either be lost or distorted with the passage of time. Once recorded, the projects can then be turned into data points in a longitudinal study.

The design of a longitudinal study becomes crucial due to the time that lapses between implementation and results. Additionally, the study might suffer from missing values, low response rate, and bias in data collection; and shortcomings in data coding and results of analysis phases. Therefore, strategies to assure data quality, efficient data collection, and analysis in this type of research needs to be addressed. With the insight from the research reported in this paper, the key attributes of such a study are presented below.

Data Quality:

1) *Develop a system to measure the levels of sustainability achieved in green building projects:* (a) adopt a green building assessment system such as LEED® that has received the greatest recognition in the U.S. green building community (USGBC 2006) for the ease of data collection; (b) develop questionnaires that employ the same criteria as the selected green building assessment system for including non certified green building projects in the sample; and (c) account for various versions of the adopted green building assessment system (i.e. LEED®) and slight changes in them in time. A potential remedy for this potential data coding problem is to use a rate of achieved points out of possible points.
2) *Account for various locations and years of construction:* RS Means historical construction cost database can be used as a reference for various locations and years of construction to conduct cost adjustments for reliable comparisons.
3) *Establish a variety in geography, owner organization, project team, and project delivery system to eliminate sampling error in data sets*: Korkmaz (2007) found in case studies the federal government in the Washington D.C. area promotes LEED® certification through permissions for higher construction intensity or requirements in lease contracts. On the other hand, stringent local energy requirements in California help develop highly performing buildings (Kats et al., 2003). The primary motive in enabling legislation for green construction may affect performance outcomes and might change in time in various geographies. Moreover, the projects owned and/or delivered by the same organizations can produce biased results. Lastly, the project delivery methods are essential in explaining the project delivery characteristics such as team integration and contractual relations. Therefore, a structure should be established in the data collection system to ensure variety in the study in terms of geography, owner, project team, and project delivery systems used and avoid sampling error.

Data Collection:

1) Develop partnerships with industry champions (e.g. USGBC) to ensure consistent data entry over time.

2) *Include all major project participants in the data collection process to avoid response and non-response bias:* (a) responses for subjective variables such as quality and team characteristics can be collected from all major team members and coded based on their average scores to avoid response bias; and (b) including all major project parties in the data collection process can improve the chance of collecting adequate data even for the projects at the lower end of green achievement scale which would enable the study to avoid non-response bias.
3) *Apply the survey in a web-based format:* This strategy enables a user friendly format to send survey, receive answers, and record data. Extra efforts to mail or scan completed surveys discourage respondents' participation. On the other hand, a web-based survey encourages interactive and motivated survey submission.
4) *Split the survey questions into parts according to their appropriateness for segments of project team members' interests /roles:* This strategy enables a shorter list of questions for each project team member to answer. It eliminates the effort needed for a single respondent to contact other project participants to provide answers for questions related to specific areas of expertise; thus each project participant needs to devote less time to complete the questions which is a major discouraging factor influencing survey completion.
5) *Contact owners as the primary respondents:* Receiving owners' perspective is crucial for green building project delivery research in aspects like team characteristics, project success, and project quality. Moreover, an owner is the only party present during the whole project delivery process, so in most cases, only the owners are able to answer questions regarding project delivery processes. Additionally, owners' commitment and guidance can motivate other project participants to become involved in the data collection process. Lastly, essential project delivery data that might be confidential for project teams can only be obtained by the owners' permission. Receiving owners' approval would help increase response rate in project delivery field-studies.
6) *Use open ended questions to help determine if any problems occur in the project are due to the project delivery practices or the external variables.*

Data Analysis and Results:

1) Utilize quantitative methods to validate associations between green building project delivery attributes and project performance outcomes.
2) Perform qualitative analyses to draw more in depth lessons from case studies and include additional variables into the set of green project delivery evaluation metrics as the knowledge base in the green market evolves in time.
3) Develop a database for project teams to not only submit their project data but also to consistently see research results as they evolve in time to establish a continuous recording and learning culture for project delivery in the green building market.

Conclusions and Directions for Future Research

Green building project delivery research has great potential to provide insights to owners in establishing their project teams and practices to maximize their project performance such as cost, schedule, and sustainability achievement. However, such

research efforts are hindered by limitations like the large number of potential variables in project delivery research and limited green building population in the market. Coupled by the data collection and analysis challenges researchers experience in the field, green building project delivery research becomes challenging to conduct and produce rigorous results.

There is a need for a longitudinal study to record the evolving green building delivery knowledge base in the market and collect the large number of projects to conduct this research with rigor. Based on the insights gained from a recent comprehensive green building project delivery research, this paper presented the potential pitfalls of such research and strategies to overcome those. These strategies are categorized under data quality, data collection, and data analysis sections. The presented strategies: (1) account for data structure changes and variations in time; (2) prevents the study design from potential biases such as response and non-response bias, and sampling error; (3) include data collection strategies to increase response rate and ensure continuous data collection in time; and (4) gives data analysis directions to gain deeper insight in green building project delivery.

After gathering more data in the course of this longitudinal research, a quantitative analysis approach can generate rigorous results. However, qualitative methods should always be apart of such studies to provide an additional method in green building project delivery research, since the green building market will evolve over time, and innovative ideas/practices project teams utilize to improve their project delivery processes may arise. Only qualitative methods can capture those new and innovative methods. Moreover, different project teams have different project goals. Using comparison techniques with case studies that have similar objectives would help project teams to select which delivery attributes to employ in their own projects. Therefore, use of quantitative and qualitative methods in green building project delivery research is useful for expanding the knowledge base in this area.

References

Beheiry, S. M. A., Chong, W. K., and Haas, C. T. (2006). "Examining the Business Impact of Owner Commitment to Sustainability." J. Constr. Engrg. and Mgmt., 132(4): 384-392.

Bennett, J., Pothecary, E., Robinson, G., (1996). “Designing and Building a World Class Industry”. Reading, UK., University of Reading.

Bilec, M. and Ries, R., (2008). "Preliminary Study of Green Design and Project Delivery Method in the Public Sector." Accepted for publication *Journal of Green Building*.

Bilec, M. and Ries, R., (2007), “Preliminary Study of Green Design and Project Delivery Method in the Public Sector.” *Journal of Green Building*, 2(2): 151-177.

Chan, A. P. C. S. D., and Chan A. P. L. (2004). "Factors Affecting the Success of a Construction Project", J. Constr. Engrg. and Mgmt., 130(1): 153- 155.

DOE, (2003). Department of Energy, “The business case for sustainable design in federal facilities”, Washington, DC: Federal Energy Management Program.

DOE. (2007). U.S. Department of Energy 2007 Buildings Energy Databook. <http://buildingsdatabook.eere.energy.gov/?id=view_book > (February 2008)

Gay, L.R., Mills, G.E., Airasian, P.W., (2005). "Educational Research: Competencies for Analysis and Applications", Eight Edition, Pearson Education, Inc.,Pearson Prentice Hall, p.184-185.

GSA, (2004). "LEED Cost study: Final report", General Services Administration, Washington, D.C., USA.

Horman, M. J., Riley, D.R., Lapinski, A.R., Korkmaz, S., Pulaski, M. H., Magent, C., Luo, Y. , Harding, N. , Dahl, P. K. (2006). "Delivering green buildings: Process improvements for sustainable construction", J. of Green Bldg., 1(1): 123-140.

Kats G., A. L., Berman A., Mills E. and Perlman J. (2003). "The Costs and Financial Benefits of Green Buildings", California, Report developed for Sustainable Building Task Force.

Konchar, M. and Sanvido, V. (1998). "Comparison of U.S. project delivery systems" Journal of Construction Engineering and Management 124(6): 435-444.

Korkmaz, S., (2007). "Piloting Evaluation Metrics for High Performance Green Building Project Delivery", Ph.D. Dissertation, Penn State, University Park, PA.

Lapinski A. R. , H. M. J., and Riley D. R. (2006). "Lean Processes for Sustainable Project Delivery", J. Constr. Engrg. and Mgmt., 132(10): 1083-1091.

Ling, F. Y. Y., S. L. Chan, et al. (2004). "Predicting performance of design-build and design-bid-build projects", J. Constr. Engrg. and Mgmt 130(1): 75-83.

MCH, (2007). "McGraw-Hill Construction Education Green Building SmartMarket Report", The McGraw-Hill Companies, Inc.

Molenaar, K. R. and A. D. Songer (1998). "Model for public sector design-build project selection", ASCE Journal of Construction Engineering and Management, 124(6): 467-479.

NIBS, (2005). "Whole Building Design Guide", <http://www.wbdg.org/>, (10/2006).

Riley, D., Magent, C. and Horman, M. (2004). "Sustainable metrics: a design process model for high performance buildings", CIB World Building Congress. Toronto,

Riley, D., and Horman, M. (2005). "Delivering green buildings: High performance processes for high performance projects", Engineering Sustainability 2005: Conference of the Mascaro Sustainability Initiative, Pittsburg, PA.

Sanvido, V. E. and Konchar, M. D. (1997). "Project delivery systems: CM at risk, design-build, design-bid-build", Austin, Texas, CII.

Thomas, S. R., Candace L. Macken, Tae Hwan Chung, and Inho Kim (2002). "Measuring the impacts of the delivery system on project performance - Design-build and design-bidbuild", Austin, TX, NIST.

USCB, (2006). "Economic Census: Annual Value of Construction Put in Place in the United States", U.S. Census Bureau, <http://www.census.gov/econ/const/C30/total.pdf>, (3/2007).

USGBC, (2006). U.S. Green Building Council. <http://www.usgbc.org/>, (10/2006).

PERFORMANCE TESTING OF AN INTEGRATED SOLAR COLLECTOR SYSTEM

Marwa Hassan[1] and Yvan Beliveau[2]

[1] Louisiana state university, CMIE Department, assistant Professor, 3128 PFT hall, Baton Rouge LA 70803, Tel: (225) 578-9189, Fax: (225) 578-9189, email: marwa@lsu.edu

[2] Georgia Anne Snyder-Falkinham Professor, Head of Building Construction Department, Virginia Tech, Bishop-Favrao Hall, Suite 430D (0156), Blacksburg, VA 24061.

Abstract

Due to the up-front costs of add-on solar collection systems, the cost-effectiveness of solar energy is still in doubt. Building integrated solar thermal systems may improve the cost-effectiveness of add-on collection systems given their ability to expand to cover the entire area of the roof at a reasonable cost. The objective of this study was to evaluate the effectiveness of a newly-developed flat-plate integrated solar collector system. The developed collector system consists of a low temperature flat plate collector integrated within a concrete building envelope. To evaluate this system, a full-scale test prototype of the solar collector was constructed and instrumented with thermocouples. Measurements were conducted over a 7-month period in which the solar collector was evaluated over different climatic conditions. Based on the results of the experimental program, it was determined that the solar collector provided an efficiency ranging from 49 to 75% in the range of ambient temperature, solar radiation, and inlet temperature evaluated in this experiment. The estimated efficiency of the system was on the high range as compared to the reported efficiency of similar systems. Depending on the extent of the collection area, the developed solar collector can provide a significant portion of the building's space heating and hot water needs especially in the spring and summer seasons.

Introduction

In recent years, solar energy has received considerable attention as a viable source of energy supply. However, due to the up-front costs of solar collection systems compared to traditional conventional systems, the cost-effectiveness of solar energy is still in doubt (Rockwell 1999). Prior to the recent increase in energy price, it was estimated that a typical add-on solar water heating system would have a

payback period ranging from 12 to 14 years. However, as energy prices continue to rise, this payback period will shorten accordingly (Dymond 2007). Integrating solar energy flat-plate collection system into the building shell and mechanical systems may reduce the cost of solar energy systems as well improve the efficiency of the collection. In solar integrated design, the building is used as part of the solar collection system. Building integrated solar thermal systems have many advantages over normal collection systems including their ability to expand to cover the entire area of the roof at a reasonable cost. In addition, these systems usually have a longer service life, which results in less replacement of materials and more conservation (Archibald 1999).

The objective of this study was to evaluate the effectiveness of a newly-developed flat-plate integrated solar collector system. The developed collector system consists of a low temperature flat plate collector integrated within a concrete building envelope. The integrated solar collector roof panel was developed based on an iterative process of design, performance evaluation, and redesign. To avoid excessive cost of experimental methods and for quick assessment of the different design parameters, the iterative design process was conducted theoretically based on a validated three-dimensional (3D) finite element (FE) model. The developed FE model considered the main controlling parameters including conduction, convection, thermal radiation, existing climatic parameters like wind speed and direction, and operational parameters such as mass flow rate. The flexibility and accuracy of this technique allowed optimizing the geometry and operational parameters of the developed solar collector system. Therefore, the optimized design was used in this study. More details about this model have been presented elsewhere (Hassan 2005).

Background

Flat plate solar collectors represent the most economical, active method of solar energy collection (Duffie and Beckman 1980). They consist of an assembly of transparent covers over an absorber plate backed with thermal insulation. The cover serves three functions: preventing convection losses, reducing thermal radiation losses, and protecting the absorber plate against environmental hazards. While the absorber is a coated plate upon which the sun's energy is converted to heat, the insulation prevents back losses. Flat plate collectors use the absorber to heat air or fluid, which can then be used or stored for later use. They are typically used for applications requiring moderate heat gain (i.e. 100°C above ambient temperature) (ASHRAE 1999). The performance of a flat-plate plate collector can be assessed by determining the amount energy collected under different climatic conditions as follows:

$$Q_u = \dot{m} C_p (T_o - T_i) \quad (1)$$

where Q_u = amount of energy collected (J/s); $\dot{m}$ = fluid mass flow rate (kg/s); C_p = fluid specific heat (J/kg°C); T_o = outlet fluid temperature (°C); and T_i = inlet fluid temperature (°C). The instantaneous efficiency of the collector is also used to assess the performance of a given design and is calculated as follows:

$$\eta_i = \frac{\dot{m} C_p (T_o - T_i)}{A_c G_T} \quad (2)$$

where, A_c = the collection area (m^2); G_T = total solar radiation (W/m^2); and all other terms as previously defined.

Solar System Description

Design Process

The proposed integrated solar collector roof panel concurrently addressed various design criteria including functional integration for thermal performance, environmental design, durability, flexibility and sustainability, and reduction of construction costs. During its development, different materials and construction techniques were evaluated to satisfy these design criteria. Thermal performance was achieved by integrating a flat plate collector with a high thermal inertia material, also known as a thermal mass. Concrete was selected since it has a high thermal capacity, which indicates that it has a high heat storage capacity ($1936 kJ/m^3.K$). It was also found that although wood can provide a longer time lag, it is more expensive to manufacture in large thicknesses.

Environmental design was achieved by orienting the building to get the maximum solar exposure. Since the developed design was implemented for a solar panel constructed in Baton Rouge (Louisiana), the integrated solar roof was to be constructed on the south façade at an inclined angle of 35^o. Flexibility and reliability were achieved through the use of innovative construction materials and techniques. Among these materials and techniques lies the use of negative form and color pigments work that allows the user to achieve any desired surface finish and color when concrete is used. The developed design also makes use of low-conductive fiber composite connectors to minimize thermal bridging while providing a structural connection between the different building elements (Sauter 1991).

To achieve sustainability, the system should be durable as well as resistant to natural disasters including floods, hurricanes, and fires. Concrete structures can be designed to accommodate the aforementioned requirements using readily available technology (Mamlouk 1999). In addition, the proposed system was designed to be 100% water-proof through the use of high quality concrete mixes with negligible air voids. By using a composite concrete system, significant funds may be saved on labor through reduction of the number of trades present on-site. More savings can be achieved due to elimination of the need for maintenance due to multi-layer failure. In addition, costs of on-site construction and labor time may be minimized through utilization of pre-casting techniques followed by fast in-place assembly.

System Description

Cross section of the integrated solar collector design is shown in Figure 1. The integrated solar collector consists of a 6.35-mm single glass panel with a selective surface, followed by a 1-mm air-gap. A new class of glass panel, which is coated with a thin, optically transparent layer of silver sandwiched between layers of anti-reflective metal oxide coatings, was used. This coated glass layer insulated the

space above the absorber plate to prevent convective loss to the outside air while allowing sunlight to pass through. The thermal collecting medium consists of a fluid (water) circulating in copper pipes that are painted black to ensure maximum solar absorption. To protect against freeze damage, a mixture of water and propylene glycol may be used as a heat exchange fluid. To minimize construction cost and time as well as to reduce convection losses, the pipes are laid within an 850mm cavity containing seven 6.35-mm connected pipes. The copper pipes are connected together by a 1-mm copper plate absorber. The absorber plate is also painted black to maximize the absorbed radiation. The absorbed plate transmits the radiation to the pipes by conduction. The fluid absorbs the solar energy and transports it to storage.

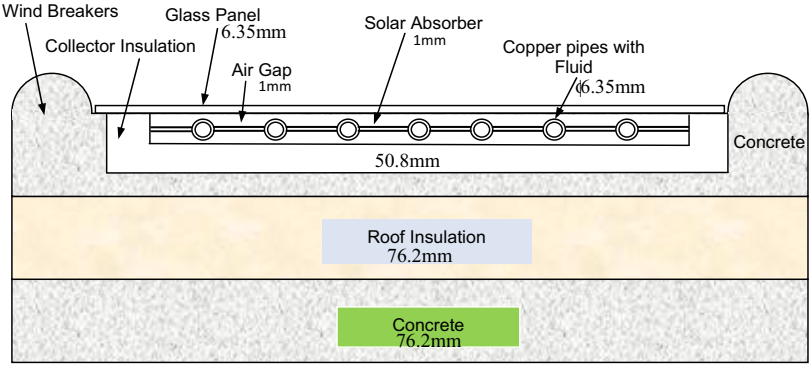


Figure 1. General layout of the developed flat-plate collector system

A 50.8-mm layer of insulation is placed below the pipes to reduce heat transfer to the adjacent 76.2-mm concrete. Spray polyurethane foam was selected as the insulating material in the developed design. This insulation material was favored in the proposed integrated system since it can be easily applied on the concrete material and provides superior insulation (R-value of 7.14 per inch after installation and 6.88 per inch after a few months) by expanding and sealing off leaks and gaps. In addition, this insulation material concurrently acts as a vapor barrier and therefore, avoids the buildup of moisture growth and mold growth. The 76.2-mm concrete layer is used to prevent growth of microbes in the polyurethane layer and to ensure healthy air quality within the system. The thicknesses of both the insulation layer and the concrete layer were selected to minimize energy losses and cost. A 76.2-mm thick polyurethane foam is placed under the concrete layer to act as a thermal insulation layer. The last layer consists of an additional 76.2-mm concrete layer that is used to ensure structural stability as well as to contribute to the thermal inertia on the inside of the facility. One innovative feature in the proposed design is that 76.2-mm semi-cylindrical concrete wind breakers are used in order to reduce convection losses by minimizing the impact of wind on the collector operation. The panel is connected by fiber reinforced plastic stirrups, used commonly in slab construction, to provide tensile and shear strength helping the panel to act as a composite system,

instead of a multi-layer system, in resisting temperature and loading changes. The aforementioned design is placed along the length of the building roof to cover the whole roof area.

Panel Construction and Instrumentation

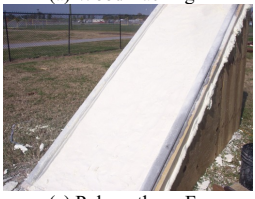
A full-scale test prototype of the solar collector was constructed at the LSU Petroleum Engineering Research and Technology Transfer Laboratory (PERTT Lab). The full-scale test setup was constructed without the roof insulation layer and the concrete structural layer presented in Figure 1, which were substituted with a wood backing. While these components are part of the proposed integrated design, their effects on the thermal performance of the collector system was thought to be negligible and were therefore omitted to reduce construction costs. Construction of the system started with placement of the wood backing, followed by pouring and finishing of the concrete layer, and application of the spray polyurethane foam (Figure 2). The copper absorber plate was then installed followed by placement of the glazing panel.



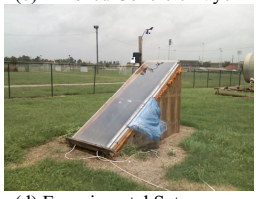
(a) Wood Backing



(b) Finished Concrete Layer



(c) Polyurethane Foam



(d) Experimental Setup

Figure 2. Construction of the Integrated Solar Collector System

The experimental setup was instrumented with T-type thermocouples placed at the fluid inlet and outlet as well at different locations in the solar collector. In addition, a flowmeter was installed prior to the fluid inlet to control and monitor the mass flow rate in the system. Readings from the thermocouples were obtained at a frequency of one measurement per minute over the entire experimental period. A weather station was also installed near the solar collector to measure air temperature, solar radiation, humidity, wind speed and direction, and rainfall. Measurements were automatically transferred wirelessly to a desktop computer placed in a nearby building. Measurements were conducted over a 7-month period (from December 13th 2007 to July 8th 2008) to evaluate the efficiency of the system over different climatic conditions.

Results and Analysis

Thermal Efficiency

To determine the thermal efficiency of the constructed solar collector system, two tests were conducted in the mid-hours of two consecutive days in May according to the ASHRAE standards (ASHRAE 93-86). Thermal efficiency was calculated based on Equation (2) at a test flow rate of 0.02kg/hr. To simulate a range of inlet fluid temperatures, one of the tests (Test 1) was conducted by connecting the solar collector system to a water heater supplying the system with water entering the system at a temperature ranging from 35 to 45°C. The second test was conducted while connecting the solar collector system to regular tap water entering the system at a temperature ranging from 25 to 30°C (Test 2). Figure 3 presents the variation of the collector's thermal efficiency with $(T_i - T_a)/G_T$. As shown in this figure, thermal efficiency of the proposed integrated system was estimated to vary from 49 to 75% in the range of ambient temperature, solar radiation, and inlet temperature evaluated in this experiment.

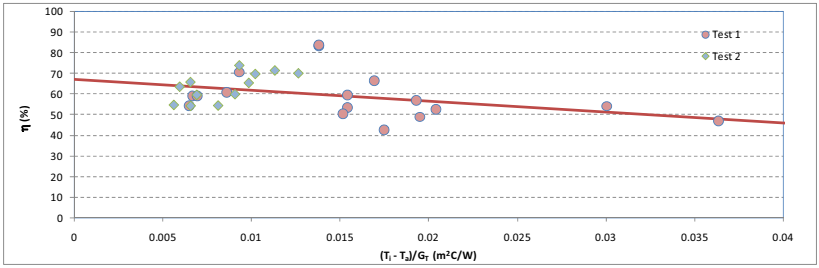


Figure 3. Experimental collector efficiency data measured for the Integrated Solar Collector System

A linear regression model was fitted to these measurements to predict the collector performance at lower solar radiation and at cooler temperatures. When the factor $(T_i - T_a)/G_T$ reaches 0.1, it was estimated that the efficiency of the system would be 15%. It is evident from these results that the flat-plate collector would perform more efficiently at high solar radiation and ambient temperature. Nevertheless, the estimated efficiency of the system was on the high range as compared to the reported efficiency of similar systems in the literature (Vejen et al. 2004; Lin et al. 2006).

Fluid Temperature Gain

Four mass flow rates were used over the course of the experiment. The mass flow rate was adjusted based on the pertinent climatic conditions and the outlet temperature of the fluid. Whenever the outlet fluid temperature increased excessively, the mass flow rate was adjusted in order to avoid damage to the collector or the integrated panel. In cold weather (from mid-December to the end of February), the mass flow rate was set at $20cm^3$/min in order to increase the fluid exposure to solar radiation and to boost the energy gain. As the weather started improving (from

March 1st to March 31st), the mass flow rate was increased to 100cm^3/min. In the month of April, the mass flow rate was set at 300cm^3/min. In the month of May, the mass flow rate was set at 700cm^3/min. For the rest of the experiment, the mass flow rate was then set at 1000cm^3/min. While these adjustments were made in this experiment manually, optimum mass flow rates may be determined automatically by incorporating an efficient control strategy, which adjusts the operation of the solar collector based on the need and conditions of the building. More details about the recommended control strategy are provided in the following sections of this paper.

Figures 4 and 5 present the increase in fluid temperature ($T_{outlet} - T_{inlet}$) in two typical days in the months of January and June, respectively. Under a mass flow rate of 20cm^3/min and with modest solar radiation, the increase in fluid temperature ranged from 12 to 25°C in January. Under a mass flow rate of 700cm^3/min and with sunny conditions, the increase in fluid temperature ranged from 25 to 35°C in June. It is noted, however, that the increase in fluid temperature can be increased by reducing the mass flow rate in the summer season. However, in order to achieve the maximum energy gain as described by Equation (1), a balance should be kept between the mass flow rate and the increase in fluid temperature. This highlights the importance of implementing an effective control strategy with the use of the solar collector.

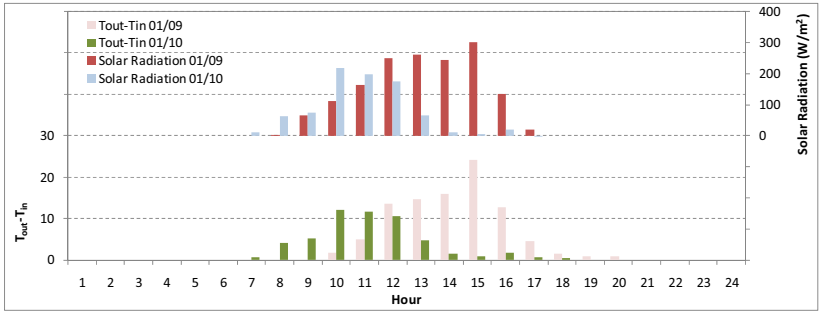


Figure 4. Increase in Fluid Temperature in January

Whenever a solar heat flux of 150W/m^2 or lower is encountered under all weather conditions, the collector experienced losses. Therefore, it is recommended that the solar panel be switched off not only during night hours but also below a solar flux of 150W/m^2 so that it can act as a normal insulated roof. As the solar intensity increases to between a solar heat flux of 150 and 300W/m^2, the heat gain increases slightly. There are no losses experienced in this range, but the energy gain is not sufficient to be used as a major heat source for the building. When the solar flux is greater than 300 W/m^2, the panel can generate enough energy to heat the structure and to act as a supplementary energy source, if needed.

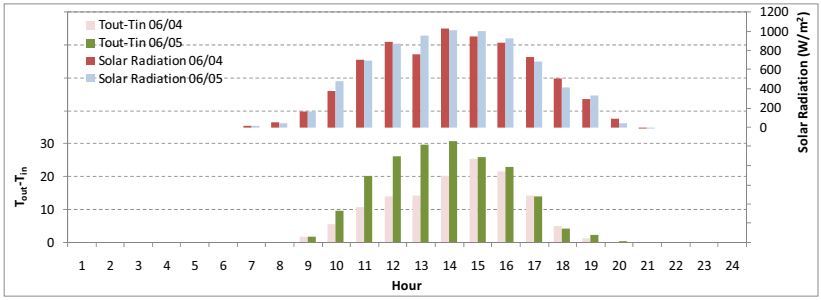
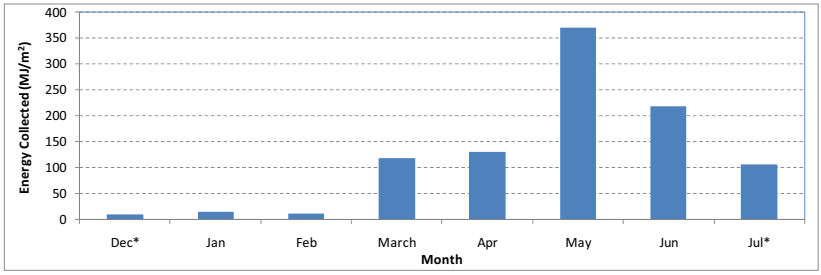


Figure 5. Increase in Fluid Temperature in June

Energy Collected

Figure 6 presents the monthly amount of energy collected as determined from Equation (1). As shown in this figure, the amount of energy collected during the spring and summer season is significantly greater than what was collected in the winter season. It also appears that operating conditions in May were properly selected. However, energy collection in June could have been improved by adjusting the fluid mass flow rate to a lower level. Therefore, there is a need to identify optimum operating conditions for the developed collector system. It is noted that these conditions depend on many factors including weather conditions (ambient temperature, solar radiation, and wind), location of the collector, and purposes of the energy collection process.

The developed solar collector system may be used to fulfill three major functions. First, the solar collector may be used to supply the building with hot water throughout the year. Second, hot water may be used to satisfy heating needs by transferring hot water to a low radiant heating system that transfers heat by radiation using water as a heat transfer fluid to supply energy to a building surface. Third, the solar collector may be used in the summer months to reduce cooling loads on the building by dissipating the heat applied on the roof, which can account for 22% of residential buildings' total heat load (Melody 2005). Whenever there is a mismatch between available energy and demand, the need for energy storage arises. Such storage eliminates one of the major disadvantages of solar energy, which is inconsistent supply. Previous research related to the developed collector system showed that a tank consisting of phase change material (PCM) may be used to store collected energy for later use (Hassan and Beliveau 2006).



* Only 13 days are covered for the month of December and 8 days for the month of July

Figure 6. Monthly Energy Collection per m2 of Roof Area Covered with the Solar Collector

Collector Control Strategy

The use of an effective control strategy will lead to improved system efficiencies. While it was not implemented in the presented experimental setup, it is recommended to integrate a simple method of control within the proposed active solar system. This control strategy regulates and ensures efficient and automatic operation of the active solar collection system. The control strategies and equipment that can be used to serve solar collection systems are quite simple; in several aspects, they are similar to those of conventional systems. The main difference between the controls used for solar collection systems and those used for conventional ones is the need for differential temperature (e.g., a collector storage differential) measurements rather than simple temperature sensing. The temperature differential can be measured using a temperature measuring instrument (e.g., thermocouple or thermistor).

The proposed control strategy should implement the following decision-making processes: *(1)* The collector system should be shut off at night. *(2)* If the output fluid temperature (T_{out}) is below the fluid inlet (T_{in}) temperature, the collector system should be shut off. A new attempt to turn the collector on may be conducted after an arbitrary waiting time. *(3)* If the output fluid temperature (T_{out}) exceeds 90°C (providing a factor of safety of 10°C), the mass flow rate should be gradually increased until the fluid temperature drops below 90°C, and then remains constant. *(4)* Output fluid temperature should be stored in a hot water tank or in a storage tank, where the excess energy is stored until the fluid's temperature is around 50°C, at which it can be released from the tank and circulated back to the solar collector for energy collection.

Conclusions

The objective of this study was to evaluate the effectiveness of a newly-developed flat-plate integrated solar collector system. Based on the results of the experimental program, the following conclusions may be drawn:

- The solar collector provided an efficiency ranging from 49 to 75% in the range of ambient temperature, solar radiation, and inlet temperature evaluated in this experiment. The estimated efficiency of the solar collector was on the high range as compared to the reported efficiency of similar systems.

- With modest solar radiation, the increase in fluid temperature ranged from 12 to 25°C in January. Under a mass flow rate of 700cm^3/min and with sunny conditions, the increase in fluid temperature ranged from 25 to 35°C in June.
- It is recommended that the solar panel be switched off not only during night hours but also below a solar flux of 150W/m^2 so that it can act as a normal insulated roof.
- Depending on the extent of the collection area, the developed solar collector can provide a significant portion of the building's space heating and hot water needs especially in the spring and summer seasons.

Acknowledgements

The financial and technical support provided by the Longwell Family Foundation, Cardinal Glass Industries, and Tiger Foam is greatly appreciated.

References

Archibald, J., "Building Integrated Solar Thermal Roofing systems History, Current Status, and Future Promise," Proceedings of the Solar 99 Conference, American Solar Energy Society (ASES), 1999, 95-100.

ASHRAE 93-method of testing to determine the thermal performance of solar collectors, ASHRAE Inc., New York (1986).

Dymond, Christopher (2007-2008), "When Solar Cookies Beat Conservation veggies", Green + Solar Building Oregon: 18-19.

Duffie, J., and Beckman W. (1980). *Solar engineering of thermal processes*, John Wiley & Sons, NY.

Hassan, M.M., Beliveau, Y., (2005). "Design, Construction and Performance Prediction of Integrated Solar Roof Collectors Using Finite Element Analysis." *Journal of Construction and Building material*, Elsevier, In Press.

Hassan, M.M., Beliveau, Y., (2006). "Modeling of an Integrated Solar System." *Journal of Building and Environment*, Elsevier, under review.

Lin, W., Gao, W., and Liu, T. (2006). "A Parametric Study on the Thermal Performance of Cross-Corrugated Solar Air Collectors." *Applied Thermal Engineering*, No. 26, 1043-1053.

Mamlouk, M. S., and Zaniewski, J. P. (1999). *Materials for Civil and Construction Engineers*, Addison-Wesley, California.

Melody, I. (2005). "Radiant Barriers: A Question and Answer Primer." Florida Solar Energy Center, available at http://www.fsec.ucf.edu/en/publications/html/FSEC-EN-15/index.htm.

Sauter, E. (1991). "Insulated Concrete Sandwich Walls." *Exterior Wall Systems: Glass and Concrete Technology, Design and Construction, ASTM STP 1034*, B. Donaldson, Ed., ASTM, 170-186.

Vejen, N.K., Furbo, S., and Shah, L.J. (2004). "Development of 12.5m2 Solar Collector Panel for Solar Heating Plants." *Solar Energy Materials & Solar Cells*, No. 84, 205-223.

INCENTIVES FOR GREEN RESIDENTIAL CONSTRUCTION

Michael Sauer[1] and Khalid Siddiqi[2]

Abstract
The objective of the study was to benchmark the relationship between municipal incentives and actual production of LEED certified multi-unit residential buildings in the US. The incentives include financial incentive, density bonus and administrative incentives provided for green projects by the local government institutions. The study conducted was based on the population of LEED certified multi-unit residential buildings in the U.S. A comparison of the regional project distribution with applicable municipal incentives enabled formulation of a correlation coefficient between the incentive and the number of LEED certified multi-unit residential projects developed in the US. Major finding from the study was that LEED certified multi-unit residential development was significantly higher in areas where incentives were made available to developers versus those where they were not. *Density Bonus* incentive, where available, was determined to be the main cause for higher production of LEED certified multi unit residential buildings in a state or county.

Introduction
Among various definitions for sustainable construction the LEED certification served as benchmark for sustainable design (Huser, 2007). Whereas the greatest shares of LEED certified buildings applied to office buildings, institutional projects and educational facilities, only 4% of LEED certified buildings were occupied by residents (RREEF Research 2007) (White Paper on Sustainability 2003). Incentives for developing or owning a "green building" varied widely on state and county level and were hard to compile (Johnson 2007). The statement "owners should receive a tax incentive for constructing sustainable buildings" ranked 2nd among attitudes and opinions in a market study to determine owner's and developer's reasons for going green (White Paper on Sustainability 2003).

[1] Senior Vice President BVT Real Estate Development, Inc., Atlanta Georgia 30339, PH (770)618 3521, FAX(770)618 3567 msauer@spsu.edu
[2] Member ASCE, Professor and Chair Construction Management Department, Southern Polytechnic State University, Marietta Georgia 30060, PH (678)915-7221, FAX (678)915-4966, Email: ksiddiqi@spsu.edu

This study compared the impact of three different incentives provided by municipalities on the county level on production rates for LEED certified multi-unit residential buildings in the U.S. The study was addressed to municipal officials. Purpose was to establish a framework for municipal officials to predict the increase for LEED certified multi-unit residential buildings in case incentives were provided by governmental institutions.

The research was based on the population of LEED certified multi-unit residential buildings in the U.S. A multi-unit residential building was defined as a building, which included two or more self-contained places of residence (Answers 2008). The definition thus included all residential dwelling units except single family homes. A comparison of the regional project distribution with applicable incentives enabled the procurement of a correlation coefficient between the independent variables "Financial Incentive", "Density Bonus", "Administrative Incentive" and the dependent variable "Number of LEED certified multi-unit residential projects".

The objective of this study was to establish a relationship between incentives and development of LEED certified multi-unit residential projects in the U.S. Focus of this study was to benchmark production of LEED certified multi-unit residential buildings as a result of incentives made available by state or local government institutions. The incentives and their impact on residential construction were examined on the county level for the entire US. In order to achieve the objective of the study, a correlation between the three types of local government incentives and the number of LEED certified multi-unit residential buildings in the area where the incentives were applicable had to be established.

The study findings would be useful municipal and local government officials who were looking for an evidence based increase in the number of LEED certified multi-unit residential developments caused by different incentives. A proof of correlation between available municipal incentives and number of LEED certified multi-unit residential buildings would assist public officials and elected representatives supporting sustainable construction in their areas of influence. Based on the correlation arrived at in this study, municipal officials could provide incentives that would lead to green development in their jurisdictions.

The existence of incentives for LEED certified multi-unit residential building caused a significantly higher number of green buildings in the county where the incentives were made available. On the other hand, the absence of municipal incentives for LEED certified multi-unit residential buildings led to a significantly lower number of green buildings, where such incentives were not available.

The research hypothesis stipulated that the existence of incentives caused a significant increase in LEED certified multi-unit residential construction in the area, where the financial incentives were provided. Research techniques employed encompassed a comparison table and a regression analysis. Based on research results it was concluded that the production of LEED certified multi-unit residential developments was significantly higher in areas where incentives were available. The study findings indicated that the incentive "Density Bonus" caused the highest increase in LEED certified multi-unit residential construction

Background:
In the US, Buildings were responsible for 38% of carbon monoxide emissions, 71% of electricity consumption, 39% of energy use, 12% of water consumption, and 40% of non-industrial waste (USGBC Research Committee 2007). Whereas these numbers formed a strong rationale for a movement of going green in construction, the development of one uniform standard to provide developers tangible goals for their projects was not accomplished for many years (RREEF Research 2007). Among various definitions for sustainable construction or green buildings the LEED certification system developed by the United States Green Building Council in 1999 provided an objective definition based on a point system that served as a benchmark for sustainable design (Huser 2007). Most state and local governments have adopted LEED standards for public buildings (What is LEED 2008).

There were 6,442 LEED certified new constructed projects in the U.S. as of March 2008. In addition another 980 LEED certified projects were under construction (USGBC 2008). However, the following shortcomings of the system could be identified:

In 2007 the majority of LEED certified buildings (47%) was occupied by governmental agencies, schools or nonprofit organizations. Multi tenant and private owner/user buildings accounted for 48.9%. Only 4% of all LEED certified buildings were occupied by residents (USGBC Research Committee 2007). 33% of all LEED certified construction was initiated by private sector corporations whereas federal, state, local government and nonprofit organizations accounted for 62% (White Paper on Sustainability 2003).

In a market study, conducted by Reed Research Group, Newton, Massachusetts (Building Design and Construction, November 2003) 68% of respondents stipulated that sustainable design had not helped to attract new business (tenants/clients) whereas 44% responded that it added significantly to construction costs. Among attitudes and opinions the statement "owners should receive a tax incentive for constructing sustainable buildings" ranked 2nd with a 3.86 score out of 5 (White Paper on Sustainability 2003). Incentives for developing or owning a "green building" varied widely on county and city level and were hard to compile (Johnson, Ben 2007). Construction cost for a sustainable building were between 0.8% and 11.5% higher on average as compared to a non-sustainable building (RREEF Research 2007).

Research Methodology
The data was collected from the United States Green Building Council. Their April 12, 2007 list provided the data base of 216 LEED certified multi-unit residential buildings in the United States of America. These 216 buildings comprised of all levels of LEED certification. In addition the U.S. Green Building Council provided a narrative overview of incentives for LEED certified buildings provided by municipalities as of August 2007. A brief description of each municipal incentive is provided in the following paragraphs (USGBC Summary 2007).
Financial Incentives: Income tax incentive caused a reduction of state income tax, property tax incentive included tax break or tax credit for property taxes, and financial grant was a partial project funding by the municipality. These three were

categorized as financial incentives as each would lead to increased financial returns when applied to a multi-unit residential building.
Density Bonus: Changes to zoning ordinances which allowed for LEED certified projects to achieve a higher unit density are called density bonus.
Administrative Incentive: Facilitating the process achieving a building permit by way of expedited permitting, fee reduction or fee waiver as well as free consultation were categorized as administrative incentive.
Density Bonus, Administrative Incentive and Financial Incentive served as independent variables for the data analysis of multi family units that were constructed in each county. The incentives were enumerated for 3099 counties in the United States. A detailed overview of the municipal incentives provided per county is available in Appendix I.

Data Analysis
Table 1 provided an overview of the number of LEED certified multi-unit residential buildings in any county and their dispersion.

Table 1: Dispersion - No of LEED certified Multi Unit Residential Projects

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	2996	96.7	96.7	96.7
	1	61	2.0	2.0	98.6
	2	19	.6	.6	99.3
	3	13	.4	.4	99.7
	4	3	.1	.1	99.8
	6	2	.1	.1	99.8
	7	1	.0	.0	99.9
	9	1	.0	.0	99.9
	12	1	.0	.0	99.9
	13	2	.1	.1	100.0
	Total	3099	100.0	100.0	

For a sample size of 216 the overall distribution of the number of LEED certified multi-unit residential projects per county followed a distribution with a mode of 0 projects per county, a median of 0 projects per county, and a mean of 0.07 projects per county. The standard deviation had a value of 0.560 projects.

Of the 3099 counties 653 provided a developer of a LEED certified multi-unit residential project a financial incentive, 2,446 did not. A Density Bonus was provided by 7 counties whereas 3,092 did not offer such incentive. 104 counties offered Administrative Incentives to developers, 2995 counties did not. Tables 2 to 5 showed the respective frequency and statistics:

Table 2: Frequency Density Bonus

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	3092	99.8	99.8	99.8
	1	7	.2	.2	100.0
	Total	3099	100.0	100.0	

Table 3: Frequency Administrative Incentive

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	2995	96.6	96.6	96.6
	1	104	3.4	3.4	100.0
	Total	3099	100.0	100.0	

Table 4: Frequency Financial Incentive

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	2446	78.9	78.9	78.9
	1	653	21.1	21.1	100.0
	Total	3099	100.0	100.0	

Table 5: Statistics

		No of LEED certified Multi-Unit Residential Projects	Financial Incentive	Density Bonus	Administrative Incentive
N	Valid	3099	3099	3099	3099
	Missing	0	0	0	0
	Mean	.07	.21	.00	.03
	Median	.00	.00	.00	.00
	Mode	0	0	0	0
	Std. Deviation	.560	.408	.047	.180

The following multi linear regression analysis was performed to provide a correlation coefficient between *Density Bonus, Administrative Incentive and Financial Incentive* as independent variables and Number of LEED certified multi-unit residential buildings per county as dependent variable. To perform the calculations SPSS for Windows was used. The regression analysis was conducted in three steps (Anderson et Al. 2005):

1. Set up of Model Assumptions

Based on the data collection the following variables were determined as candidate variables:

Dependent Variable: Y = Number of LEED certified buildings per County
Independent Variables: X_1= Density Bonus provided by county (values 0 or 1)
X_2= Administrative Incentive provided by county (Values 0 or 1)
X_3= Financial Incentive provided by county (values 0 or 1)
Level of Confidence: 95%

The examination of the Scatter Plots for the candidate variables showed possible positive relationships between each independent variable and the dependent variable. Based on the regression model the following estimated multi linear regression equation was determined:

Multi linear regression model: $Y_i = \beta_0 + \beta_1 X_i + \beta_2 X_i + \beta_3 X_i + \varepsilon$ (1)

Multi linear regression equation: $Y_i = \beta_0 + \beta_1 X_i + \beta_2 X_i + \beta_3 X_i$ (2)

Estimated multi linear regression equation: $\hat{Y}_i = b_0 + b_1 X_i + b_2 X_i + b_3 X_i$ (3)

Assumptions for this model are data linearity (a linear regression suits best the model), the data are normally distributed (the error term is a normally distributed variable), homoskedasticity (the variance of ε, σ^2, is the same for all values of X_i), and statistical independence (the values of ε are independent).

Equation 3 was then tested with SPSS through a stepwise algorithm with PIN ≤ 0.5 and POUT ≥ 0.1. SPSS confirmed the estimated multi regression equation as best predicted model.

$$\hat{Y}_i = b_0 + b_1 X_{1i} + b_2 X_{2i} + b_3 X_{3i} \quad (4)$$

Indicators were:
Adjusted R^2 for this model provided a value of 0.064 (highest value). The residual scatter-plot showed a normal pattern. There was no indication of a violation of the four model assumptions.

Tables 6a and 6b showed the variables entered and a summary of the regression model:

Table 6a: Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Density Bonus	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Administrative Incentive	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	Financial Incentive	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

Table 6b: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.213[a]	.045	.045	.547
2	.238[b]	.057	.056	.544
3	.255[c]	.065	.064	.542

For the estimated regression equation

$$\hat{Y}_i = b_0 + b_1 X_{1i} + b_2 X_{2i} + b_3 X_{3i}$$

A correlation coefficient R of .255 indicated a positive correlation between the independent variables X_1 = Density Bonus, X_2 = Administrative Incentive, X_3 = Financial Incentive and the dependent variable Y = number of LEED certified buildings.

The coefficient of determination R^2 provided a measurement how well the estimated regression equation fit the data (measurement of the total variability in the dependent variable that is accounted for by the independent variable). Values for R^2 can rank between 0 and 1. The R^2 value of 0.065, therefore, could only be interpreted as moderately strong value.

2. Test of the model for significance

The significance of the model was tested with two tests. An F-Test was performed to determine the overall significance of the model (Anderson, et. Al, 2005). For the stipulated level of significance (95%) the p-value to be tested was $\alpha = 0.05$. A p-value of the model $\leq \alpha$ would proof the model's significance.

Table 7: ANOVA, Table for Significance

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	63.352	3	21.117	72.012	.000[c]
	Residual	907.593	3095	.293		
	Total	970.945	3098			

SPSS delivered a p-value for the overall significance of the model of 0.000.

As a second test a T-Test was performed to determine the marginal significance of each single variable in the model (Anderson, et. Al, 2005). For the stipulated level of significance (95%) the p-value to be tested was $\alpha = 0.05$. A p-value for each variable $\leq \alpha$ would proof the variables significance to the model.

SPSS delivered the following values for each independent variable:

P-value from SPSS for variable: $x_1 = 0.000$
P-value from SPSS for variable: $x_2 = 0.000$
P-value from SPSS for variable: $x_3 = 0.000$

Conclusion of the SPSS Analysis
It was concluded, that for a confidence level of 95% the overall relationship between the independent variables of the model and the dependent variable was significant. Furthermore each variable was of marginal significance to the model. The developed model thus represented a significant regression relationship between the independent variables X_1 = Density Bonus, X_2 = Administrative Incentive, X_3 = Financial Incentive the dependent variable Y = Number of LEED certified projects.

3. Use of the estimated regression equation for prediction and estimation
Table 8 showed the SPSS results for the coefficients of the estimated regression equation:

Table 8: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
3	(Constant)	.026	.011		2.299	.022
	Density Bonus	2.391	.205	.203	11.637	.000
	Administrative Incentive	.351	.054	.113	6.476	.000
	Financial Incentive	.128	.024	.093	5.334	.000

$b_0 = 0.026$; $b_1 = 2.391$; $b_2 = .351$; $b_3 = .128$

The relationship between the independent variables X_1 = Density Bonus, X_2 = Administrative Incentive, X_3 = Financial Incentive the dependent variable Y = Number of LEED certified projects could thus be written as the estimated regression equation

$$\hat{Y} = 0.026 + 2.391\ X_1 + 0.351\ X_2 + 0.128\ X_3$$

Since for each variable possible values comprise only of either 0 or 1 a ranking among the three independent variables could be established with X_1 (Density Bonus) having the largest impact and X_3 (Financial Incentive) having the smallest impact on the number of LEED certified projects in a county. Based on the developed estimated simple regression equation the following relationship between independent variable financial incentive and the dependent variable number of LEED certified buildings could be predicted:

If a county provided a Density Bonus, an Administrative Incentive and a Financial Incentive the number of LEED certified buildings would be estimated at

$Y = 0.026 + 2.391 + 0.351 + 0.128$
$Y = 2.896$

At a confidence level of 95% Table 9 showed the relationship between the independent variables and the dependent variables that could be predicted:

Table 9: Confidence Interval

Model		95% Confidence Interval for B	
		Lower Bound	Upper Bound
3	(Constant)	.004	.048
	Density Bonus	1.988	2.794
	Administrative Incentive	.245	.458
	Financial Incentive	.081	.174

Conclusions:

The distribution of LEED certified multi-unit residential projects in 3099 counties of the United States of America shows a mode of 0, a median of 0 and a mean of 0.07. Without further analysis a municipal official could predict the mean (0.07) as estimator for the number of projects to be expected in a county.

A regression analysis performed examining the relationship between the independent variables ***Density Bonus, Administrative Incentive and Financial Incentive*** provided by a county and the dependent variable "Number of LEED certified multi-unit residential buildings" concluded 2.896 to be the point estimator for the number of projects per county if all three incentives were to be provided. The regression equation furthermore showed that a ranking of the three independent variables existed with *Density Bonus* being the biggest incentive and *Financial*

Incentive being the smallest incentive for a developer constructing a LEED certified multi unit residential project.

However, the adjusted R2 of the regression model only showed a value for a combination of all three variables of 0.065. This indicated that only 6.5% of all 216 LEED certified projects could be explained by the combination of the three independent variables. In order to further determine a developer's motivation for constructing a multi-unit residential project the study recommended conducting additional qualitative research. Other factors that motivate LEED certified residential development such as tenant demand, investor demand or peer pressure are recommended for future studies.

Furthermore the incentives "Density Bonus" and "Administrative Incentive" could also be assessed in terms of financial values. This would enable verification or refutation of the determined ranking of appeal/impact of the different incentive types on developer's motivation to develop LEED certified residential buildings.

References:

Anderson, David R., Sweeney, Dennis J., Williams, Thomas A. (2005) Statistics for Business and Economics, 2005

Answers (2008), www.answers.com/topic/apartment-building

Huser, Jamey (2007) Regional Challenges of LEED certification, *NAIOP newsletter*, June 2007

Johnson, Ben (2007) Green Incentives – It's a hodge-podge out there, in *National Real Estate Investor*; November 2007

LEED Projects Directory, www. USGBC.org

RREEF Research (2007), The Greening of U.S. Investment Real Estate, November.

USGBC 2008, Green Building Facts, 2008

USGBC Research Committee (2007), A National Green Building Research Agenda, November 2007

USGBC Summary of Government LEED Incentives – August 2007

What is LEED, www.searchdatacenter.techtarget.com/sDefinition, 2008

Where our Readers stand on Sustainability, in *Building Design and Construction*, November 2003,

White Paper on Sustainability 2003, in *Building Design and Construction*, November 2003, www.bdcnetwork.com

ADAPTABLE AND VISITABLE HOUSING: AFFORDABLE AND SUSTAINABLE CHANGES

Lisa M. Johnson[1] and Qian Chen[2]

[1]Graduate Student, Department of Food, Agricultural, and Biological Engineering, The Ohio State University, Columbus, OH 43210; PH (614) 292-7246; FAX (614) 292-9448; e-mail: johnson.2448@osu.edu
[2]Assistant Professor, Department of Food, Agricultural, and Biological Engineering, The Ohio State University, Columbus, OH 43210; PH (614) 292-2254; FAX (614) 292-9448; e-mail: chen.1399@osu.edu

Abstract

Sustainable development has attracted considerable interest from residential communities to 'green' existing homes and build new sustainable ones. The focus is on the reduction of energy consumption and environmental impacts of the built houses. This paper takes the issue of human/societal factors, especially the visitability, into consideration in developing sustainable houses. Visitability refers to a specially designed house that allows people with disabilities to visit and live in. This paper emphasizes the importance of visitable housing and discusses probably the biggest barrier—potential cost increases in construction. A list of visitable and accessible housing features is given to help homeowners and building practitioners select the most appropriate features for their specific projects with no or minimal cost increases. This paper delivers an important message to the general public and building professionals that making specific changes initially can not only reduce the cost of housing renovations for people with disabilities but also allow the homes to be sustainable considering long term human dynamics. It also calls for the support from legislators and home developers for this movement.

Keywords: Accessibility, Adaptability, Construction Cost, Sustainable Housing, Visitability

Introduction

Rising energy costs and global warming have been among the most compelling issues in recent years. Accordingly, seeking clean, renewable energy, reducing environmental impacts, and promoting sustainable development have become the focal research areas. The sustainability movement has also gained momentum in

various industry fields such as automotive, computer, and food. The same happens in the US construction industry. The LEED (Leadership in Energy and Environmental Design) green building rating system from US Green Building Council has already become the nationally accepted benchmark for the design, construction, and operation of high-performance green buildings. Sustainable techniques have been increasingly employed in commercial and industrial buildings as well as residential houses.

Compared with other sustainable features, visitablity has long been ignored in the development of sustainable housing. Due to improved enforcement of the Fair Housing Act and relevant social changes, public housing becomes more accessible with enhanced adaptability and visitability. However, for single family homes and duplexes (except those custom-built for occupants with disabilities) accessibility is much less regulated and considered in both design and construction (HUD 1998). At present, many states allow single family homes to be constructed for the need of today only and not for the future of the families or the goal of allowing people with disabilities to visit others' homes (Concrete Change 2008).

Barriers to including universal design as a standard sustainable feature consist of the lack of basic understanding on the necessity of accessibility and the lack of guidelines and regulations at a higher level. Also, cost increases often associated with accessible housing prevent people from accepting features they currently do not use. This paper aims to educate homeowners and housing developers that sustainable home development needs to consider how a family changes over time and offers an upfront approach to providing homes for everyone from now and into the future with manageable costs.

Through literature review, personal interviews, and questionnaire surveys, the authors intend to investigate 1) how making visitable changes in private housing can be widely accepted; 2) what the cost difference will be in materials and construction methods/processes between newly-constructed adaptable and visitable homes and normally designed homes based on the living areas; and 3) how adaptable and visitable housing can be standardized in Ohio and nationwide. The authors also present a list of the selected visitable/accessible home features/items and related cost variations when compared with those less accessible items used in current homes. Knowing potential changes ahead of time, homeowners and housing developers can make educated choices during new construction rather than waiting for more costly renovations when occupants age or become disabled.

Literature Review

Sustainability and Adaptability/Visitability

The idea of sustainability emerged from a series of meetings and reports during the 1970s and 1980s. For example, the first Earth Day was held in 1970 to mark the birth of modern environment movement with rising concern about the environmental crisis. Conference on the Human Environment held in 1972 communicated that human activities were harming the environment and putting human's at risk. In 1976, Habitat, the first global meeting to link human settlement and the environment highlighted the problems being faced due to the increasing population. The Brundtland's Commission released Our Common Future in 1987 to capture

widespread concern about the environment and poverty in many parts of the world. Sustainable development was raised in this report and defined as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (WCED 1987).

Adaptability/visitability is a movement requiring all new homes to offer a few specific features that make the homes easier for people who develop mobility impairments to live in and visit. Firm features which accommodate visitability include at least one non-step entrance accessible through a non step passageway, wide passage doorways, and at least a half bath on the first floor. Other accessible features may include reinforcement in bathroom walls or accessible electrical controls. Sometimes, it is more effective to have the placement of a full bath with maneuvering space and a bedroom on the main floor (Concrete Change 2008). When homes are designed upfront using visitable guidelines, easier adaptations could be done according to the needs of the families who reside in the homes. It would also be greatly helpful for visitors in wheelchairs and/or with other disabilities.

Energy efficient, environmentally friendly, water conservation, clean indoor air, and cost effective are the most widely known features for sustainable homes. Adaptability and visitability, in contrast, are somehow ignored. However, while social benefits are increasingly considered an important sustainable feature (Sustainable Home Brisbane 2008), adaptability and visitability in housing development gain more and more attention mainly because of the aging population and the rise in disabilities due to social changes (Maisel 2005). In addition, incorporating the accessible design into sustainable housing development to meet the future's needs saves renovation costs for homeowners and the construction industry.

Related US Regulations

There is a great need to make adaptable/visitable changes in the design before houses are constructed so more people can live where they want, live in their homes for longer, or safely visit the houses of others. As mentioned earlier, the lack of guidelines and regulations at a higher level is a possible barrier to including universal design as a standard sustainable feature.

At the federal level, the Fair Housing Act of 1991 has mandated the design and construction of new multifamily housing (consisting of four or more units) to be built after the date of March 13, 1991. With this mandate, public housing becomes more accessible with enhanced adaptability and visitability. Consequently, disabled people have gained more freedom to choose where to live and visit others' homes. The act is also of benefit to the aging population and projects that allow more people to be physically able to stay in their homes safely for a longer period of time (HUD 1998). However, federal regulations in accessibility for private housing are limited. So far, 95% of all new private housing is still constructed with step access and/or narrow doorways to the bathroom. It has been known that statistically, 25~60% of all new private family houses will, over their lifetime, have an occupant with a severe mobility impairment, not including short-term injuries (Concrete Change 2008).

At the state level, Florida passed the first accessible state mandate for single family housing in 1989, which only included the bathroom design. Later on, more states passed accessible policies with a total of 17 known laws, of which 11 are

mandatory for only state or federally funded properties (subsidized and unsubsidized), five are voluntary, and one does not declare. With those mandatory policies, enforcement is one large problem since only seven of them have enforcement mechanisms. For other good policies set in place, they are absolutely voluntary with either an incentive base (Illinois) or a certificate opportunity (Georgia) (IDEA 2008). A need for more enforceable state regulations can be envisioned.

Common Design and Construction Changes or Enhancements

We have known that some visitable changes are solid enhancements which are completely necessary while some other changes are optional but would lessen the barriers within a house (Concrete Change 2008). Two documents, "Universal Design in Housing" by the Center for Universal Design (2006) and "Practical Guide to Universal Home Design" by the Iowa Program for Assistive Technology (2004), give a good overview of many of the simple design changes that make the homes more easily accessible. Both lists are created to minimize potential barriers in a house. The targeted people includes families who 1) have young children, 2) want to stay in their homes as they grow older, 3) want to simplify their housekeeping, 4) have people who are taller or shorter than average, and 5) have members using wheelchairs or walkers. These changes can be small and simple; more design and construction enhancements can be added to these lists. Housing developers should provide minimum visitability suggestions to homeowners as well as offer floor plans which are even more visitable.

Accessibility and Affordability Survey

Before furthering this research toward the cost issue associated with visitable homes, the authors want to get direct input from people with disabilities for their views on accessibility and affordability. A questionnaire with seven questions was designed to learn 1) the severity of the mobility impairment affecting the surveyed individuals, 2) the priority of rooms associated with the most environmental barriers, 3) the reasoning behind not conducting the wanted visitable renovations within their own homes, 4) the homes they would most likely buy if given an opportunity to purchase a new home, and 5) the features and spaces which they cannot use within their current homes or prevent them from visiting other homes. The formats of these questions and the required responses varied, including multiple choice, ranking, and yes/no. There were also spaces left for free inputs and comments. Printed questionnaires were distributed specifically to people who have permanent physical disabilities or a member from their families.

Survey Results and Discussions

The survey was conducted on July 20, 2008 in Columbus, OH during a conference mainly involving people with disabilities and their families. Seventeen completed questionnaires were received. Since many of the questions requested respondents to mark all that apply, the number of responses for these questions varied.

The first question aims to clarify the types of disability the respondents may have. Among 17 respondents, seven use walking braces, eleven use a scooter or a

wheelchair, three use crutches, walking sticks, canes or walkers, and five of the respondents do not use any mobility devices. When being asked to prioritize areas in the home from 1 to 8 (1 being the highest priority) based on their family's needs for accessibility, six respondents chose the bathroom as their highest priority while seven others chose the bathroom as their second highest. Seven people marked the entrance as their first priority. Kitchen and hallways were also highly prioritized.

Of the 17 survey participants, 16 would like to make renovations to enhance their home's accessibility but have not done so. Fifteen marked financial as a reason for not performing the renovation, four marked the lack of professional support to make decisions (such as design changes) as a reason, four would prefer to move, and two have a lack of building permits. When being asked the type of house people with disabilities would purchase, seven respondents would prefer their home to be completely accessible with a slightly higher initial cost. Twelve wanted their home to be easy to adapt and within manageable renovation cost and one respondent thought that accessibility would not be a consideration for his/her family.

When being asked to list spaces and features within their own home they could not use, the answers included closets, laundry room, basement, second floor, attic, roof, bathroom (including walk-in shower, toilet, and sink), and kitchen (including counter, cabinets, high shelves, stove/oven, and microwave). Many of these spaces such as bathroom and kitchen were duplicated throughout the survey. Seven out of the 17 people could not visit the homes of others because of accessibility reasons, such as stairs leading into the home, the width of doorways, and other constricted spaces such as bathrooms. Other useful comments and inputs received from the respondents include but are not limited to:

"*Our house is the least accessible home I've seen and would take too much to fix.*"

"A*ll homes should be built with accessibility in mind. I know homes in the future will be fun, beautiful and accessible thanks to people who understand the needs of people with disabilities.*"

"*It's so expensive…also I think if it was more mainstreamed, more effort would be put into making the "adaptive structures" more seamless or "pretty" so they would be a compliment to the building, not an eyesore.*"

"*It's very frustrating to spend so much money on making a home accessible for it to lose property value. It's a double loss.*"

"*Everyone's needs are different, so each home needs to be based on individual need*" (reference to an early answer to the choice—home is easy to adapt within manageable renovation cost).

"*Almost every type of accessibility enhancement is invariably helpful to non-disabled people (lever door knobs when carrying groceries, no step entrances when pushing strollers, etc.). Accessibility enhancements are typically quite expensive. However, if incorporated into codes or adapted by "mainstream" contractors, then due to economies of scale, these types of improvements will drastically reduce the cost.*"

Based on the questionnaire results, the researchers investigated further the costs associated with making minor floor plan and feature changes upfront to accommodate

more family dynamics.

Cost Increases for Design and Construction Changes: a Case Study

During the research, it was difficult to obtain detailed pricing information the housing companies charged for visitable home feature upgrades either because these companies were busy or because they were not comfortable sharing their prices. One local housing development company was found to be willing to accept interviews and share their price upgrades for certain accessible options. They also provided a house plan (as shown in Figure 1) which they have upgraded recently to make the home more visitable than the original design. This plan had an original selling price of $150,000, but after the minor upgrades, this house was sold for $154,650. These were purely optional upgrades. A home buyer could have these added if they want to pay the extra fee associated with the "upgrade."

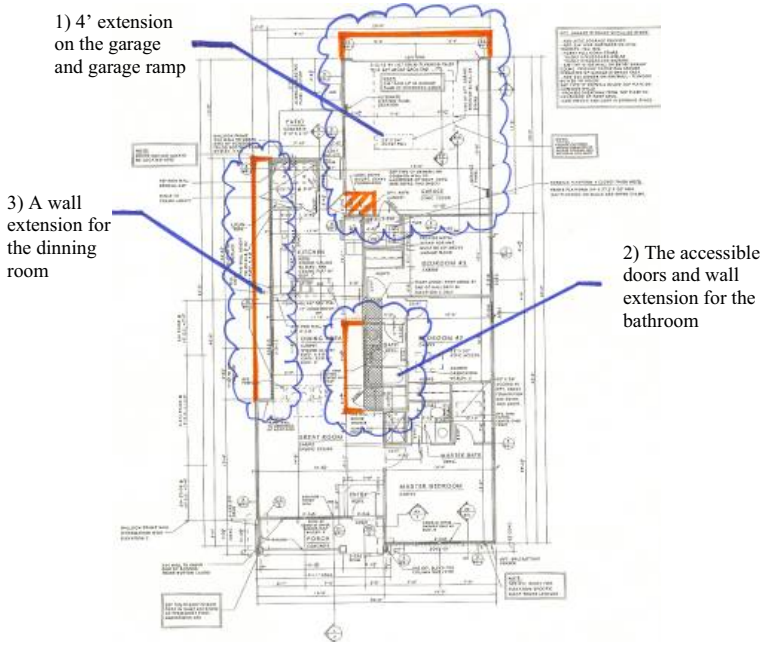


Figure 1: First floor housing plan with certain accessible upgrades.

To meet the minimum visitability requirements, the housing development company had to upgrade this home to include 1) the 4' extension on the garage and the garage ramp and 2) the accessible doors for a bathroom on the first level. These two changes and other selected options for making the home more visitable are all listed in Table 1. Table 1 also displays two cost columns for comparison. The first cost column

contains corresponding price information for these changes and options given by the company. The second provides the estimated prices for these changes and options conducted by this research based on *RSMeans Building Construction Cost Data 2008* (Babbbitt et al. 2007) and product prices available at Lowes.com (2008). In the following, detailed explanations for these changes and options are provided.

Table 1: Cost increases associated with changes and options for visitability.

Visitable Changes and Selected Options for Upgrade	**Given cost**	**Estimated cost**
4'Extension on Garage and Garage Ramp	$3,800.00	$1,218.80
Shower with Seat in the Master Bathroom	$125.00	$38.00
Grab Bars within the Bathroom	$150.00	$323.08*
Wall Extension	---------	$142.00**
Accessible Water Closet	$150.00	$0.00
Mast Bath – Lever Kitchen - Tub Faucet	$75.00	$77.49
Accessible Doors (3'doors rather than 2'-8" doors)	$200.00	$150.75
Toggle Light Switches	$150.00	$0.00***
Total Price Increase for These Options	**$4650.00**	**$1,950.18**

**Price includes wall extension to make a larger bathroom for access.*

***Wall extension on the floor plan is suggested here to give space back to the dining area which was taken away for the bathroom.*

****$6.86 for a 3-way light switch compared to $4.99 for a 3-way toggle switch.*

The first change was related to the garage. The company suggested a 4' extension on garage and garage ramp at a given cost of $3,800. This paper proposes a similar change that costs much less (see Table 1). This change is to raise the level of the garage floor by one CMU block. This would, in turn, minimize the needed size for the ramp (see the bottom left hand corner of the garage, Figure 1), not requiring the 4' extension at all. The second change concerns the bathroom. The estimated price of the bathroom upgrade includes a wall extension, increasing the square footage and allowing for the maneuvering space, as well as wall blocking for safe input of grab bars in the future, if needed. The third change involved a wall extension for the dinning room, which moves the wall out to replace some of the space lost within the bathroom extension. It also makes the kitchen and laundry room larger. This wall move was estimated at $142.00, but adding 72 square feet to the floor plan.

From the above cost comparison, it is concluded that, because these changes are purely options and not provided as a base design, the prices given by the company are much higher than cost estimates generated by this research due to the procurement, logistics and production reasons. A suggestion to this company would be to include these features as base products since they are easy changes that accommodate the mass of society who will most likely need these adaptations anyway. As mentioned earlier, 25~60% of all new homes will have an occupant, over the lifetime of the house, with a permanent physical disability; this does not include visitors with disabilities (HUD 1998). If the builder sets up a visitable home not as an option, but as one of their standard models, the cost can be much reduced by proper planning.

Generally speaking, the total cost of making visitable changes upfront is minimal compared with making the changes down the road. For example, on new construction, $200 is spent for a zero-step entrance plus $50 for each interior door. However, to renovate an existing home, the average cost of widening one interior

doorway is $700 and the average cost of making one no-step entry is $3,300 (Concrete Change 2008).

Visitable Housing Features with No or Minimum Cost Increases

Table 2 provides a summary of some typical items that would make the home more livable and easier to navigate than a minimally visitable house. These items are for an economical house and are available at Lowes (Lowes.com 2008). The ideas for these features were gathered through the "Universal Design in Housing" and the "Practical Guide to Universal Home Design" booklets. But the authors selected the most critical and easily adaptable items that can improve the accessibility for common homes. A cost comparison with those less accessible items used in current homes is also provided to show the potential cost increases or savings.

Table 2: List of visitable and accessible housing features for home enhancement.

Feature/Item			Cost Change	Reason for Accessibility Increase
Throughout the house		**Toggle Switch** 3-Way Decorator Switch	+67%	This switch only needs a little push to operate. The toggle design is easier to reach and use than the usual switch, especially when the individual has low mobility of the arm or their hands are full of items.
		**Interior Doors** 36"	+19%	The 36" interior door allows for 34" clear space when open, allowing access for wheelchairs and easier movement of furniture through door ways (and hallways, that are also at least 36").
Entry		Entry Door 36" with glass panel	+0%	The 36" Entrance door allows 34" clear space. The center glass panel allows for a "peephole" at the eye level of an average height person, a child and a wheelchair user. Another option is a door with two peep holes (higher for standing adults and lower for children and wheelchair users).
		**Lever Style Door Locks** Electronic Keypad	-7%	These handles are easy to operate door levers with keypad for a password and keyless entry. The handles could be opened with a fist and no grip is necessary, making it more accessible than a door knob.
Laundry room		**Washing Machine** Front Load Washer	+0%	Front loading washing machine allows easier transfer of clothing from a laundry basket and into the machine and from the machine into the basket. The front controls are easy to reach.
Kitchen		**Refrigerator** Side-by-Side Refrigerator	+12%	A side-by-side refrigerator/freezer allows users in wheelchairs, shorter than average people and children to reach parts of both refrigerator and freezer. A top mount refrigerator does not allow for everyone to reach the freezer storage space with ease.

		**Faucet** Single Handle Pull-out Spray	+27%	The single handle faucet allows for ease of use and heat adjustment. The pull-out spray nozzle allows for the faucet to go to the dishes and allows for less movement of items. The faucet can be mounted on the side of the sink rather than the back for easier reach.
		**Range** 30-Inch Double Oven Freestanding Gas Range	+0%	This oven has two cooking compartments, it would allow less bending, easier use for a wheelchair user and front controls, which are easier to reach than rear controls (front controls are ideal for wheelchair users, but with children side controls would be better).
		Kitchen Cabinets Heights ranging from 31" to 35"	+0%*	Some cabinet companies sell cabinets at varying heights. If heights are varied throughout the kitchen, more people can comfortably use the space including children and people using wheelchairs.
Bathroom		**Water Closet** Highline Comfort Height Toilet	+31%	This toilet rim height is 16.5" which makes the seat at the right height for comfort use for many people and the flush valve can be used with minimum effort.
		**Grab Bars** 24" Designer Elite Grab Bar	+$50**	It is suggested to provide blocking behind the walls, as the walls are constructed, for future proper installation of grab bars, even if grab bars are not originally needed. $50 per bathroom for blocking.
		**Tub/Shower Faucets** Single Handle	+42%	The single handle allows for easier use. Because it is a lever, the user does not need gripping strength to start or stop the water flow.
		Anti-Scald Handheld Shower	+$38***	Anti-scald features create a safer shower. Shower hose lets the water move, rather than the entire body making the item easier to use for everyone.
		**Sink Faucet** Single Handle Chrome Lavatory Faucet	+0%	The single handle does not require gripping strength and allows for easy adjustment of the water temperature.

*Kitchen cabinets that are special ordered can be ordered to any height, not changing the price.
**Adding blocking behind the walls adds an initial cost of $50, but saves a long term cot of $700.
***This item has no comparison, because it is an add-on.

This information will be very useful for homeowners or housing developers to select better home features/items in new construction with no or minimum cost increases. That means, providing the accessibility for housing does not necessarily result in a cost increase. In future research, this table can become more inclusive and detailed. When possible, the contractor should choose items which will help people live within their house easily and safely, not only considering people with disabilities, but also considering long term family dynamics.

Conclusions

As concluded in this paper, the existing regulations and law enforcements on adaptable/visitable housing are far from adequate and effective. The current movements and practices still do not meet the needs of today's society, not to mention the needs of the future society. Today, homebuilders and homeowners still construct houses that are not even visitable at the minimum. In response, this research provided the needed information to enhance the basic understanding on the necessity of accessible housing movement as well as to attract the practitioners' attention to initiate changes for visitability at the early stage of their projects to minimize associated construction costs. The paper explicated that the visitability movement should be part of sustainable housing development to allow today's homes to be sustainable for the families and their visitors over time.

References

Babbitt, C., Baker T., Balboni B., and Bastoni R. (2007). *RSMeans Building Construction Cost Data 2008*, 66th Edition, P.R. Waier (Ed.), R.S. Means Company, Kingston, MA.

Center for Inclusive Design and Environmental Access (IDEA) (2008). "Existing state visitability laws." State Univ. of New York at Buffalo, Buffalo, NY, <http://www.ap.buffalo.edu/idea/Visitability/reports/existingstatelaws.htm> (Aug. 22, 2008).

Concrete Change (2008). <www.concretechange.org> (Aug. 4, 2008)

HUD (1998). *Fair Housing Act Design Manual: A Manual to Assist Designers and Builders in Meeting the Accessibility Requirements of the Fair Housing Act*, US Department of Housing and Urban Development (HUD), Washington, DC, <http://www.huduser.org/publications/destech/fairhousing.html (Aug. 4, 2008).

Iowa Program for Assistive Technology (2004). *Practical Guide to Universal Home Design*, Center for Disabilites and Development, Univ. of Iowa Hospitals and Clinics, Iowa City, IA. <http://www.uiowa.edu/infotech/universalhomedesign.pdf> (Aug 4, 2008).

Lowes.com (2008). <http://www.lowes.com/lowes/lkn?action=home> (Aug. 4, 2008)

Maisel, J.L. (2005). "Visitability as an approach to inclusive housing design and community development: A look at its emergence, growth, and challenges." IDEA, State Univ. of New York at Buffalo, Buffalo, NY, <http://www.ap.buffalo.edu/idea/Visitability/reports/Visitability%20Final%20Report%2012.15.04.pdf> (May 20, 2008).

Sustainable Home Brisbane (2008). "Sustainable housing design." <http://www.sustainablehomebrisbane.com.au/DESIGN.htm> (Aug. 29, 2008).

The Center for Universal Design (2006). *Universal Design in Housing*, College of Design, NC State Univ., Raleigh, NC. <http://www.design.ncsu.edu/cud/pubs_p/docs/UDinHousing.pdf> (Aug 4, 2008).

World Commission on Environment and Development (WCED) (1987). *Our Common Future*, Oxford University Press, p.43.

LEED CERTIFICATION: A CONSTRUCTOR'S PERSPECTIVE

John Schaufelberger[1] and Joshua Cloud[2]

[1] Member, ASCE, Professor, Department of Construction Management, University of Washington, 120 Architecture Hall, Box 351610, Seattle, WA 98195-1610, USA, PH 206-685-4440, FAX 206-685-1976; e-mail: jesbcon@u.washington.edu
[2] Project Manager, McKinstry Company, 5005 Third Avenue S., Seattle, WA 98134-2423, PH 206-832-8340, FAX 206-658-1810, email: joshc@mckinstry.com

ABSTRACT

The Leadership in Energy and Environmental Design (LEED) green building rating system has been gaining increased attention. Considerable literature has been published that describes the roles of the owner and designer, but little research has been published on the role of the constructor. To identify issues relative to the constructor's role, a study was undertaken to assess past experiences of builders that have undertaken LEED-certified projects. Contractors who built 22 projects in ten states were surveyed to determine their experiences. From the survey results, the trends, best practices, and lessons learned were compiled and evaluated. The study results indicated that integrated project delivery methods were more conducive to the delivery of LEED-certified projects than was a design-bid-build approach. Through analysis of the data collected, a four-step guide was developed that can be used by constructors who are considering working on LEED-certified projects.

KEY WORDS: sustainable construction, green construction, LEED certification, green building

INTRODUCTION

Many project owners are emphasizing sustainable or green construction techniques that minimize the impact of construction processes on the environment. A frequently used criteria for assessing the environmental impact of projects is the Leadership in Energy and Environmental Design (LEED) rating system developed by the United States Green Building Council (USGBC). LEED is a performance-oriented system in which credits are earned for satisfying specific criteria that were designed to address specific environmental impacts.

The USGBC developed its initial LEED rating criteria in 1998 after several years of evaluating and establishing appropriate measures (USGBC 2007). Further

refinements occurred in 2003, 2005, and 2007. The versions are continually updated and provide four levels of certification: certified, silver, gold, and platinum. The USGBC publishes nine different LEED rating systems (USGBC 2007):

- LEED for new construction and major renovations (LEED-NC)
- LEED for existing buildings
- LEED for commercial interiors
- LEED for core and shell
- LEED for schools
- LEED for retail
- LEED for healthcare
- LEED for homes
- LEED for neighborhood development

The LEED-NC rating system is divided into six categories (USGBC 2007):

- Sustainable sites
- Water efficiency
- Energy and atmosphere
- Materials and resources
- Indoor air quality
- Innovation in design

There are a total of 69 points available within the current LEED-NC system. At least 26 points must be earned for a project to be certified, at least 33 points must be earned to achieve a silver rating, at least 39 points must be earned to achieve a gold rating, and at least 52 points must be earned to achieve a platinum rating (USGBC 2007).

A project team interested in obtaining LEED certification for their project must first register this intent with USGBC. Once the project is registered, the project team collects the information and performs the calculations needed to satisfy the credit submittal requirements and submits the information to the USGBC. When the project is completed and all documentation submitted, the USGBC reviews the information and awards the appropriate level of certification. As of August 2008, there were 1,705 LEED-certified projects in the United States with an additional 13,741 registered projects (USGBC 2008).

Construction of a LEED-certified project requires a team effort that includes the project owner, the design team, and the construction team. Most of the existing literature regarding LEED-certification focuses the roles of the owner and design team in the selection of building performance criteria and building materials. For example, R. S. Means (2002) published an early guide for constructing sustainable buildings that discusses green building approaches and provides cost data for green materials, components, and systems.

There were a few publications that addressed sustainable construction issues. The Washington Department of General Administration (2005) published some guidelines regarding reduction of waste from construction projects. Riley et al (2005)

analyzed the role of mechanical contractors in constructing green projects, and Pulaski and Horman (2005) proposed a continuous value enhancement process for managing sustainable construction. The Environmental Protection Agency (2007) issued a Comprehensive Procurement Guideline for selection of recycled-content products for construction. The Cascadia Chapter of the USGBC (2008) identified 17 credits for which it believes the constructor is responsible for implementing and documenting. Glavinich (2008) reviewed the green construction process and discussed the builder's role in design development, green subcontracting, green material procurement, documentation and commissioning, but does not discuss the constructor's role in achieving specific points. Kibert (2008) described green building systems and implementation.

Other than the previous citations, little has been published regarding the role of the constructor in the certification process. To identify and address issues relative to the constructor's role, a study was undertaken to assess past experiences of construction firms that have undertaken projects that sought LEED certification (Cloud 2006). This paper reports the results of this study.

RESEARCH METHODOLOGY

To identify contractors who had completed LEED-certified projects, 54 case studies on the USGBC web site were reviewed. Of the case studies described, only 29 contained contact information for the constructor. These 29 contractors were contacted by telephone and email and asked to participate in a web-based survey. The basic research questions addressed in the survey were:

- What has and has not worked for constructors as they pursued LEED certification on projects?
- What could be done to simplify and streamline the LEED certification process for constructors?
- What information should construction personnel know before beginning a LEED project?

Using these research questions as a guide, a web-based questionnaire was developed to collect information regarding the constructors' experiences with LEED-certified projects. The 29 contractors were each sent emails that contained a link to the web-based questionnaire.

A total of 22 completed questionnaires were received. While information regarding the identification of the company and project were collected in case clarification was needed regarding the responses, the information was not used in data analysis. The constructors completing the questionnaires had executed LEED projects in ten states, as shown in Table 1.

Table 1. Project Locations

State in Which Project was Located	Number
Michigan	3
Nebraska	1
New Hampshire	1
New Mexico	1
New York	3
North Carolina	2
Ohio	1
Oregon	5
Vermont	1
Washington	4

DATA ANALYSIS

The first question asked the respondents to identify the type of project for which they were completing the questionnaire. The results are shown in Table 2. A majority of the projects were either office buildings or academic facilities.

Table 2. Project Types

Type of Project	Number
Higher education	5
Commercial office	5
Multi-family residential	2
Mixed use	2
Government building	2
K-12 school	2
Library	1
Healthcare	1
Interpretive center	1
Animal care	1

The next question asked for the size of the projects. The responses are shown in Table 3. A majority of the projects had gross areas of 4,650 square meters or more.

Table 3. Project Size

Gross Area	Number
Over 9,300 square meters	5
4,650 to 9,300 square meters	9
2,325 to 4,650 square meters	3
930 to 2,325 square meters	3
Less than 930 square meters	2

The next question asked for the construction cost for the projects. The results are shown in Table 4. No clear trends were noted here. Slightly over half of the projects were in the range $5 million to $50 million.

Table 4. Project Construction Cost

Construction Cost	Number
Over $100 million	1
$50 to $100 million	3
$10 to $50 million	6
$5 to $10 million	6
$1 to $5 million	4
Less than $1 million	2

The next question asked for the delivery method used on the project. The responses are shown in Table 5. An integrated form of project delivery was used for most of the projects. A design-bid-build approach was used for only 4 of the 22 projects.

Table 5. Delivery Method Used on Project

Delivery Method	Number
Construction manager at risk	13
Design-bid-build	4
Design build	3
Agency construction manager	1
Design assist	1

The next question asked for the pricing method used on the construction contract. The results are shown in Table 6. A cost-plus fee was used in 15 of the 22 projects.

Table 6. Construction Contract Pricing Method

Pricing Method	Number
Cost-plus fee with Guaranteed Maximum Price	13
Lump sum	7
Cost-plus fee	2

The next question asked for the level of certification achieved by the project. The results are shown in Table 7.

Table 7. LEED Certification Achieved by Project

LEED Certification	Number
Certified	5
Silver	11
Gold	6

The next set of questions asked the respondents to identify which of the 17 construction-related certification credits defined by the Cascadia Chapter of the USGBC were achieved on the project. The results are shown in Table 8. Site development, construction waste management, use of recycled materials, use of regional materials, and use of low-emitting materials credits were the most frequently achieved credits.

Table 8. Contractor-Based LEED Credits Achieved

Credit Description	Number of Projects Achieving
Sustainable Sites	
5.2 Site development: maximize open space	13
Materials and Resources	
2.1 Construction waste management: divert 50% from disposal	20
2.2 Construction waste management: divert 75% from disposal	15
3.1 Material reuse: 5%	3
3.2 Material reuse: 10%	1
4.1 Recycled content: 10%	20
4.2 Recycled content: 20%	14
5.1 Regional materials: 10%	22
5.2 Regional materials: 20%	15
6.0 Rapidly renewable materials	1
7.0 Certified wood	7
Indoor Environmental Quality (IAQ)	
3.1 Construction IAQ management plan: during construction	12
3.2 Construction IAQ management plan: before occupancy	11
4.1 Low-emitting materials: adhesives & sealants	14
4.2 Low-emitting materials: paints & coatings	17
4.3 Low-emitting materials: carpet systems	21
4.4 Low-emitting materials: composite wood & agrifiber products	8
Innovation	15

The respondents were asked to identify techniques used to simplify the process of attaining constructor-based credits. Responses included:

- Used spreadsheets to organize all of the construction credits and notified appropriate subcontractors and suppliers.
- Placed all of the LEED requirements into subcontracts where credits were to be earned by subcontractors.
- Developed a web-based tool to streamline the collection of LEED documentation from subcontractors and suppliers.

- Wrote LEED specifications that contained appropriate submittal requirements and included them in subcontracts.
- Included status of LEED documentation in weekly owner and subcontractor coordination meetings.

The respondents were then asked to identify what they would have done differently to achieve more points, if they were to do the project over. The most common responses were:

- Collaborate with the owner and design teams as early as possible to maximize the use of the expertise of the entire project team.
- Start the documentation process and coordination with the subcontractors as early as possible.
- Contractually obligate the subcontractors to provide the necessary documentation.

Next the respondents were asked to evaluate the certification process. The responses are shown in Table 9. A majority of the respondents experienced some difficulty with the certification process.

Table 9. Respondent Evaluation of LEED Certification Process

Rating	Number
Very easy	0
Easy	0
Straightforward	5
Slightly difficult	16
Very difficult	1

The respondents were then asked to compare the time required for a LEED-certified project with a non-LEED-certified project. The results are shown in Table 10. A majority of the respondents indicated that additional time is needed to prepare and track the documentation that must be submitted to justify award of points.

Table 10. Additional Time Needed for LEED Documentation

Time Required	Number of Responses
Way too long – the extra time added significant schedule headaches to the project	2
A lot longer	14
Not much longer	6
No additional time was needed	0

The respondents were then asked to identify the additional cost incurred in tracking and preparing the LEED documentation that would not be required on a non-LEED-certified project. The responses are shown in Table 11. It was interesting to note that 13 of the 22 respondents indicated that the additional cost incurred by the constructor was less than 1% of the project costs. The level of certification sought

did not seem to influence the additional cost required for the documentation. Constructors for three of the Gold-certified projects reported spending less than 1% additional on the documentation, while the constructors for the other three Gold-certified projects reported spending between 1% and 5%. Constructors for seven of the Silver-certified projects reported spending less than 1%, while the constructors for three of the Silver-certified projects reported spending between 1% and 5%.

Table 11. Additional Cost Incurred by Constructor on LEED-Certified Project

Additional Cost	Number of Responses
No additional cost	2
Less than 1% of project costs	11
1% to 2% of project costs	5
2% to 5% of project costs	3
5% to 10% of project costs	0
More than 10% of project costs	1

The respondents were then asked to identify techniques for minimizing the additional cost associated with a LEED-certified project. The most common responses were:

- Ask the designers to include the LEED requirements in the specifications so that the subcontractors understand the documentation requirements.
- Develop tracking spreadsheets to track the preparation of all needed documentation.
- Include requirements in subcontracts scopes and bid packages.
- Start collecting the documentation at the beginning of the project.
- Review status of LEED documentation with owner and designer at project coordination meetings.
- Understand the project goals and which LEED credits are to be pursued.
- Use a LEED Accredited Professional on the team.

In conclusion, the respondents were asked to identify the resources that were most helpful in managing the LEED documentation process. The most frequent responses were:

- LEED Accredited Professionals within the construction firm
- LEED reference guide published by USGBC
- LEED consultants

LEED Accredited Professionals are individuals who have passed the USGBC accreditation examination that tests the person's knowledge of green design and construction and the LEED certification process.

CONCLUSIONS

While the sample size evaluated was small, some general conclusions could be identified. The study results indicate that efficient execution of a LEED-certified project requires an early decision by a project owner to pursue certification and early collaboration among the owner, designer, and builder. An integrated form of project delivery, such as construction manager-at-risk or design-build, facilitates this early collaboration, because these approaches allow selection of the constructor early in the design process. Sixteen of the 22 projects surveyed in this study used construction manager-at-risk and design-build. Specific construction-related points need to be identified early, and LEED requirements included in the contract specifications. Subcontractors and suppliers need to understand their responsibilities regarding appropriate documentation. The cost to track and prepare LEED documentation needs to be included in the construction budget. The status of LEED documentation collection needs to be discussed at project coordination meetings.

Based on analysis of the data collected, the following four-step guide is recommended for contractors interested in undertaking LEED-certified projects:

- Seek projects that use an integrated method of project delivery that foster a collaborative approach to design and construction.
- Encourage project staff to become LEED Accredited Professionals so that they fully understand the certification process.
- Develop internal organizational procedures to streamline submission and management of certification documentation.
- Start the documentation process as early as possible. Ensure that subcontractors and suppliers understand the documentation that is needed.

REFERENCES

Cascadia Chapter of U. S. Green Building Council (2008). Build it LEED: A General Contractor's Toolkit for Implementing LEED, Seattle, Wash.

Cloud, J. (2006). LEED Certification: A Constructor's Perspective, Masters Thesis, Department of Construction Management, University of Washington, Seattle, Wash.

Glavinich, T. E. (2008). Contractor's Guide to Green Building Construction, John Wiley and Sons, Inc., Hoboken, N. J.

Kibert, C. J. (2008). Sustainable Construction: Green Building Design and Delivery, 3rd ed., John Wiley and Sons, Inc., Hoboken, N. J.

Pulaski, M. and M. Horman (2005). The Continuous Value Enhancement Process to Efficiently Achieve Sustainable Project Objectives, ASCE Construction Research Congress, San Diego, Calif., 126-130.

Riley, D., V. Sanvido, M. Horman, M. McLaughlin, and D. Kerr (2005). Lean and Green: The Role of Design-Build Mechanical Competencies in the Design and Construction of Green Buildings, Proc., ASCE Construction Research Congress, San Diego, Calif., 116-120.

R. S. Means (2002). Green Building: Project Planning and Cost Estimating, Kingston, Mass.

U. S. Environmental Protection Agency (2007). Comprehensive Procurement Guidelines, Washington, D. C.

U. S. Green Building Council (2008). Green Building Facts, Washington, D. C.

U. S. Green Building Council (2007). LEED for New Construction Reference Guide, Version 2.2, 3rd ed., Washington, D. C.

Washington State Department of General Administration (2005). Construction Waste Management, Olympia, Wash.

OPTIMIZATION MODEL FOR THE SELECTION OF MATERIALS USING THE LEED GREEN BUILDING RATING SYSTEM

Daniel Castro-Lacouture*, Jorge A. Sefair†, Laura Flórez†, and Andrés L. Medaglia†

* Building Construction Program, College of Architecture, Georgia Institute of Technology, 280 Ferst Drive, 1st Floor, Atlanta, GA 30332, USA; PH (404) 385-6964; FAX (404) 894-1641; e-mail: daniel.castro@coa.gatech.edu
†Centro de Optimización y Probabilidad Aplicada (COPA), Industrial Engineering Department, Universidad de los Andes, Bogotá D.C., Colombia; PH (571) 339-4949 ext 2880; FAX (571) 332-4321; e-mail: {j-sefair, amedagli}@uniandes.edu.co, l.florez403@egresados.uniandes.edu.co

Abstract
The green building philosophy has recently taken a central role in the construction industry, mitigating the environmental impact of buildings. Buildings are responsible of a large portion of harmful emissions and use a large fraction of the total natural resources. Moreover, the bad quality of indoor environments in office buildings can affect the health of employees, reducing their productivity. Because materials used in construction projects are responsible for a significant fraction of this environmental footprint, a better selection and use of materials could lead to a green certification such as the one given by the Leadership in Energy and Environmental Design (LEED) rating system. This paper illustrates how an optimization model can be used to help decision makers to select the right materials, incorporating design and budget constraints while maximizing the number of material-related LEED-based credits. A case study based on real data is analyzed from different angles to demonstrate the effect on the optimal choice of materials due to changes in construction market conditions.

1. Introduction

Buildings have a significant impact on the environment because they are responsible for a large portion of carbon emissions (Keysar and Pierce 2007, Venkatarama-Reddy and Jagadish 2003, Yudelson 2008) and use a considerable number of resources and energy (Pulselli et al. 2007). In addition, the bad quality of indoor environments in office buildings may affect the health of employees, reducing their productivity (Ries et al. 2006).

The green building (GB) movement emerged to mitigate the impact of buildings on the environment and to improve the building construction process, bringing significant economic, financial, social, and environmental benefits (Wang et al. 2005, Thormark 2006, Ross et al. 2006, Edwards 2003, Kats 2003, Ries et al. 2006, Muse and Plaut 2006, Baker 2006). To realize such benefits it is not only necessary to select wisely the appropriate technologies, but the right materials (Wang et al. 2005, Moeck and Yoon 2004).

Selecting inappropriate materials can be expensive, but more importantly, it may preclude the achievement of the desired environmental goals. The Leadership in Energy and Environmental Design (LEED) rating system is a widely applied rating system used to determine the level of accomplishment of environmental goals. The LEED rating system is based on credits, evaluating specific requirements of the candidate building. For instance, it states that the total value of the recycled content from materials must be at least 10% of total cost of materials. If this and other requirements are reached, then a certain number of points are awarded, helping the building to obtain a green certification. The LEED rating system has established a strong credibility among experts (Pulselli et al. 2007, Ding 2008), comprising more than 7,500 companies and organizations (Yudelson 2008, Ross et al. 2006). In fact, variations of the LEED system have been chosen in countries like México, Brazil, Canada, and India.

The LEED rating system encourages the use of materials extracted, processed, and manufactured regionally, supporting at the same time the development of local economies (USGBC 2008). The LEED system also promotes the use of materials with high recycled content, rapid renewable periods, responsible harvesting management, low-emitting contaminants, and proper solar reflectance index. As a result, if a building wants to earn the LEED points associated to the previously described standards, a complex and comprehensive material selection process is required.

The material selection problem has been tackled with the support of analytical tools such as multiobjective optimization (Sirisalee et al. 2004, Ashby 2000), ranking methods (Jee and Kang 2000, Chan and Tong 2007), index-based methods (Holloway 1998, Giudice et al. 2005), and other quantitative methods (Farag 2002). However, the current green building literature lacks of a method that helps decision makers to select the appropriate materials, considering design and budget constraints while looking at the same time for the accomplishment of environmental goals.

To help decision makers with the selection of appropriate materials, this study applies a mixed integer optimization model that incorporates design and budget constraints while maximizing the number of material-related credits reached under a modified version of the LEED rating system (Castro-Lacouture et al. 2008). The model guides decision makers towards a detailed plan that describes the choice of materials and their extent of use, allowing them to include preferred materials and design parameters. The model can also be used to show the additional budget required to obtain extra credits, suggesting decision makers the steps to be followed towards the improvement of the green performance of a building. A sensitivity analysis on the model input parameters highlights the importance of the availability of green

materials and the impact on the LEED credits due to a constrained budget and the market conditions.

2. Optimization model for green material selection

The optimization model considers that buildings are comprised of systems like wood finishes, floors, walls, windows, and roofs. Each system is built using a specific set of materials classified in categories such as adhesives and sealants, paints and coatings, carpets, roof materials, permanently installed woods, and temporally installed woods. One particular system can be built using materials from different categories. Thus, the cornerstone decision in the model is the extent of use of materials to build each system while maximizing the chances for a green certification such as LEED. For instance, if the floor system area is 1000 m2, then it must be decided the right combination of materials to cover it. A possible recommendation from the model is to buy 1000 m2 of floor wood w1 or to buy 600 m2 of floor wood w1 and 400 m2 of floor wood w2. However, this decision cannot be taken without considering in the selection process the environmental impact of materials, the design requirements and the available budget, being the latter a crucial factor in the building success (Sherwin 2006).

The optimization framework shown in Figure 1 supports the decision maker in the complex process of material selection. The data input module collects information on the available materials, their price, and environmental properties such as recycled content, volatile organic compounds (VOC) content or emission factor, reflectance index for roof materials, place of origin, renewable period and forest certification for woods, and urea-formaldehyde content.

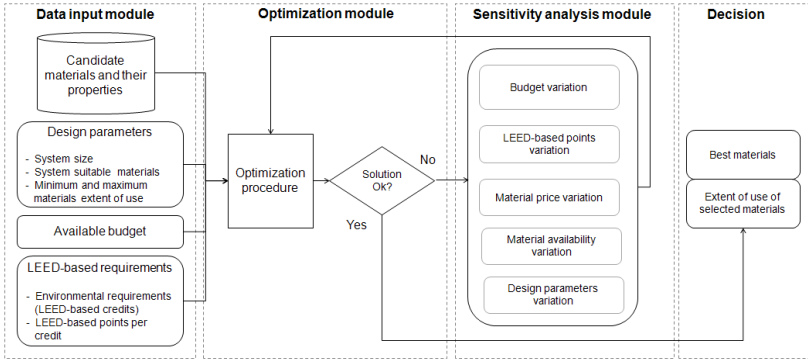


Figure 1. Optimization model framework

The data input module also includes the design parameters, which define the system size, the subset of suitable materials to build the system, and the minimum and maximum fraction of the system than can be built using those materials. For instance, consider that suitable materials for the floor system are woods *w1*, *w2*, *w3*,

w4, w5, and *w6*. The designer knows that at least 20% of the floor area, but no more than 40%, must be built using either wood *w1*, *w2,* or *w3*; a half of the system must be built using wood *w4;* and at least 20% but no more than 30% of the system must be built using either wood *w5* or *w6* (see Table 1). In this case, the optimization model selects the right type of woods while meeting the designer criteria.

Table 1. Floor system design criteria

Material	Lower bound*	Upper bound*
w1	20%	40%
w2		
w3		
w4	50%	50%
w5	20%	30%
w6		

*100%=total area

In addition to allocate a budget for material purchasing, the decision maker defines the LEED-based credit parameters in the data input module. A description of the LEED-based requirements is provided in Table 2. Those requirements are included in the optimization model as constraints. Figure 2 shows a graphical representation of the constraints associated with the accomplishment of credits 6 and 7 from the materials and resources area (see Table 2). If the total cost of rapidly renewable (RR) wood-based materials is greater than 2.5% of the total material cost, then the variable z_1 takes the value of 1, indicating that the LEED credit 6 is accomplished. In this case, the auxiliary term takes the value of zero and the inequality holds. Conversely, if the variable z_1 takes the value of 0, then the LEED-based credit 6 is not accomplished and the auxiliary term takes the value of G (a conveniently large number). A similar mechanism is used for other LEED credits considered in the model.

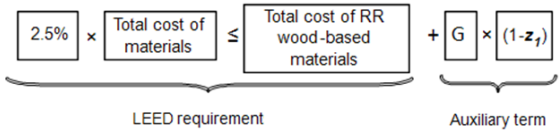


Figure 2. Operation of LEED-based constraints

Once all the data input is entered, the optimization module builds the model that maximizes the number of LEED-based points awarded through credit accomplishment (see Table 2). Mathematically, the model's objective is to maximize the number of z variables that take the value of 1, indicating the credit accomplishments. The output of the optimization model is a detailed selection of the best materials and their extent of use for each system in the building. A detailed description of the optimization model can be found in Castro-Lacouture et al. (2008).

Table 2. LEED-based requirements

Credit	Area	Name	Intent	Description
7.2 Points: 1	Sustainable Sites	Heat Island Effect, Roof	Reduce heat islands	Use roofing materials having a solar reflectance index (SRI) equal to or greater than 78 for low-sloped roofs (≤2:12) or 29 for steep-sloped roofs (>2:12). These values must be used for a minimum of 75% of the roof surface.
4.1 Points: 1	Materials and Resources	Recycled Content - 10%	Increase demand for building products that incorporate recycled content materials, reducing impacts from extraction and processing of virgin materials.	Use materials with recycled content such that the content constitutes at least 10% (based on cost) of the total value of the materials in the project. Only include materials permanently installed in the project, except mechanical, electrical, plumbing components and specialty items such as elevators. The recycled fraction of the assembly (by weight) is multiplied by the cost of assembly to determine the recycled content value.
4.2 Points: 1		Recycled Content - 20%		Use materials with recycled content such that content constitutes an additional 10% beyond Credit 4.1 (total of 20%, based on cost) of the total value of the materials in the project.
5.1 Points: 1		Regional Materials, 10% Extracted, Processed & Manufactured Regionally	Increase demand for building materials and products that are extracted and manufactured within the region, supporting local economies and reducing the environmental impacts resulting from transportation.	Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within the same region of the project site for a minimum of 10% (based on cost) of the total materials value. Only include materials permanently installed in the project, except mechanical, electrical, plumbing components and specialty items such as elevators.
5.2 Points: 1		Regional Materials, 20% Extracted, Processed & Manufactured Regionally		Use building materials or products that have been extracted, harvested or recovered, as well as manufactured, within the same region of the project site for an additional 10% beyond Credit 5.1 (total of 20%, based on cost) of the total materials value.
6 Points: 1		Rapidly Renewable Materials	Reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials.	Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 2.5% of the total value of all building materials and products used in the project, based on cost.
7 Points: 1		Certified Wood	Encourage environmentally responsible forest management.	Use a minimum of 50% (based on cost) of wood-based materials and products, which are certified (e.g., Forest Stewardship Council's -FSC), for wood building components (e.g., structural framing and general dimensional framing, flooring, sub-flooring, wood doors, and finishes). Only include materials permanently installed in the project.
4.1 Points: 1	Indoor Environmental Quality	Low-Emitting Materials, Adhesives & Sealants	Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.	All adhesives and sealants used on the interior of the building shall comply with the volatile organic compounds (VOC) limits provided in USGBC (2005) page 65.
4.2 Points: 1		Low-Emitting Materials, Paints & Coatings		Paints and coatings used on the interior of the building shall comply with the volatile organic compounds (VOC) limits provided in USGBC (2005) page 67.
4.3 Points: 1		Low-Emitting Materials, Carpet Systems		All carpet installed in the building interior shall meet the product requirements of the Carpet and Rug Institute's Green Label Plus program.
4.4 Points: 1		Low-Emitting Materials, Composite Wood & Agrifiber Products		Composite wood and agrifiber products used on the interior of the building shall contain no added urea-formaldehyde resins. Laminating adhesives used to fabricate on-site and shop-applied composite wood and agrifiber assemblies shall contain no added urea-formaldehyde resins.

Source: Castro-Lacouture et al (2008). Adapted from USGBC (2005).

Finally, the optimal solution is used in the sensitivity analysis module, where the solution robustness is evaluated by measuring the impact on credit accomplishments due to changes in the budget, LEED-based points, material prices, material availability, and design parameters. This sensitivity analysis enriches the decision maker information, supporting the final decision.

3. Model use example

This section is based on the case study presented in Castro-Lacouture et al. (2008), where the model was applied to an 11-story office building with an area of 6,000 m^2 and a total budget for materials of about USD 186,000. Eight systems and forty materials were considered, as it is shown in Table 3. A system can be divided in subsystems with a fixed area. For instance, the windows system is divided into three subsystems where a set of suitable materials is specified.

Table 3. System and suitable materials

System	Subsystem	Materials
Wood components	1	*w1,w2*
	2	*w3*
	3	*w4,w5*
Construction (wood)	1	*cw2,cw3*
	2	*cw4*
	3	*cw5,cw1*
Adhesives and sealants	1	*s1,s2,s3,s4,s5*
Paint	1	*p1,p2 ,p3*
	2	*p4,p5*
Carpet	1	*c1 ,c2 ,c3,c4,c5*
Roofs	1	*r1,r2*
	2	*r3,r4,r5*
Glass	1	*g1 ,g2,g3,g4,g5*
Windows	1	*v1*
	2	*v2,v3,v4*
	3	*v5*

Table 4 shows the optimal solution (labeled *base case*) with the best materials and their extent of use. For instance, it was found that the best materials to build the wood component system are woods *w2, w3,* and *w4.* Furthermore, the optimization model calculates the extent of use of each material, determining that 67.5 m of wood *w*2, 33.7 m of wood *w3*, and 67.5 m of wood *w4* are required to complete the wood component system. Even though the optimization model maximizes the number of LEED-based points awarded, this solution only awards 7 out of 11 available points (see Table 2) due to lack of budget.

To determine the additional budget required to award all LEED-based points, a variant of the optimization model is used. The new model minimizes cost, subject to guaranteeing the accomplishment of the 11 LEED-based credits. Table 4 shows the results of this analysis. Notice that the choice of materials is now different compared

to that in the base case. For instance, paint *p1* is used instead of *p3*, whereas glass *g5* is used instead of *g3*. Although this new set of materials along with their extent of use awards all the available LEED-based points, it also implies an additional investment in more expensive materials, requiring a budget increase of about USD 23,000. For a further discussion about this procedure the reader is referred to Castro-Lacouture et al. (2008).

The model can also be used to evaluate the impact of material price on the optimal solution. Table 4 shows the optimal solution in an inflationary scenario where material prices are increased by 1%. In this scenario, the only change in the optimal solution compared to the base case is that roof material *r5* is replaced by *r3*, which is less expensive. Although the optimal solution is almost the same, replacing roof materials implies a reduction of the awarded LEED-based points, failing to accomplish credit 7.2 of sustainable sites area (see Table 2).

Material availability is also a critical factor for the success of a green building project. If materials with desired properties are not available, environmental goals will be jeopardized. Table 4 shows the optimal solution when candidate carpets are reduced to those with a VOC emission factor higher than those suggested in credit 4.3 from the indoor environmental quality area (see Table 2). Similarly to the inflationary scenario, there is just a single change where carpet *c1* is replaced by *c3,* but still important enough to fail the related LEED-based credit.

Table 4. Optimal solutions in the sensitivity analysis

System	Optimal solution (base case) 7 points		Optimal solution (minimum cost to award all credits) 11 points		Optimal solution (increasing material prices) 6 points		Optimal solution (material unavailability) 6 points	
	Material	Required Quantity	Material	Required Quantity	Material	Required Quantity	Material	Required Quantity
Wood components (m)	*w2*	67.5	*w1*	67.5	*w2*	67.5	*w2*	67.5
	w3	33.7	*w3*	33.7	*w3*	33.7	*w3*	33.7
	w4	67.5	*w5*	67.5	*w4*	67.5	*w4*	67.5
Construction (wood) (m)	*cw3*	3507.4	*cw3*	3507.4	*cw3*	3507.4	*cw3*	3507.4
	cw4	876.8	*cw4*	876.8	*cw4*	876.8	*cw4*	876.8
	cw1	4384.3	*cw1*	4384.3	*cw1*	4384.3	*cw1*	4384.3
Adhesives and sealants (gal)	*s1*	5.0	*s1*	5.0	*s1*	5.0	*s1*	5.0
Paints (gal)	*p3*	230.7	*p1*	230.7	*p3*	230.7	*p3*	230.7
	p4	57.6	*p5*	57.6	*p4*	57.6	*p4*	57.6
Carpet (m^2)	*c1*	17.2	*c1*	17.2	*c1*	17.2	*c3*	17.2
Roof (m^2)	*r2*	54.2	*r2*	54.2	*r2*	54.2	*r2*	54.2
	r5	488.6	*r5*	488.6	*r3*	488.6	*r5*	488.6
Glass (m^2)	*g3*	91.3	*g5*	91.3	*g3*	91.3	*g3*	91.3
Windows (m^2)	*v1*	317.8	*v1*	317.8	*v1*	317.8	*v1*	317.8
	v3	635.6	*v3*	635.6	*v3*	635.6	*v3*	635.6
	v5	105.9	*v5*	105.9	*v5*	105.9	*v5*	105.9

4. Concluding remarks

Although the existing building construction literature presents many techniques for material selection, none of them considers simultaneously design parameters, budget, and environmental goals. To fill this void, the model outlined in this paper considers the above mentioned aspects, and proposes the best choice of materials and their extent of use.

To measure the environmental impact of materials, a modified version of the LEED rating system was used. The LEED system was adapted to the context of the case study where neither an assessment method is applied nor a complete material database is available. Nevertheless, a more sophisticated measure system can be embedded in a model of this kind, incorporating a wider spectrum of environmental impacts such as those generated along the material life cycle. However, if this is the case, an overwhelming process for data preparation is required in order to estimate the impact of each candidate material or, at least, each family of materials.

The applied model allows the decision maker to determine the robustness of an optimal material choice due to data input changes. Through a sensitivity analysis the impact of budget additions, material prices, and material availability on the optimal choice is evaluated. It has been shown, as expected, that additional budget will lead to more LEED-based points, through the purchase of materials with better environmental properties that are often more expensive. Moreover, if the price of materials is increased by 1%, a material substitution is observed, sacrificing the accomplishment of some environmental goals. Material availability also affects the number of points awarded. If the required materials are not available or the material properties are unknown, environmental goals will be impossible to meet. Further sensitivity analysis can be conducted using the outlined optimization model. As mentioned in Castro-Lacouture et al. (2008), the number of LEED-based points awarded by a particular area can be changed. By doing so, the system is promoting the accomplishment of certain credits by modifying the optimal choice of materials. For instance, if the number points awarded in credit 4.2 is doubled, then the LEED-based system is promoting the use of materials with recycled content.

A natural extension of this work could include the remaining credits from the LEED rating system. By doing so, a wider scope of decisions can be supported, including those beyond material selection such as selection of water efficiency technology and energy management systems. Another possible extension to the proposed model is to include price discounts in material acquisitions or price bundling (Rosenthal et al. 1995). This could reflect a common practice in the construction industry where discounts are available depending on the purchasing quantity or when buying in bulk.

Given the limitations of the LEED rating system, the inclusion of green measures covering broader environmental impacts such as life cycle analysis (LCA) will help the decision maker to minimize the building's impact on the environment. As LEED incorporates life cycle economic and environmental impacts in its future versions, the proposed optimization tool can be easily adjusted, while still considering design parameters, budget and environmental goals.

References

Ashby MF. Multi-objective optimization in material design and selection. Acta Materialia 2000; 48(1):359-369.

Baker G. Certification impacts private sector. Environmental Design + Construction 2006; 9(6):80-82.

Castro-Lacouture D, Sefair JA, Flórez L, Medaglia AL. Optimization model for the selection of materials using a LEED-based green building rating system. Building and Environment. Forthcoming. 2008.

Chan JWK, Tong TKL. Multi-criteria material selections and end-of-life product strategy: Grey relational analysis approach. Materials & Design 2007; 28(5):1539-1546.

Ding GKC. Sustainable construction: the role of environmental assessment tools. Journal of Environmental Management 2008; 8(1):451-464.

Edwards B. (Ed.). Green buildings pay. (2nd ed.). London; New York: Spon Press; 2003.

Farag M. Quantitative methods of materials selection. In: Kutz, M. editor. Handbook of materials selection. New York: Wiley; 2002.

Giudice F, La-Rosa G, Risitano A. Materials selection in the life-cycle design process: a method to integrate mechanical and environmental performances in optimal choice. Materials & Design 2005; 26(1):9-20.

Holloway L. Materials selection for optimal environmental impact in mechanical design. Materials & Design 1998; 19(4):133-143.

Jee DH, Kang KJ. A method for optimal material selection aided with decision making theory. Materials & Design 2000; 21(3):199-206.

Kats G. The cost and financial benefits of green buildings: a report to California's sustainable building task force. Sacramento, CA: Sustainable Building Task Force; 2003.

Keysar E, Pierce AR. Decision support tool for green building: Facilitating selection among new adopters on public sector projects. Journal of Green Building 2007; 2(3):153-171.

Pulselli RM, Simoncini E, Pulselli FM, Bastianoni S. Emergy analysis of building manufacturing, maintenance and use: Em-building indices to evaluate housing sustainability. Energy and Buildings 2007; 39(5):620-628.

Moeck M, Yoon JY. Green buildings and potential electric light energy savings. Journal of Architectural Engineering 2004; 10(4):143-159.

Muse A, Plaut JM. An inside look at LEED: Experienced practitioners reveal the inner workings of LEED. Journal of Green Building 2006; 1(1):3-8.

Ries R, Bilec M, Gokhan NM, Needy KL. The economic benefits of green buildings: A comprehensive case study. The Engineering Economist 2006; 51(3):259-295.

Rosenthal EC, Zydiak JL, Chaudhry SS. Vendor Selection with Bundling. Decision Sciences 1995; 26(1):35-48.

Ross B, Lopez-Alcala M, Small III AA. Modeling the private financial returns from green building investments. Journal of Green Building 2006; 2(1):97-105.

Sherwin D. Reducing the cost of green. Journal of Green Building 2006; 1(1):46-54.
Sirisalee P, Ashby MF, Parks GT, Clarkson PJ. Multi-criteria material selection in engineering design. Advanced Engineering Materials 2004; 6(1-2):84-92.
Thormark C. The effect of material choice on the total energy need and recycling potential of a building. Building and Environment 2006; 41(8):1019-1026.
USGBC (United States Green Building Council). LEED for new construction & major renovations (Reference Guide Version 2.2). Washington, D.C; 2005.
Venkatarama-Reddy BV, Jagadish KS. Embodied energy of common and alternative building materials and technologies. Energy and Buildings 2003; 35(2):129-137.
Wang W, Zmeureanua R, Rivard H. Applying multi-objective genetic algorithms in green building design optimization. Building and Environment 2005; 40(11):1512-1525.
Yudelson, J. The green building revolution. Washington, D.C.: Island Press; 2008.

QUANTIFICATION OF CARBON FOOTPRINT ON UNDERGROUND UTILITY PROJECTS

Shaik Sihabuddin[1] and Samuel T. Ariaratnam[2], MASCE

[1]Graduate Research Assistant, Ira A. Fulton School of Engineering, Arizona State University, Tempe, Arizona; email: ssshaik@asu.edu
[2]Professor, Ira A Fulton School of Engineering, Arizona State University, Tempe, Arizona; PH (480) 965-7399; FAX (480) 965-1769; email: ariaratnam@asu.edu

Abstract:
The utilization of traditional open-cut methods for the installation of underground utilities has been common practice in the construction industry for many years. Today, engineers are being tasked with the requirement of selecting a suitable construction method that not only offers the most economical solution, but also minimizes impact to the environment. Trenchless construction methods offer such solutions for installing new utilities and rehabilitating existing infrastructure. The use of multiple construction equipment during open-cut construction, along with extended project schedule, invariably results in considerably more emitted emissions into the atmosphere compared to employing trenchless methods, which have minimal on-site equipment requirements. Pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_X), particulate matter (PM), and sulfur oxide (SO_X) are identified by the United States Environmental Protection Agency (US EPA) as emissions emitted from equipment engines. This paper describes a methodology developed for quantifying the carbon footprint of a typical underground utility project. Case studies of trenchless pipe replacement, horizontal directional drilling, trenchers, and traditional open-cut are used to demonstrate the reduction in emissions by adopting trenchless technologies. Reducing emissions into the atmosphere is a vital step in developing sustainable solutions for infrastructure construction.

INTRODUCTION

The impact of construction technology on the environment is little understood by the construction industry. The world is moving towards providing a better and cleaner

environment for future generations. The recognition of urgency to curb emissions worldwide has forced the industry to work on developing methods to reduce emissions. Many countries now instill pre-determined targets in pollutants that need to be achieved by the middle of this century. The determination of impact of construction activities on the environment necessitates the estimation of the pollutant contribution by construction. The agencies provided with the duty to curb these emissions are moving towards strict emission standards for mobile sources including passenger vehicles and freight trucks. The Air Quality Management District (AQMD) in Sacramento metropolitan area has required that projects that exceed the short term construction threshold of 85 pounds per day of nitrogen oxide (NO_X) must mitigate the air quality impact (SMAQMD 2008). The construction industry which consumes a large quantity of the fossil fuels will be a major future target.

The Governor of California signed the Global Warming Solutions Act of 2006 on September 27, 2006. The Act became effective in January 2007. The act sets up the first enforceable statewide program in the U.S. to cap all greenhouse gas emissions from major industries and includes penalties for non-compliance (Press Release GAAS:684:06, 2006). The act requires the California Air Resources Board (CARB) to develop regulations and market mechanisms that will ultimately reduce California's greenhouse gas emissions by 25 percent by the year 2020. The initial step towards identifying the impact is to quantify the emissions from the construction activities. This paper demonstrates a novel methodology for quantifying emissions on underground utility construction projects. Four different construction methods: 1) trenchless pipe replacement; 2) horizontal directional drilling; 3) trenchers; and 4) traditional open-cut are used to demonstrate the approach.

LITERATURE REVIEW

The consciousness of the world towards reducing pollutant emissions to the environment can be realized by various developments globally. Current developments include curbing the emissions of greenhouse gases, incentives for using alternate fuels, setting target emissions for the future and developing plans to achieve these targets.

McElroy (2007) discussed the recognition of Biodiesel for its potential contribution to reduction of emissions. The California Department of Transportation (Caltrans) has a requirement, by the State's Global Warming Solutions Act, to reduce carbon dioxide emissions to 1990 levels by 2020. The mobile sources in the Los Angeles area contribute to 70% of the pollution. However, Biodiesel contributes to air pollution, as far as nitrogen oxides (NO_x) are concerned.

One of the major international pacts that bring together most of the countries in the world towards curbing pollutant emissions is the "Kyoto Protocol". The goal of the "Kyoto Protocol" is to reduce worldwide greenhouse gas emissions to 5.2 percent below 1990 levels between 2008 and 2012 (West 2008). "The challenge is to design a future agreement that will significantly step up action on adaptation, successfully halt the increase in global emissions within the next 10-15 years and dramatically cut back emissions by 2050," said Yvo de Boer, Head of the U.N.'s Climate Change

Secretariat (Cropley 2008). The UN Kyoto protocol was the first international agreement to curb the emissions of greenhouse gases.

Researchers calculate the worldwide carbon dioxide emissions in 2006 to be 35% greater than that of 1996 (Rice 2007). However, with considerable efforts being made to reduce emissions, the carbon dioxide emissions are increasing at a rate of 3.3% per annum from 2000 (Rice 2007). This proves that the human activities are leaving behind rather disruptive impacts on our environment.

Ghenu et al. (2008) has estimated the hourly emission factors for NO_x, CO, and PM 2.5 for working days and weekends inside an urban street in France. The real time data were compared with the available Operational Street Pollution Model (OSPM). The real-time data showed a variation by a factor of two in comparison to the OSPM model.

The use of local data to model the emissions from highway sources can have a large impact on the magnitude and distribution of emissions predicted and can significantly improve the accuracy of local scale air quality modelling assessments (Cook et. al. 2006). The initial approach can be to determine the emissions using the national averages. However, in order to accurately determine the emissions because of an activity, more refined emission factors are required.

Atmosfair (2003), initiated in Berlin, Germany, has developed a model to calculate aircraft emissions. The model calculates the emissions from the aircraft engines based on the type of aircraft, the flying altitude, the flight path and various other external factors. The emission calculator does not calculate the emissions of NO_x and particles and their impacts individually, but instead draws the impacts of these pollutants together via the CO_2 and Radiative Forcing Index (RFI). The CO_2 and effective CO_2 emissions are calculated by simple multiplication of quantity of CO_2 emitted per kg of kerosene consumed and the RFI.

Carboncounter.org was started as a collaborative approach between "The Climate Trust" (a non-profit organization) and "The Mercy Corps" (an international relief and development agency) (The Climate Trust, 2006). The model developed by the site provides an emission calculator to estimate an individual's home, auto and air travel emissions. The calculator takes into consideration only the carbon-dioxide (CO_2) emitted into the atmosphere and not any other gases or particles.

Climatefriendly (2007) is a for-profit organization in Australia that provides offset to the individuals and companies since 2004. The model can calculate emissions from the home or office, automobile and flight. The country's average emissions data are used to calculate the particular emissions for a household or office. The necessity of detailed input for the model provides the accuracy and comprehensiveness for calculation of emissions from the activities.

NativeEnergy (2008) is a privately-held Native American energy for-profit company founded in 2000. The emission factors that are used in the calculations are derived from the state average (i.e. type of vehicle) or calculated based on the emission factor (i.e. emission of carbon-dioxide from burning one pound of fuel). The model also provides insight into the feasibility of the model to calculate emissions based on the level of detail provided by the user.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (US EPA)

The Environmental Protection Agency (EPA) is an agency of the United States Government that sets the national standards for environment protection using environmental assessment, research, and education. The EPA has collected data on operation characteristics of different equipment. They have also categorized the engines based on their power. The emissions data are available for different categories of engines performing different activities. With the different emission control standards that are being enforced by the EPA, there is a reduction of sulfur and nitrogen emissions. To determine emissions from equipment and vehicles, the emission factors are calculated based on available EPA test data (EPA, 2002 and 2003). This approach helps to estimate pollution using equations that are applicable for a particular operation. A new emission calculator tool was developed based on these emission factors. The user-friendly calculator determines the pollution based on the equipment characteristics and activity characteristics of the equipment.

EMISSION CALCULATOR TOOL

The authors developed an emission calculator in MS Excel using Visual Basic coding. The calculator utilizes the EPA approved formulae and test data to estimate emissions from each project. The input data required for the calculation can be obtained from daily progress reports of the project and the equipment operation data available from the contractor. The calculator is a tool for contractors and other stakeholders to estimate the impact of their construction on the environment. The data required to estimate the emissions from equipment include: 1) equipment characteristics such as power, model year, engine technology, useful hours and cumulative hours used to date; 2) fuel characteristics such as type and sulfur content; and 3) activity characteristics such as representative equipment cycle, power used and hours of use. The data required to calculate emissions from transport include: 1) transport characteristics such as model year, gross vehicle weight and mileage on the vehicle; 2) fuel characteristics such as type and sulfur content; and 3) activity characteristics such as altitude of operation, number of trips, one way distance and return distance. Results of the tool to calculate emissions from four utility construction projects are detailed in the following sections.

UTILITY CONSTRUCTION PROJECTS

The emission calculator tool was used to determine the emissions from four different utility construction methods: 1) trenchless pipe replacement; 2) horizontal directional drilling; 3) trenchers; and 4) traditional open-cut

Overall, three project sites were visited to collect the data on the activities for each utility installation method. The details on the project and data collected for calculation is discussed in the following sections.

Trenchless Pipe Replacement in Phoenix, Arizona

The project consists of upsizing a 300mm (12") sewer line to 450mm (18") clay pipe at the intersection of N 35th Avenue and Desert Cove Dr. in Phoenix, Arizona. The line was a gravity sewer with a grade of 0.5% at a depth of approximately 4m (12 ft). The method adopted by the contractor was trenchless pipe replacement using static pipe bursting. The method of static pipe bursting requires target and launch pit excavations (Lueke and Ariaratnam, 2001). The machine is lowered into the target pit and the new pipe is pulled in from the launch pit. The total length of this installation was 100m (327 ft).

Two excavators were used for the excavation of the pits and for lowering shoring into the pit. A Groundoburst 400 G3 static bursting machine was used in the project. The existing pipe was expanded to a diameter of 600mm (24") to accommodate the 450mm (18") clay pipe, which had an outer diameter of 550mm (22"). The soil was soft clay with no rocks or gravel layers. The excavated material was used for the backfill. Subsequently, there was no requirement of hauling the materials from the site. One of the lanes on N 35th Avenue was closed for facilitating the movement of equipment.

The site activities commenced with the excavation of the launch and target pits. The clay pipe sections were 2m (6.57 ft). After the excavation and shoring of the pits, the jacking frames were lowered in the target pit. Chain links of 1.5m (5 ft) lengths were linked progressively and inserted within the existing 300mm (12") pipe. When the links reached the launch pit, a bursting head was attached to the links and new clay pipe sections were attached to the bursting head. The bursting head has a diameter of 600mm (24"). The bursting head was pulled through the existing pipe by the power unit placed near the target pit. The pipe sections were lowered into the pit using an excavator and sections were locked into place using jacking force. The pipe sections moved along a rail in the launch pit and entered the existing pipe. The power unit pulled the new pipe sections using a force of 160 tons. Another excavator at the target pit lifted the chain links with the progress of pipe in the hole. The operating times and usage were documented for calculating the emissions shown in Table 1.

Table 1. Field data collected on trenchless pipe replacement project

Equipment							Activity		
Name	Model	Engine Model (Tier)	Model Year	Rated hp	Cum. Usage (hrs)	Useful Life (hrs)	Name	Total Time (mins)	Load Factor
Groundoburst	400G3	Tier 0	2006	36.5	1624	5000	Push the chain links	70	24
							Pull the bursting head & pipe	101	72
							Idling between the pull	274	6
Excavator	Komatsu PC228	Tier 2	2005	143	2000	8000	Excavating launch pit & place shoring	390	100
							Place shoring & railings	90	100
							Lowering pipe sections	15	60
Excavator	Komatsu PC300LC	Tier 2	2005	245	2583	12000	Excavating target pit & place shoring	360	100
							Place shoring & frames	90	100
							Hauling chain links	101	60
Loader	CAT 930G		2007	149	950	10000	Hauling pipe sections	65	100
							Assisting the operations	60	65

Horizontal Directional Drilling in Goodyear, Arizona

A commercial shopping complex called "Estrella Falls Mall" is currently being constructed between McDowell and Virginia Avenue to the north of I-10 in Goodyear, Arizona as part of the McDowell Commercial Corridor Phase II development. The construction is a shopping mall with internal roads associated with the construction. The delays associated with the future gas lines lead the contractor to construct the roadways provided in the construction drawings. Even though the construction site is barren with lot of work areas, the gas lines need to be aligned beneath the roadways. With the roadways already compacted, the contractor opted for using directional drilling to go beneath the roadways.

The installation process included setting up the rig at the entry pit, drilling the pilot bore and pullback of the new product pipe. The depth of the installation varied between 1.5m (60") and 2.4m (94") with an installation length of 29m (95 ft). The site activities started with the excavation of the entry and exit pits for drilling. The pipe was fused at the site for installation. Equipment setup took about one hour prior to commencement of the 114mm (4½") diameter pilot bore. After the pilot bore proceeded from the entry to the exit pit, the drill bit was removed and a reamer with a swivel and product pipe was pulled through the borepath. The reamed hole had a diameter of 150mm (6") with a 100mm (4") Fusible PVC™ pulled in place. Since the entire site was under construction, there was no necessity to haul the excavated material from the site. The operating times and usage were documented for calculating the emissions and are presented in Table 2.

Table 2. Field data collected on horizontal directional drilling project

Equipment							Activity		
Name	**Model**	**Engine Model (Tier)**	**Model Year**	**Rated hp**	**Cum. Usage (hrs)**	**Useful Life (hrs)**	**Name**	**Total Time (mins)**	**Load Factor**
Drill Rig	Ver. D36x50	Tier 2	2006	140	380	6000	Pilot Hole	30	68
							Backream and pullback	20	41
							Pull back the drilling rods	10	20
Fluid Mixing System	Honda GX270	Tier 2	2006	9	15	500	Supply drilling fluid	60	100
Vac Truck	Kohler CH25S	Tier 2	2006	25	718	3000	Vacuuming the spoils	60	100

Truck					Activity			
Name	**Model**	**Model Year**	**GVW (lbs) or Class**	**Mileage**	**Name**	**Oneway Dist. (mi)**	**Return Dist. (mi)**	**Trips**
Transport	International	1993	65000	605096	Transport equipment	4	0	1
Vac Truck	Chevy 3500	2000	15000	75451	Transport Kohler CH25S	4	0	1
Vac Truck	Chevy 3500	2000	15000	75451	Movement in the site	2	0	1

Trenching in Scottsdale, Arizona

The project required installation of two 50mm (2") conduits for electrical, two 100mm (4") conduits for Qwest communications and two 50mm (2") communication cables for Cox Communications. The project site was located at the intersection of Hillside Rd and Indian Bend Rd at Scottsdale, Arizona. The depth of the installation was 1.37m (54") from the surface. The project was a combination of open-cut and trenching. The length of installation trenched using the trencher was 100m (300 ft). All utility crossings were exposed using a backhoe. Only the length of the alignment

excavated using the trencher was studied for emissions. Since the excavation was in the right-of-way of the street, the contractor had to provide access to the adjacent properties.

The location of the site was near the foothills of a mountain and the soil investigation revealed the presence of a hard rock strata. The low productivity of the backhoe in hard rock strata forced the contractor to use a trencher for the job. This minimized the work of the backhoe using it to work only on the stretches of utility crossings. The trench width was 450mm (18”). The restriction of dumping the material on the street warranted a loader to haul the excavated material to the dumpsite. The dumpsite was located at a distance of 0.5 miles from the site. For dust control, a laborer was required on-site to spray water at the blades of the trencher and on the excavated material. The scope of the contract was to excavate, install the pipes and backfill with Aggregate Base Course (ABC). The backfill material is a self-compacting slurry that is delivered to the site. The pipes were placed in the trench by the laborers. Hence, the placing of pipes and backfilling were not considered in the emissions. Also, road paving was not included in the scope of this contract.

The proposed alignment of the trench was marked on the road and the trencher was set up along the alignment. The conveyor of the trencher was adjusted to dump the excavated material on the street. The loader constantly loaded the excavated material onto a dump truck. The excavated material was hauled at the rate of 1.5 ft per minute. The trencher was moving at the rate of 3.5 ft per minute. The operating times and usage were documented for calculating the emissions and shown in Table 3.

Table 3. Field data collected on trencher project

Equipment							Activity		
Name	**Model**	**Engine Model (Tier)**	**Model Year**	**Rated hp**	**Cum. Usage (hrs)**	**Useful Life (hrs)**	**Name**	**Total Time (mins)**	**Load Factor**
Trencher	Vermeer T955	Tier 2	2005	400	2060	15000	Excavation of the trench	86	100
Backhoe	CAT 420E	Tier 2	2005	90	1308	5000	Loading excavations	180	90
							Assisting operations	32	50
Water Pump	Honda WT30X	Tier 1	2002	10	15	500	Dust Control at site	86	100

Truck					Activity			
Name	**Model**	**Model Year**	**GVW (lbs) or Class**	**Mileage**	**Name**	**Oneway Dist. (mi)**	**Return Dist. (mi)**	**Trips**
Transport	Chevy C7500	1993	33001	95156	Hauling excavted material	0.7	0.7	20
Water Truck	AeroMax L9000	1993	33200	34697	Hauling water	5	5	1

Traditional Open-Cut Construction in Queen Creek, Arizona

This project consisted of a pipeline that will deliver 48 million gallons per day (mgd) of raw water from the Central Arizona Project (CAP) Canal, located East of Schnepf Road in Pinal County, to the new joint Gilbert/Chandler South Water Treatment Plant (SWTP), located at Recker Road and Ocotillo Road in Gilbert, to meet the growth and water demands in the Town of Gilbert and City of Chandler. This will be accomplished by constructing 13 miles of waterline using 1200mm (48”) concrete pipe. The depth of the installation varies between 4m (12 ft) and 5.4m (18 ft).

During data collection, the installation crew was working on the south side of Queen Creek/Pima Road, east of Meridian Road, heading east toward Ironwood Road

installing 6m (20 ft.) sections of concrete pipe. There are site restrictions for dumping the materials on one side of the trench. Two haul trucks to the nearby dumping site were transporting 40% of the excavated material. The productivity of the crew was 400 ft/day for a 9 hour workday.

The site activities included excavation, lowering or dragging the shoring, dropping the pipe section, backfilling, and compacting. The productivity of the crew depends on the productivity of the trackhoe. The construction operation at the site was cyclic, repeating for every pipe section installation. The operating times and usage for installing a single pipe section of 6m (20 ft) were documented for calculating the emissions and shown in Table 4.

Table 4. Field data collected on trencher project

Equipment							Activity		
Name	**Model**	**Engine Model (Tier)**	**Model Year**	**Rated hp**	**Cum. Usage (hrs)**	**Useful Life (hrs)**	**Name**	**Total Time (mins)**	**Load Factor**
Trackhoe	CAT 385B	Tier 2	2004	513	5259	20000	Excavation	10	100
							Drag Shoring	1	100
							Place pipe	4	80
Loader	CAT 950G	Tier 2	2004	183	6738	10000	Laoding & Backfill	15	80
Loader	CAT 950H	Tier 2	2004	216	11315	14000	Laoding & Backfill	15	80
Compactor	Komatsu PC400	Tier 3	2006	345	2109	16000	Compaction	15	100
Truck							**Activity**		
Name	**Model**	**Model Year**	**GVW (lbs) or Class**		**Mileage**		**Name**	**Oneway Dist. (mi)**	**Return Dist. (mi)**	**Trips**
Water Truck	Peterbilt	2006	15876		17318		Water for dust control	7	7	0.5
Haul Truck	Peterbilt	2007	22750		37190		Hauling excavated material	0.8	0.8	3
Haul Truck	Ford	1995	58000		122721		Hauling excavated material	1	1	3

SUMMARY OF EMISSIONS

Utility projects involving trenchless pipe replacement, horizontal directional drilling, trenching and traditional open-cut construction were studied for their emissions. The data collected was input into an "Emission Calculator" tool to calculate various emissions with the emissions from each project summarized in Table 5.

Table 5. Summary of emissions from four different utility construction projects

Construction Method	Location	Pipe size	Length and depth	Emissions					
				HC (lbs)	CO (lbs)	NO_x (lbs)	PM (lbs)	CO_2 (lbs)	SO_2 (lbs)
Pipe bursting	Phoenix, AZ	Upsize from 12" to 18"	372ft at 12ft avg depth	2.6	10.0	29.6	1.7	4224.2	8.5
HDD	Goodyear, AZ	4" PVC	95ft between 60" and 94"	0.1	0.5	1.2	0.1	156.2	0.3
Trencher	Scottsdale, AZ	2": and 4" lines	300ft at 4.5ft depth	0.8	5.7	9.2	0.6	1225.0	2.3
Open cut	Queen Creek, AZ	48" concrete	20ft section at 15ft avg depth	0.2	0.9	2.6	0.1	394.0	0.7

CONCLUSIONS

With many government agencies moving towards a greener environment, it is necessary for the construction industry to understand and estimate their emission generation. Decision makers are now being tasked with selecting an appropriate construction method, which is not only cost and time effective, but also less harmful to the environment. This paper presented the use of an emissions calculator to determine emissions generated from four typical equipment used in underground utility construction. With the availability of historical data on projects, a contractor could estimate the projected emissions prior to commencement of a project. This would also enable government agencies to include a "carbon footprint" component into the contractor selection process.

Overall, twelve projects (three of each construction method) have been evaluated with collected data inputted into the emissions calculator. It is quite evident that trenchless construction methods produce fewer emissions compared to traditional open-cut excavation. This is largely due in part to the reduced construction time and minimal on-site equipment requirements offered by trenchless construction.

REFERENCES

Atmosfair gGmbH. (2003). "The emissions calculator." Atmosfair gGmbH, Kaiserstr, Bonn, Germany. <http://www.atmosfair.de/index.php?id=5& L=3> (Nov. 19, 2007).

Climate Friendly. (2007). "Calculate my." <https://climatefriendly.com/shop> (Nov.19, 2007).

Cook R., Touma J.S., Beidler A., Strum M. (2006). "Preparing highway emissions inventories for urban scale modeling: A case study in Philadelphia" Transportation Research Pat D 11, 396-407.

Cropley, E. (2008). "Climate negotiators start work on 'Kyoto II'." Reuters, <http://www.reuters.com/article/environmentNews/idUSBKK14531120080330> (Mar. 29, 2008).

EPA. (2002). "Exhaust and Crankcase emission factors for non-road engine modeling – Compression ignition." EPA420-P02-016, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency (U.S EPA), Washington, DC.

EPA. (2002). "Update of Heavy-Duty Emission Levels (Model Years 1988-2004) for Use in MOBILE6." EPA420-R-02-018, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency (U.S EPA), Washington, DC.

EPA. (2002). "Update heavy-duty engine emission conversion factors for MOBILE6, Analysis of BSFCs and calculation of heavy-duty engine emission conversion factors." EPA420-R-02-005, Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency (U.S EPA), Washington, DC.

EPA (2003). "Mobile 6.1 Particulate Emission Factor Model Technical Description: Final Report" Document no. EPA 420-R3-001 Assessment and Modeling Division, Office of Transportation and Air Quality, United States Environmental Protection Agency (US EPA), Washington, DC

Ghenu A., Rosant J.M., Sini J.F. (2008). "Dispersion of pollutants and estimation of emissions in a street canyon in Rouen, France." Environmental Modeling & Software 23, 314-321.

Lueke, J.S. and Ariaratnam, S.T. (2001), "Rehabilitation of underground infrastructure utilizing trenchless pipe replacement", Practice Periodical on Structural Design and Construction, ASCE, February, 6(2), 25-34.

McElroy, A.K. (2007). "Court Snubs Clean Diesel Technology." Biodiesel Magazine, <http://www.biodieselmagazine.com/article.jsp?article_id=1915> (Mar. 13, 2008).

NativeEnergy Inc. (2008). "How we calculate." <http://www.nativeenergy.com/pages/how_we_calculate/34.php> (Nov. 23, 2007).

Press Release GAAS:684:06 (2006). "Gov. Schwarzenegger Signs Landmark Legislation to Reduce Greenhouse Gas Emissions." Office of the Governor, Los Angeles, CA <http://gov.ca.gov/index.php?/press-release/4111/> (Mar. 18, 2008).

Rice, D. (2007). "World's carbon dioxide emissions rising at alarming rate." USA TODAY, <http://www.usatoday.com/weather/climate/globalwarming/2007-10-22-carbon-emissions_N.htm> (Mar. 18, 2008).

Sacramento Metropolitan Air Quality Management District (SMAQMD) (2008) "AQMD Recommended Mitigation for Reducing Emissions from Heavy-Duty Construction Vehicles" SMAQMD, Sacramento, California, <http://www.airquality.org/ceqa/mitigation-heavy-construction.shtml#footnote1> (Apr. 21, 2008)

The Climate Trust. (2006). "Offset your emissions."<http://www.carboncounter.org/> (Nov. 19, 2007).

West, L. (2008). "Should the United States Ratify the Kyoto Protocol?" About.com: Environmental Issues, <http://environment.about.com/od/kyotoprotocol/i/kyotoprotocol.htm> (Mar. 20, 2008).

IMPROVING ENERGY EFFICIENCY IN BUILDING THROUGH AUTOMATED COMPUTER DESIGN PROCESS

Jason Charalambides[1]

[1]California State University at Fresno, 2320 E. San Ramon Avenue, M/S EE94, jcharalambides@csufresno.edu

Abstract

Passive solar heating and light control have been traditionally accomplished through simple rules that matured to shape vernacular architecture. Although many more issues were addressed, the comfort level in terms of thermal energy as well as light control, were key issues in traditional buildings. New materials and techniques altered the balances, setting the use of new types of energy as essential parts of modern design.

The power of modern technology, though applied toward the use of materials to generate viable enclosures, it has not been used to its full potential toward the efficient use of solar energy and against the dependency of commercially available energy. The use of computers aiding us toward design has been limited in practice to electronic drafting or modeling [Aish, 2000]. Other than the recently developed packages like Ecotect that integrates to commercially available Computer Aided Design (CAD) software, relatively minimal was the work done toward aiding a designer to energy consumption in a visually responsive interface. In order to facilitate the designer in an efficient manner, an algorithm that seamlessly works within commercially available CAD/BIM packages has been developed. The developed program has the advantage of generating an initial input by itself into the CAD interface instead of retroactively evaluating a pre-existing form that the designer has already generated. It determines the optimum openings and shading devices for a given space at any specific latitude and interactively generates virtual models for the user. The main issues addressed are thermal comfort and light control. Although it is not anticipated that passive solar control will provide thermal comfort under all possible scenarios, the algorithm offers optimum use of solar energy.

INTRODUCTION

Architectural design is a process where individual projects need to be addressed according to the specificities of objectives and what the site has to offer. Designing a

Green building is as case specific as the combination of parameters such as material availability, budget, architectural agenda, climate, site, building codes, available technology, local workforce and project feasibility all combined. It would be correct to claim that, at least for the client, the issue is not trivial, and for all the parties involved in such a project, the result is not obvious. Furthermore, it is very unseemingly that any specific result would be more advantageous under all possible circumstances.

The above parameters set the standards under which risk analysis should take place before a project begins. Nevertheless, building Green will soon turn out to be the only option. Like in every case of risk analysis, uncertainty is addressed through the accumulation and process of data. The accumulation of data is also the process a designer goes through in order to prioritize and know specifically how to design the project. In the case of designing with energy efficiency, the most important goal is to use the minimum amount of energy to keep the interior of a building within the comfort zone. Although direct solar radiation is the most important energy source, solid masses and openings should be balanced to minimize need of other sources of energy for lighting. Glare control may become a major issue in the decision making for orienting openings to an interior space.



FIGURES 1&2 VERNACULAR CRACKER HOUSE IN FLORIDA DESIGNED BY RANDY CULLOM AND LIZ SEIBERLING (HTTP://WWW.PHYS.UFL.EDU/%7ELIZ/HOME.HTML), COMPARED TO PHILIP JOHNSON'S MODERNIST GLASS HOUSE IN NEW CANAAN.

The absence of superficial ornament and the portrayal of the actual building materials and the generated geometries as the ornament of the buildings encourage the use of rational methods of design based on concepts and parameters that can be quantified and measured; methodologies that Information Technology has been very successful in processing already. The success of an architectural project, as presented by the theories of Vitruvius needs to incorporate the beauty that the user will appreciate. It can be noted that with every technological advance, new construction materials appear and a new aesthetic is developed. To many, new non traditional forms that seemingly incorporate no sign of aesthetics may be repulsive at first. The Eiffel tower is a prime example. The level of interest will be raised by the implementation of unanticipated arrangements of geometric forms that will intrigue the sensory stimulation of the user [Rapoport, 1977]. Vernacular architecture as seen in figure 1 would not constitute imagery a resident of a cold northern climate would be accustomed to. The climate of a region like Florida is very different from that of Connecticut and so is the type of foliage, the type of sunlight, the temperatures and

the environment in general. An aesthetic can always be developed toward the appreciation of new forms based on new materials and a different rationale. Such is the case of Philip Johnson's house in figure 2, emphasizing the qualities of new materials used in the second Modernist era. The rationale for building for energy efficiency is as valid as any previous that lead to a new established architectural movement.

THE BEGINNING

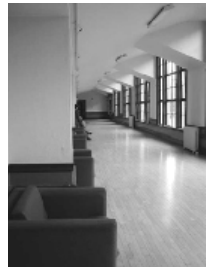
The process for design automation for energy started with the idea of generating an automated routine that would determine the noon sun angles at specified dates and aid the designer to specify the location and the length of a shading device. Thus the shading devices applied on the south direction of a building would provide full coverage on a hot summer day and full exposure to the sun on a cold winter day on a moderate climate site. Students at California State University at Fresno were given a classroom assignment to estimate the location and length of a shading device for a South facing window. Then the process continued to a random orientation where the timing would correspond to afternoon hours at different dates. The assignment lead to the idea of compiling a program that would function as a sun angle, energy, and shading device calculator in order to simplify the process of a series of equations. The program still carries this title. Given the number of available software packages that generate numerical results that aid in retrofitting existing structures, the purpose of this project was to compile a program that would interactively aid the user in designing and producing an initial form in a visually responsive manner. It had to be possible to integrate to existing software and for the developed program to communicate with the commercially available CAD package.

This concept for launching a new scheme prioritizes the objective of energy efficiency over other parameters that can be addressed at a second stage. By implementing this principle the computer produces an initial solution that may be unforeseen by the designer, who in turn can recycle the result with the aid of the computer. Sequin and Kalay present a method of design recycling with analytical process conducted by the user [Séquin / Kalay, 1998]. Instead, the analysis and validation proposed in this case would be conducted by the computer. This allows the designer to apply intuition through the input of systematic or random plausible solutions that can satisfy criteria of the architectural agenda.

At the basic level a simple Visual Basic for Applications (VBA) would suffice. However, the effect of latent heat within the building and harsh low angle sunlight became quickly evident and raised questions. Similarly the fact that in most areas, early morning sun may be allowing a quick regain of the energy lost during the night was taken into account. On the other hand, a continuous reception of solar energy is not desired after the enclosed space is set within the comfort zone during the late afternoon unless if the afternoon temperatures fall so drastically that low sun angles will perpetuate the comfortable temperatures. Geographic locations such as Seattle or Portland are examples of such conditions. Also, at locations like the previously mentioned that have long periods of overcast, natural light is greatly appreciated but this may result in large energy losses due to the substantial openings necessary while

the sun rays are blocked. An example is the case of Gerlinger Hall at the University of Oregon. All these cases lead to a series of parameters that needed to be addressed and aspired results to be achieved through further enhancing the automation within a CAD program.





FIGURES 3 & 4 – STUDENTS AT CALIFORNIA STATE UNIVERSITY, TESTING SUN ANGLES AND DESIGNED SHADING DEVICES. THE SOUTH FACING CORRIDOR OF GERLINGER HALL – UNIVERSITY OF OREGON

The other issue to be addressed within the application was the effect of contrast glare and light diffusion within an enclosed area. Since the design of the openings would allow full exposure or blocking of direct sunlight within an enclosed environment, it became evident that problems with the evenness of lighting and the desired amount of diffusion would need to be addressed. There can always be several methods to solve such issues, and the level of complexity within this program and at this stage should remain to that of being able to recognize if glare will occur, allowing the designer to provide other possible solutions until the problem is resolved. The purpose is to avoid the generation of a finalized design and retroactively apply solutions such as application of film or tinted glass. The option of applying mechanisms of light diffusing from skylights will be addressed at a later stage. The basis for this option has already been set within the interface.

The selection of programming language to be used was set on two basic parameters. One was the rigor of the functions that a software package could support, and the other was the interface that the user would have to address. On the first one, given the power of contemporary machines, the looping processes and mathematical functions that would need to be supported would only cause a minor time difference in the generation of a result. The user would spend orders of magnitude more time engaging in his decision making parameters that the delay or the swiftness of the response of the software would be negligible.

THE INTERFACE FOR A COMPUTER SOFTWARE

The issue of interface was of particular concern since as it would be vital to the objectives of the project. The main goal was the generation of a program that would allow the designer to engage into the control of the energy in a building. Therefore, the program's interface would be effective only if no special skills would be required from the user. The original idea was that the software functions in background and

there is very little involvement from the side of the user. That would have been the ideal solution, but the issue of data accumulation had to be addressed. Ideally there would have been a database where weather conditions could be recovered and imported into the software to be compiled. A database for that would have been ideal but such a standardized set of information that could be applicable globally was not an available option. Although some databases do exist, mainly coming from Swiss software, a significant amount of information would still be needed. Instead, a future process of gradual and continuous building and updating a standardized database that would integrate within the program is considered as a plan. Thus at an early stage, a more interactive interface with a series of tags and controls was considered the solution to opt for.

The language used was Visual Basic (VB) which provides a Graphic User Interface (GUI) and is similar to the VBA language used within most available CAD software. The option of using VBA altogether was also considered, but rejected. The advantage would have been the fact that there is only one single application and no issue of communication between software would have been necessary to address. The disadvantage was that a VBA application, even if it could carry a long series of commands, it would bear the limitation of being used within a specified commercially available CAD package. Therefore, a split into a main application through which the user would administer a series of necessary calculating routines, and one that would translate the data to a model within the CAD program was considered as more efficient. A series of data could be exported from the main application, and a VBA routine within the CAD package could import them and generate a virtual model. This would allow a development of similar VBA applications for other commercially available CAD packages, and make the main calculating application more universal. Consequently, the algorithm is split into a main calculating application and a secondary operating applet.

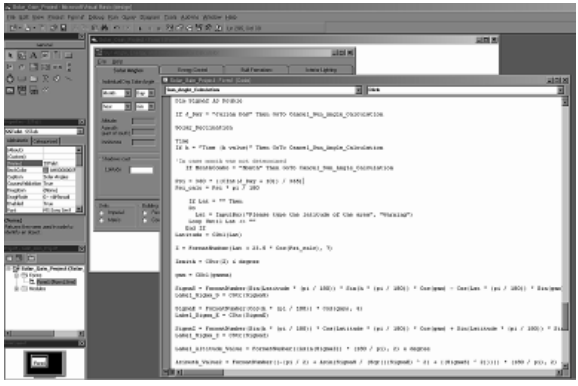


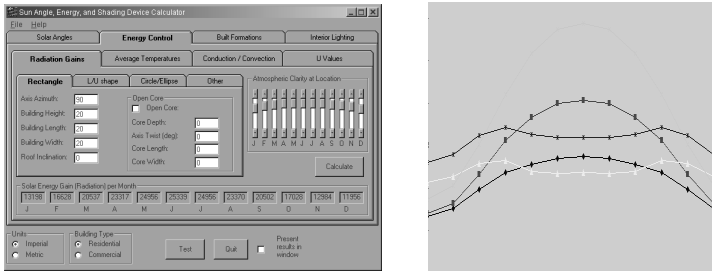
FIGURE 5 – DEVELOPING THE ALGORITHM IN VB GRAPHIC USER INTERFACE

COMPILING THE PROGRAM

A set of parameters and routines was arranged in a series of tabs within the graphic interface, leading the user to a series of data to submit and consequently permitting a series of tasks to be performed by the program. Options like the presentation of calculated values within a window, or use of metric or imperial system were made available. The actual calculation is set on metrics but the input and the output numeric values can be viewed in either system.

The first issue addressed was the calculation of critical sun angles. Those would be the cases were maximum or minimum exposure would be desired. At an initial stage these can determine a more generic configuration and provide the necessary information for the user to manually set the dimensions for window openings and shading devices. The most important contribution of this function is that it allows the user to make modifications to an ongoing design scheme without engaging into the rest of the information and parameters.

A section of the program estimates the total radiation received on a building during each month. The dimensions are given and based on the total exposure at any angle of incidence, the amount of energy is calculated for every one minute increments. Given that the atmospheric clarity plays a significant role, a set of manual controls has been provided for the user to determine an estimated average value. Other factors such as wind chill or shading have not been incorporated as those are very random or site specific. The atmospheric filtering controls can be used for such functions instead in view of the fact that the numerical effect within the algorithm will be comparable.



FIGURES 6 & 7 – THE SOLAR ENERY SECTION OF THE PROGRAM WITH THE ATMOSPHERIC FILTRATION CONTROLS. OUTPUT OF CALCULATIONS OF ENERGY GAIN FROM A SERIES OF DIFFERENT BUILT CONFIGURATIONS.

Another section of the program is the “built formation”, an option that allows the user to determine the dimensions of the site and given the volume and number of floors, the program suggests a preliminary set of dimensions and orientation. This brings the previous function in play, with a series of loop processes to provide the most advantageous curve of energy reception by minimizing it during summer and maximizing it during winter.

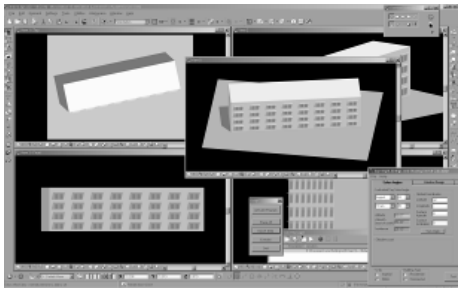


FIGURE 8 – A GENERATED MODEL WITH THE SHADING FOR FULL COVERAGE ON AUGUST 22 AT 10:30 AM ON THE SOUTHEAST SIDE OF THE BUILDING.

Finally, the section about lighting estimates the amount of natural light received within a given interior space and determines whether there may be an issue of extreme contrast and glare. The result allows the user to modify the materials for a different U value and accordingly define larger or smaller windows and orient them at different directions in order to achieve better light diffusion.
The user has the option of manipulating forms that were generated within the CAD interface since the formats applied will be native to the CAD software. Forms generated may be unprecedented, with shading devices at unusual angles. Although these are editable, the whole concept can be viewed as a new aesthetic that satisfies the needs of a contemporary building science.

CONCLUSIONS

With all the available technology and the multitude of materials available, contemporary architecture suffers in terms of optimizing the available technological resources. Designers have started to recognize the value of information technology, using computational power of what is available rather than transforming the computer to an perform in digital format what was analog drafting in the past. The process can be accelerated through the accumulation of information and the generation of methods of assessment and decision to be taken. BIM is still in a stage where users perform calculations to provide input that is simply recorded into a file that can be viewed in virtual 3D space. Automation is a key issue to guarantee success of this evolutionary stage of CAD. The computation power of IT in conjunction with the information that can be accumulated should allow the computer to perform the calculations and generate the results for the users to review and finalize. The contribution of the compiled program is the easy accessibility to an essential tool for a designer as he makes decisions that will have a significant impact on the efficiency of the operating costs of a new building. The compiled program communicates with existing CAD packages and transfers data that automatically generate an optimal initial form for the designer. Given the Graphic User Interface, the user can further enhance the output by adjusting and manipulating data within the program and reevaluating them to produce amended output forms. The building form that results

from an initial output may not necessarily be the most aesthetically appealing but it provides a well calculated bulk shape that can be altered and refined by the designer to the further needs of the architectural program.

REFERENCES

Aish, R, "Mitigation from an individual to an enterprise computing model and its implications for AEC Research" (white paper submitted to the Berkeley-Stanford CE&M Workshops: Defining a Research Agenda for AEC Process/Product development in 2000 and beyond), 2000.

Charalambides, J. E, "Developing a computer assisted multi-disciplinary decision making platform", *2008 Structures Congress*, Structural Engineering Institute – American Society of Civil Engineers, Vancouver B.C. April 24-26, 2008.

Davies, N, "BIM Elements", *Bentley Systems eSeminar*, 2007.

Rapoport, A, *Human Aspects of Urban Form*, 1977.

Séquin, C, H, Kalay, Y, "A suite of prototype CAD tools to support early phases of architectural design", *Automation in Construction* 7, 1998, pp.449–464.

KEY PROCESSES IN THE BUILDING DELIVERY OF GREEN HOSPITALS

Elena Enache-Pommer[1] and Michael Horman[2]

[1] Graduate Assistant, Dept. Architectural Engineering, Pennsylvania State, University, 104 Engineering Unit A, University Park, PA 16802
[2] Associate Professor, Dept. Architectural Engineering, Pennsylvania State University, 104 Engineering Unit A, University Park, PA 16802

Abstract:
The healthcare industry is one of the largest and most significant built environment markets today with over 120,000 buildings in the United States. Moreover, in the next 15 years, an estimated $300 billion will be spent on hospital construction across the United States. Therefore, there is a great opportunity for research and improvements to be made in this area. The built environment has a great impact on healthcare, particularly on the health, safety and well-being of patients and staff. Green healthcare can enable improved clinical outcomes; lower operating costs, energy consumption and water use. Healthcare facilities are amongst the most complex types of facilities to design, construct and operate. This research study outlines the findings from four children's hospitals with different levels of sustainability in regards to, the project delivery process, greening strategies and lean principles. The key processes investigated are: transparency in relation to green outcomes, owner commitment, early team selection, team experience, early adoption of green, the commissioning process, energy modeling and the role of the construction management team in the delivery of a green hospital. The findings provide a detailed description and analysis of the delivery process for each case study. The results show that certain delivery process attributes vary with the level of sustainability being sought by the hospitals, with the top three attributes being: owner commitment, expertise on sustainable delivery and early timing of sustainable objectives.

1. Introduction

There are few certainties with our economy at the moment, but one constant is that healthcare expenditures will continue to rise. The healthcare industry provides an important opportunity to dramatically impact how the built environment affects human health and well-being. Healthcare is a $1.4 trillion industry in the United States, accounting for 13.2 % of the entire U.S. gross domestic product (GDP), with

projected growth to $2.8 trillion, or 17 % of GDP by 2010 (Frampton 2003), being the world's largest. There are over 120,000 healthcare buildings in the United States at the moment and in the next 15 years, an estimated $300 billion will be spent on hospital construction across the United States (Ulrich 2004).

The built environment has been shown to impact healthcare, particularly the health, safety and well-being of patients and staff. For example, research has shown poor ventilation and indoor air quality are major causes of nosocomial infections. Improper lighting is correlated with patient depression and medication errors. Excessive noise upsets patients and causes increased stress and lack of sleep. In addition, the healthcare industry is also one of the most significant consumers of resources and producer of waste, and, therefore, has a large ecological footprint (Frampton 2003). For these reasons, it is important that healthcare facilities are constructed, and operated appropriately in order to demonstrate that they are a source of health for our communities.

2. Objective and Background

At the moment there are major challenges to incorporating green strategies in the healthcare building industry, more so than the commercial and residential building industry. Children's hospitals are a type of healthcare facilities where the consequences of poor building design, construction and operations have the potential to affect the lives and health of the children and staff. This paper seeks to provide an understanding of the key processes that are most critical for the delivery of green healthcare facilities. Understanding the delivery process and the key processes involved are the first and most important steps in facilitating the construction of more green facilities, and in reducing the challenges that come with it.

Designers and constructors have to create children's hospitals that are playful and provide a supportive environment for the children, while performing technically and functionally.The following factors presented in Table 1 have been identified through the literature review as critical in the delivery process of a green healthcare facility.

Table 1: Key green issues

Key issues/ processes
• Transparent delivery process in relation to green outcomes
• Early adoption of green
• Business case for green initiatives
• Owner commitment
• Architect and construction manager commitment and role
• Early team selection/ team experience
• Commissioning process
• Energy modeling
• Integrated approach

3. Research Methodology

To investigate this problem, this paper uses detailed case study research to investigate the differences that exist in the building delivery processes for each of a

LEED Platinum, the Dell Children's Hospital of Austin, two LEED certified, Children's Hospital of Pittsburgh and Hershey Children's Hospital and a hospital that is not LEED certified, the Philadelphia Children's Hospital. The case studies provide a wide range of data, and the comparison between two moderate, a highly green project, and a non-certified project will be beneficial for the design and construction industry.

3.1 Case Studies

3.1.1 The Dell Children's Hospital of Austin

The Dell Children's Medical Center of Central Texas is located on 32 acres of the old Robert Mueller Municipal Airport. It is four-stories, containing approximately 480,000 square feet. The hospital also has a Healing Garden, totaling 3 acres, that is located on the south side.. (Dell 2007). The project was fast-track, being on an aggressive 27 month schedule, and it opened in June 2007. The hospital is on track for being LEED Platinum, which will be the first LEED Platinum hospital in the nation. The hospital is located in a brownfield development, adding to the list of LEED points. The runway of the Muller airport was demolished and recycled. 35,000 tons of asphalt were used as a base for the parking lots. The construction cost for the facility is estimated to be around $110,000,000, while the 35,500 combined cooling-heating power plant is estimated to have a construction cost of approximately $18,000,000.The children's hospital uses sustainable building practices as seen in Table 2 (Dell 2007):

Table 2: Sustainable Building Practices at Dell

Sustainable site planning	The site is part of the City of Austin's Smart Growth Initiative
Water Conservation	The facility contains a rainwater collection system and is xeriscaped for water efficiency
Energy Efficiency& Energy Plant on site	Heat recovery systems and high efficiency equipment Seton is building a District Energy Plant on site which provides power and chilled water and steam to the hospital and the surrounding areas.
Conservation of Materials and Resources	Use of Recycled Materials and low VOC Minimize construction waste
Indoor Environmental Quality	Optimize natural daylight, eliminate airborne pollutants

3.1.2 Children's Hospital of Pittsburgh

The New Children's Hospital of Pittsburgh is located in Pittsburgh's Lawrenceville neighborhood on 10 acres -1.5 million square feet of usable space. Te actual hospital is 900,000 square feet with 262 beds. The cost of the hospital is approximated at $555million. The hospital is under construction on the urban campus of the former hospital, which will benefit the new hospital by using some of the assets of the previous hospital.(Pittsburgh 2007)

The hospital has been designed with the children in mind from the very beginning and it is committed to family centered care. The hospital is on track to be LEED certified. The facility l is grounded on five principles: patient safety and quality, family-centered care, technological sophistication, quiet building and environmental sustainability.

3.1.3 Penn State Hershey Children's Hospital

Penn State Children's Hospital is part of the Penn State Medical Center, the only medical school and university hospital in Pennsylvania located outside the urban areas of Philadelphia and Pittsburgh. The new Children's Hospital will be approximately 323,500 square-feet. The hospital will have a total cost well in excess of approximately $270 million dollars and is seeking to raise $65 million in philanthropy.(Hershey 2007). The proposed new seven-story Children's Hospital and adjacent Cancer Institute (which is currently under construction) will make up the new face and main entrance to the entire hospital. The conceptual design of the hospital was developed through business case studies, interviews with various user groups, visits to other children's. All new construction Penn State facilities are mandated to be LEED certified and this will be one of them.

3.1.4 Children's Hospital of Philadelphia

In 2001, The Children's Hospital of Philadelphia began a five-year, $650 million facilities expansion. Since then, the expansion has grown substantially to include CHOP's development of the former Philadelphia Civic Center. The plan will require another seven years to complete with an overall cost in excess of $1.5 billion. When complete, this expansion is expected to double the size of the main campus.

3.2 Data Collected

After an extensive literature review and recommendations from industry representatives and academic researchers, the issues identified in Table 1 were selected to be most important in the delivery of a successful green, LEED certified building and healthcare facilities. The stakeholders for each project, owner's representative, architecture firm and construction manager, were interviewed based on the issues below in Table 3:

Table 3: Data Collection Tool

Broad key green process	**Specific attributes**	**Data collected**
Transparent delivery process in relation to green outcomes and an integrated approach	Integrate sustainable project objectives well with other delivery aspects during programming, design and construction	Were all project members aware of the green outcomes? Good communication between stakeholders?
	Sustainable attributes are not singles out as additional requirements	Was there any rework or delays due to poor understanding of green strategies?
	Thoroughly communicate the project's sustainable attributes to each project member	Were eco-charettes conducted? How often and who participated?
Early adoption of green	This enables a more clear understanding of project scope requirements and project needs	When was the notion of green first introduced? At what point in the delivery
	Saves project rework due to accurate project bids and costs	Who proposed the notion of green? (owner, architect, design-builder)
	Saves time for incorporating sustainable objectives later in the project	Was the team trained on these sustainable objectives?

	A sustainability filter can be applied to all decisions	Were green objectives discussed in relation to overall project goals and objectives?
Business case for green initiatives	Project budget aligned with environmental project goals	Was there a business case for going green performed?
	Life-cycle cost analysis data to justify operational savings	Is life-cycle analysis data available?
	Payback period for sustainable objectives	What is the payback period for the sustainable aspects and LEED certification?
Owner commitment	Increased commitment from the owner side leads to better project planning and to better cost and schedule performance	Was the owner the green driver of the project? Did the owner introduce the concept of green? Was the owner in charge of educating the rest of the team members?
Architect and CM commitment to green and a consistent approach	Better delivery in regards to green aspects if teams are committed to sustainability.	Are these teams committed to sustainability as one of their core values regardless of owner commitment?
Early team selection/ team experience	bringing the teams together early engages critical process integration and allows system and environmental knowledge to evolve as design begins	Individual experience of team members with healthcare facilities? With green buildings? Did the project have a sustainability consultant in the beginning?
Energy Modeling	Energy modeling helps optimize the building design and allows the design team to prioritize investments in the strategies that will have the greatest effect on the building's energy use	Who was in charge of energy modeling? What were the costs associated with it? Effort and rework? At what stage in the design were energy simulations used?

3.3 Process Maps

One type of analysis in this research is **process mapping** analysis. The critical processes and events for each children's hospital are modeled and compared. Process modeling is the critical step in analyzing and understanding the delivery process. The Lean and Green process modeling protocol is used to model each step in the delivery process and convey it in a simple and effective way. Comparisons between the four case studies are more effective by creating transparency through the process models. The timing and sequence of the different activities has been identified in each process model and also which stakeholders where involved in what phases of the projects. (Klotz 2007): Level 1 represents a big picture map to understand the overall delivery process (master plan, schematic design, design development, construction documents etc) and organization. The Level 2 map focuses on each individual process, for example programming stage or design, and interview members in each project who understand best the applicable process. Microsoft Visio has been used to create the maps. An example from the Hershey Process Map is presented below in Figure 1.

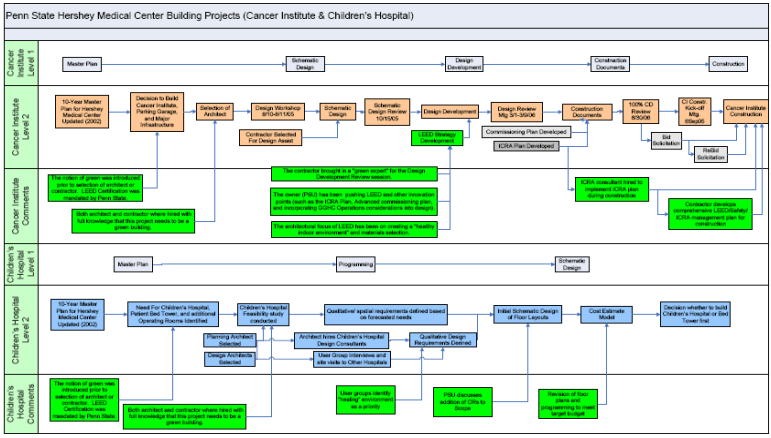


Figure 1: The Hershey Process Map

Green buildings are often perceived as having a higher first cost due to the complexity of materials, systems and building envelopes, although their life-cycle cost is lower (Klotz 2007) The process maps for the three children's hospitals show that they all had a conventional delivery process starting with a master plan followed by programming, schematic design, design development, construction documentation, construction and occupancy and maintenance. The Dell Children's Hospital of Austin has been a design-bid-build project from the start, but acted more like a design-build project. The Children's Hospital of Pittsburg was also design-bid-build, but it changed to a fast-track CM at risk in the later phases of the project. The Hershey Children's Hospital is in the design development phase right now, although the master plan was developed in 2002. The delays due to financing in the case of the Hershey project and site selection for the Children's Hospital of Pittsburgh are examples of situations where specific phases in the delivery process could take longer than expected. The Dell Children's Hospital followed their strategic plan they set in the beginning and opened in July 2007, while the other hospitals are set to open in 2009 and 2010 specifically. This shows that the commitment for a LEED Platinum project to be completed on time commitment to green features is higher than a LEED certified project. A lot of green building processes have a lot of wasteful rework, delays, changes and overproduction due to inappropriate delivery processes. Process waste can undermine sustainable outcomes and limit the business case for sustainability (Lapinki 2005). If process waste is decreased in the delivery of green buildings, then sustainable strategies could be used without the higher first costs.

3.4 Data Analysis

Using pattern-matching analysis and cross-case techniques, comparisons have been made between the four case studies for each of the factors investigated.

Pattern-matching logic compares an empirical based pattern with a predicted one. If the pattern coincides, the results strengthen the internal validity of the case study research. The predicted pattern for this research suggests that higher levels of transparency, owner commitment, early adoption of green, team experience, commissioning and energy modeling are required for a project to achieve LEED Platinum and be successful in terms of cost, quality and time. In other words, these levels of commitment based on the project teams increase as the LEED certification level goes up. Figure 2 below shows a graphical representation of the results by matching the green building factors with each case study. The red arrows represent a high level of commitment from the team in respect to each factor; similarly, the black arrows are one step below red, representing an average level of commitment based on comparisons with the other projects in this case study and also project reviewed through the Lean and Green Research Initiative database and literature. The blue arrows represent a low level when compared to the other projects, while the white arrows indicate that data was not available or the respective factor does not apply for those projects.

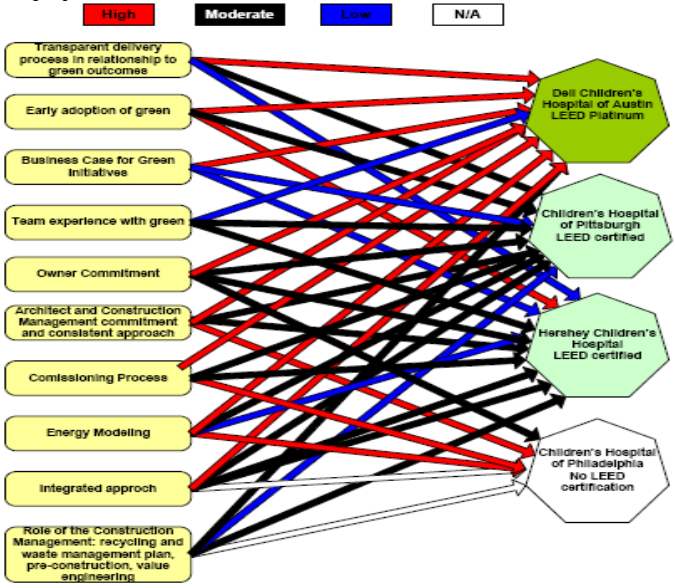


Figure 2: Pattern-matching analysis

The patterns, prior to performing the data collection and analysis, have been expected to be mostly red toward the top, for the LEED Platinum project and transitioning to blue towards the bottom, for the project that received no LEED certification. In contrast to the expected outcomes, the project that did not seek LEED certification performed better than the projects that are LEED Certified in a few aspects such as energy modeling, commissioning process and the use of project teams that are committed to sustainability as one of their core values. This graphical

representation of the results shows that the key processes are found within each case study, but at different levels. There is a higher commitment and presence of the factors in the LEED Platinum project.

Using pattern-matching analysis and **cross-case analysis**, comparisons have been made between the four case studies for each of the factor investigated. The factors are divided into specific attributes, and their occurrence in each case study is depicted in the following tables.

- "XX" represents that the specific attribute is existent within the case study, based on multiple sources of evidence. For example, a sustainability filter has been applied to all decisions at Dell and that is represented by a "XX"
- "X" represents that the specific attribute was somewhat existent in that case study. For example, at Hershey the team had some previous experience with green buildings but they are not considered experts in this field and that is represented by a "X"
- An empty box represents that the attribute is not specific to the case study, and it is not existent in the case study based on the interviews with the specific stakeholders
- N/A suggests that data is not available for the case study, or not applicable.

Multiple stakeholders were interviewed in order to arrive to these results.

- *Early adoption of green*

Specific attributes	Dell CH	Hershey CH	CH Pittsburgh	CH Philadelphia
Enabled a more clear understanding of project scope requirements and project needs	**XX**	**X**		N/A
Saved project rework due to accurate project bids and costs				N/A
Saved time for incorporating sustainable objectives later in the project	**XX**	**XX**		N/A
Sustainability filter applied to all decisions	**XX**			N/A

The notion of green was introduced very early in the programming phases by the owner at the Dell Children's Hospital, and similarly at Hershey it is a campus-wide mandate for the Penn State campus. The owner at Dell proposed that this hospital be LEED Platinum and took a "do whatever it takes approach" without sacrificing it or backing out. The green objectives were discussed periodically in relationship to the project goals and objectives, and the team was trained on the LEED certification process. At the Children's Hospital of Pittsburgh the adoption of green happened in the design phases of the project. A sustainability filter has been applied to all decisions at the Dell Children's Hospital, but not at the other children's hospital. An early adoption of green enabled a more clear understanding of the project goals and needs at Dell, but due to lack of previous team experience with LEED there have been a few issues with bids and costs in regards to the LEED

aspects. Although LEED certification at the Hershey Children's Hospital has been mandated from the beginning it has not been a priority for the team yet.

4. Summary and Outcomes

The research findings show that the factors investigated are critical in the delivery of a successful green children's hospital and are found in various degrees and levels in the four case studies investigated. The research findings show that a strong owner commitment to sustainability, family-centered care and a healing environment are very important in the delivery of a children's hospital. Dedication, belief, commitment and the executive mindset play a very important role in the delivery of the projects investigated. The critical factors investigated in this research are common between the case studies but at very different levels. The study shows that there is a stronger occurrence of these factors in the LEED Platinum projects compared the other three case studies investigated.

The key processes in the delivery of a green children's hospital are listed and explained below and outcomes resulting from each in regards to the projects investigated:

1) *Transparent delivery process:* Integrating the sustainable project objectives well with other delivery aspects during programming, design and construction and not singling them out as additional requirements can reduce delays, rework and costs for the project.

2) *Early adoption of green* enables a more clear understanding of project scope requirements and project needs. The adoption of green early in the project saves project rework due to accurate project bids and costs and saves time for incorporating these sustainable objectives later in the future.

3) *Business case for green initiatives*: life-cycle cost analysis to justify operational savings, having the project budget aligned with the environmental project goals and knowing the payback period for sustainable objectives can decrease misconceptions related to green building costing more than conventional buildings.

4) *Owner commitment*: increased commitment from the owner's side leads to better project planning and to better cost and schedule performance.

5) *Architect and construction manager commitment to green* and a consistent approach: there is better delivery in respect to green aspects if the teams are committed to sustainability as one of their core values, regardless of the owner commitment.

6) *Early team selection/ team experience*: bringing the team together early engages critical process integration and allows system and environmental knowledge to evolve. Previous team experience and having a sustainability consultant contribute positively to the success of green healthcare projects.

7) *Commissioning process*: the commissioning process should be specified early and the quality assurance should be focused on the specification phase, rather than after installation. The commissioning process can have an influence on the cost, quality and timeframe of the project.

8) *Energy Modeling* helps optimize the building design and allows the design team to prioritize investments in the strategies that will have the greatest effect on the building's energy use

9) *Integrated Approach*: high integration between project participants contributes positively to achieving project goals.

The following specific cases were worth noticing:

- The architecture and the construction management team had to learn the LEED process "on the job" at the Dell Children's Hospital of Austin and there were a very few cases when that negatively affected the project, but their commitment to LEED contributed greatly to the success of the project.
- There are different levels of owner commitment, commissioning, energy modeling, early adoption of green and an integrated approach for each of the projects investigated. The higher the levels in these categories, the less delays and rework the project experiences. And similarly, a LEED Platinum children's hospital requires more commitment to these factors than a LEED certified project.
- A strong commitment to green does not necessarily mean a strong commitment to the LEED certification process. At the Children's Hospital of Philadelphia the team was committed to green aspects and sustainability in general but the LEED certification and documentation has not been a focus.

The research results show that the delivery attributes vary with the level of sustainability being employed for each case study with the top three process attributes, in order of importance being:

1. Owner commitment
2. Expertise of project team members with the delivery of sustainable healthcare facilities, such as a sustainability consultant
3. Early timing of sustainable objectives being introduced.

The owner commitment played the most important role in the successful delivery of the four projects investigated, and this is dissimilar to previous research and industry experiences that state the early introduction of sustainable objectives is the most critical aspect. This outcome leads to some intriguing and potentially significant future research for understanding and improving the delivery process of green children's hospitals.

References

Dell, C. (2007). "Dell Children's Hospital News." Retrieved 15 June, 2007, from http://www.dellchildrens.net/.

Frampton, L., Gilpin, L., Charmel, P., (2003). Putting Patients First: Designing and Practicing Patient-Centered Care. San Francisco, Jossey-Bass Pubication.

Hershey, M. C. (2007). "Penn State Milton S. Hershey Medical Center." Retrieved 17 May, 2007, from http://www.hmc.psu.edu/.

Klotz, L., Horman, M., Bodenschatz, M. (2007). "A Modeling Protocol for Evaluating Project Delivery." *Lean Construction Journal* 3(1)

Lapinki, A. (2005). Delivering Sustainability: Mapping Toyota Motor Sales Corporate Facility Process. Architectural Engineering. State College, The Pennsylvania State University. M.S.

Phelps, A., Horman, M, Barr, M, Riley, D., Vanegas, J., Pearce, A., (2005). "Bridging the Physics of Building with the Physiology of Health Care: Greening Healthcare Facilities." *Journal of Green Building* 1(2): 164-175.

AN INVESTIGATION OF REAL OPTION THEORY TO EVALUATE DESIGN, PROCUREMENT AND CONSTRUCTION OF RENEWABLE ENERGY FACILITIES

Carol Menassa, S. M. ASCE[1] and Feniosky Peña Mora, M. ASCE[2]

[1] PhD Candidate in Construction Management, Civil and Environmental Engineering Department and Masters of Science in Finance Student, College of Business, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL 61801, USA, Phone 217/333-2071, FAX 217/265-8039, menassa2@illinois.edu
[2] Edward William and Jane Marr Gutgsell Endowed Professor of Construction Management and Information Technology, Civil and Environmental Engineering Department, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL 61801, USA, Phone 217/244-0187, FAX 217/265-8039, feniosky@illinois.edu

ABSTRACT
Now a day, the architecture, engineering and construction (AEC) community has to find effective tools and methods through multi-disciplinary research to deal with pressing issues of sustainability. One important aspect of sustainability is the underlying costs associated with the design, procurement, construction, and operation and maintenance of renewable energy facilities both in the United States and abroad. This paper investigates theories from financial engineering, particularly real option theory, and methods of incorporating them with life cycle costing to perform economic analysis studies of constructing and operating renewable energy facilities with specific emphasis on biofuel production. It is perceived that the results of this research will allow the decision maker to dynamically account for the uncertainties in the project cash flows through the application of real options when performing financial evaluations leading to life cycle cost analysis of biofuel production facilities. The last section of the paper illustrates the added value obtained from applying one of the several real option scenarios related to the timing of the investment.

INTRODUCTION
Now a day, the global investment in clean energy supplies that are low in carbon has increased from $28.6 billion in 2004 to $118 billion in 2007 (BP 2008a). This comes at a time when the world faces two main energy concerns related to the economical and secure availability of energy supplies, as well as the environmental harm caused by the increased use of fossil fuels (IEA 2006). The International Energy Agency has projected that total demand for low-carbon energy sources to increase at a rate of 1.3% per annum up until 2030 (BP 2008a; IEA 2006).

In the Unites States (US), electrical power and transportation represent the highest energy consumption levels at 40 and 29 percent respectively of the total energy demand (DOE/EIA 2008). Only 15% of the US energy demand is being met from renewable and low-carbon energy sources with the remaining 85% coming from non-renewable fossil fuels. This places the US among the highest countries in green house gas (GHG) emissions at approximately 5,900 million metric tons (DOE/EIA 2008). Given that transportation is the second largest sector in fossil fuel consumption and GHG emissions, it is inevitable that creating a sustainable transport future is amongst the top most concerns in the nation (BP 2008a). Among the most feasible and possible solutions for this problem is the development and production of biofuels that provide the highest possible energy content while at the same time reduce the GHG emissions (BP 2008a and 2008b). According to BP, biofuels today account for only 2% of the world's global transportation fuels but is expected to increase to 30% in key markets in the future (BP2008b). For example, in the US, the Energy Independence and Security Act of 2007 sets a mandatory Renewable Fuel Standard (RFS). This RFS sets the target biofuel production to 36 billion gallons of biofuel by 2022, a 29.5 billion gallons increase from the 2007 production level (RFA 2008a, CRS 2007).

One important aspect of biofuel production is the underlying costs associated with the design, procurement, construction, and operation and maintenance of these energy facilities. Given the variability of the feedstock used to produce the bio-fuels, and the different available and continuously emerging technologies, the design and procurement of the constructed facility infrastructure should be supported by a financial evaluation tool that allows engineers and decision makers to economically evaluate alternative options, and only choose those options that maximize the expected yield from the constructed facility during its life cycle from design and procurement to construction, operation and maintenance. This paper investigates theories from financial engineering, particularly real option theory, and methods of incorporating them with traditional life cycle costing to perform economic analysis studies of constructing and operating biofuel energy facilities. Such an economic analysis identifies alternative options (e.g., expand, contract, change scale) for a given facility's production systems and assesses the economic impact over the life of each option. The last section of the paper indicates that incorporating one of the various real options (in this case the option to defer investment in the construction of the facility) in the life cycle valuation methodology provides the project developers with better insights into the project alternatives. This approach increases the value of the investment in the project, and allows for better decision making during the scheduling of the engineering, procurement and construction (EPC); and operation and maintenance (O&M) activities.

BIOFUEL PLANT – EPC REQUIREMENTS

Conventional or first generation biofuels such as ethanol and biodiesel are typically made from corn, sugarcane and beet, wheat or oilseed crops such as soy and rape (BP2008c). However, extensive research is being undertaken to identify and develop crops with improved potential for biofuels including non-edible crops and agricultural waste (BP2008c). These new generation biofuels will be produced more efficiently

and thus contribute to greater reduction in GHG emissions. Biofuels are typically blended with gasoline to help reduce GHG emissions because it is naturally rich in oxygen which helps to improve combustion. In 2007, ethanol use in the U.S. reduced C02-equivalent greenhouse gas emissions by approximately 10.1 million tons, equal to removing more than 1.5 million cars from US's roadways (RFA 2008a). The decision to develop a new biofuel plant depends on several factors including: price of the commodity ($/gallon) (Commodity = Ethanol), price of the feedstock and natural gas, market demand, proximity to grain elevators and feedstock supply (local versus imported (Rouse 2007). Thus, the advantages and disadvantages of constructing a biofuel facility are shown in Table 1.

As can be seen from Table 1, several disadvantages contribute to the slow insurgence of biofuel producing plants in the US. Among these disadvantages are the high costs of developing a given biofuel facility. This high development cost covers several activities related to the EPC of the biofuel facility that can be summarized as follows:

1) Engineering technology: This involves deciding whether conventional, advanced or cellulosic biofuels are to be produced by the built up facility. These 3 types of biofuels are classified by the US Environmental Protection Agency depending on the level of GHG emission reductions expected from blending these biofuels with gasoline (RFA 2008b).
2) Production equipment based on the selected engineering technology
3) Grain handling systems based on the feedstock that is compatible with the engineering technology
4) Location of the power plant: This typically depends on the proximity to transportation and distribution networks such as rail.
5) Waste management system: This depends on the chosen recycling process and the associated amount of waste water to be generated.

Table 1: Advantages and Disadvantages of Constructing a Biofuel Facility

Advantages	Disadvantages
Reduce GHG	Capital Cost of Development
Reduce Fossil Fuel Use	Capital Cost of Production
Increase national energy security	Energy required to grow crops
Enhance rural development	Energy required to produce ethanol
Sustainable fuel supply for future	Not fully developed technologies

Thus, for a biofuel facility to be an economically feasible endeavor, a feasibility study that takes into account the life cycle costs of the constructed facility needs to be undertaken. These life cycle costs will typically vary with the expected amounts of production, short and immediate acquisition costs, unit and total cost of production, procurement and construction costs, and long term operation and maintenance costs. In addition, this feasibility study should take into account three major sustainability cost indicators: environmental, economic and social (Koo and Ariaratnam 2008).

TRADITIONAL LIFE CYCLE COST ANALYSIS

Life cycle cost (LCC) is used to compare alternatives of a given facility by identifying and assessing economic impacts over the life of each alternative. In essence, both present

and future costs should be taken into account and related to one another. These costs include the following (Dell'Isola and Kirk 2003):

1) Initial Project Costs: Design fees, construction costs including site acquisition; construction management and administration; and reservation costs (e.g., construction contingency, furnishings and equipment, financing costs)
2) Annual Costs: Energy and fuel costs; maintenance, repair and custodial costs; alterations and replacements; and other associated costs (e.g., facility management costs, debt service, staffing, security, taxes, water and sewer, fire insurance).

Thus, for a given construction project (e.g., biofuel facility) competing alternatives are compared by bringing present and future expected costs of the facility to a common point in time. Traditionally, two methods have been used for this purpose. The first, known as the present worth method, involves discounting all future costs to the present time at a given discount rate, and then adding these discounted costs to the initial costs of EPC. In the second method, all present and future costs are converted to annual series of expenditures over the life cycle of the project. Dell'Isola and Kirk (2003) provide a detailed discussion on the application of each of these two methods. Once the method of analysis is chosen, then all alternatives of the facility can be compared, and the alternative that yields best value in terms of costs versus revenues is chosen.

These traditional valuation tools can be used to perform the LCC analysis when explicit assumptions regarding the expected future cash flows for each alternative under consideration (i.e., costs of operating the facility and perceived revenues) can be made with certainty. However, as in any large-scale construction project, there are a number of uncertainties that will affect the expected future cash flows including both cost of operation and perceived revenues. For example, new biofuel technologies are continuously being explored to find better and efficient ways to reduce cost of feedstock and production, and maximize the properties of the generated biofuel. Thus, implementing a certain technology might seem economical at the present time, but might become inefficient if new technologies become available and are adopted by competitors in the market. This case scenario will result in a change in the expected future cash flows where future projected revenues from the project might change drastically if the competitor adopts a new technology that enhances production quality and lowers associated costs. This implies that early assumptions regarding the cash flows are difficult if not impossible to make during the project planning and budgeting phase. Therefore, it is important that any LCC analysis take into account uncertain factors for each project alternative being investigated. For example, an alternative might be more valuable if it allows the owner to invest a small amount of money at the present time, and defer the investment until more information about the associated project conditions become available. For example, it might be valuable to postpone major investment in the biofuel facility, like purchasing the process equipment, until a major highway or railway project is completed in the vicinity of the facility to ensure economical distribution of the produced biofuel to the consumers.

Another important aspect of the traditional LCC approach is that it does not take into account the three sustainability cost indicators discussed in the previous section. Incorporation of these three sustainability cost indicators (i.e., environmental, economic and social) in any LCC analysis will ensure that the chosen biofuel facility alternative not only provides immediate benefits to the owner of the project but also benefits the ecosystem (e.g., reduces GHG), provides a well articulated project funding plan, and participates in improving the social well being of the community. In order to overcome

these two problems in traditional LCC, option pricing and real option theories are being currently investigated as possible solutions.

OPTION PRICING AND REAL OPTION THEORIES

Options on traded assets like stocks, foreign currencies and commodities give the holder the right to buy (call options) or sell (put options) these assets at a fixed price referred to as the exercise price on or before expiration date (Hull 1999, Cox et al. 1979, Black and Scholes 1973). European options can be exercised on the expiration date only, while American options can be exercised any time before expiration. Options offer the investor the flexibility to postpone investment decisions until information about future market conditions become available. This increases the upside potential of the investment whereby buying/selling occur only if market conditions are favorable and positive payoffs are realized. On the other hand, the down side losses are capped down to zero (no negative payoffs) when the market conditions are not favorable (Fichman and Tiwana 2005, Trigeorgis 1993).

The application of option pricing theory in capital investment decisions comes in the form of Real Options, which exploits the fact that "investment flexibility" in real (that is, non-financial) projects, e.g. the ability to defer investment or expand, contract, or abandon a project, is analogous to financial options (Boute et al. 2004, Trigeorgis 1993). For example, investments made to acquire a real asset in analogous to Call Options while disposing of a real asset for a salvage value is similar to exercising a Put Option (Fichman and Tiwana 2005, Luehrman 1995). Real options are "active" management tools that provide the decision maker with the flexibility to change the course of an investment, as more information regarding the uncertain future cash flows becomes available (Trigeorgis 1993). Options to defer, expand, stage, or abandon the investment at any time in response to changes in the future circumstances of the project add more value to a project (Boute et al. 2004, Trigeorgis 1996). The market value of the real options depends on the value of the underlying asset (e.g., project cash flows), and how this value changes during the life of the project due to inherent uncertainties (Ng and Bjornsson 2004, Trigeorgis 1996).

Real options have been used as a financial valuation technique for different types of capital budgeting endeavors where flexibility and active decision making is essential for the success of the project under uncertainty. Examples from literature include: oil reserve start up projects (Trigeorgis 1993 and 1996), IT project management (Fichman et. Al 1995), and pharmaceutical product research/development projects (Copeland and Tufano 2004). The literature review also indicates that the applicability of real options to construction management has been researched in a variety of situations. For example, Ho and Liu (2003) presented a model to evaluate single and multi investments in A/E/C technologies, Ng and Bjornsson (2004) discussed the use of real options to evaluate alternative investment strategies in A/E/C projects, Boute et al. (2004) evaluated the added value from re-scheduling a project when additional information become available.

EXAMPLE OF VALUING BIOFUEL INVESTMENTS AS REAL OPTIONS

The modern theory of option pricing dates to 1973 when Black and Scholes presented the first satisfying formula for valuing European call/put options as a function of the price of the underlying common stock and time (Black and Scholes 1973). In 1979,

Cox et al. described a simple "risk-neutral" approach to option pricing using binomial trees that simplifies and facilitates analysis and computation (Copeland and Tufano 2004, Cox et. Al 1979). The essence of modern option pricing theory is that the absence of arbitrage opportunities in a financial market (the absence of the ability to get something for nothing) is equivalent to the existence of so-called risk-neutral probabilities that can be used for valuation. "Such risk neutral valuation enables present value discounting, at the risk free interest rate, of expected future payoffs". (Trigeorgis 1993, Cox et al. 1979) The application of the binomial method in valuing investments to construct a biofuel production facility is illustrated with in the example below.

Suppose that a biofuel plant developer is planning to build a new facility to produce a total of 125 million gallons per year (i.e. underlying asset). Initiating the project, however, requires that the developer purchase the land to build the facility and develop the infrastructure facilities necessary for the smooth operation of the biofuel plant. The total cost including the plant purchase cost is expected to be I_1.The estimated cost of a construction for the chosen processing technology is I_2. Production of the ethanol can only begin after the construction of the facility is fully completed. However, the demand for ethanol is still uncertain and developer expects to either sell 40% per year of its total production under the worst case scenario or 100% per year under the best case scenario. For the purpose of this example, it is assumed that the developer has to install all the necessary production facilities now. However, in reality the developer might have the option to stage the construction, and expand the level of production only if the market conditions are favorable. Fig. 1 shows the analogy between financial options, real options and the option of developing the bio-fuel facility.

Purchasing the land and developing the secondary infrastructure will afford the developer the opportunity to defer final plant construction and operation until uncertainty about the demand for the ethanol in the market is resolved. In this case, it is assumed that the uncertainty will be resolved in 1 year. After that period, the developer will exercise the option to develop the plant if the market demand is on the high best case scenario side, or forgo this project for another endeavor if the demand is on the low worst case scenario side. If the total expected operating cash flows from the plant is equal to V, then the option to defer the investment for one year is equivalent to an American call option purchased at a cost of I_1, and exercised in 1 year for a strike price equal to I_2 only if V is greater than I_2. On the other hand, if in 1 year V was less than I_2, then the developer will not construct the facility. Thus, deferring the investment until more information about the demand becomes available, will result in a value creation to the developer equal to $\max(V-I_2, 0)$ as shown in Fig.2.

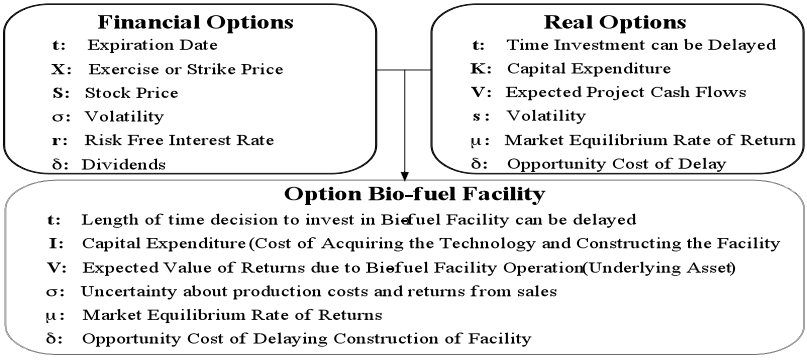


Fig. 1: Analogy with Financial and Real Options

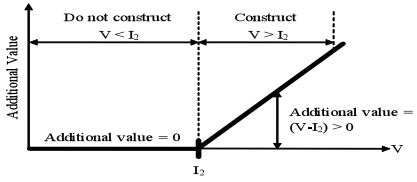


Fig. 2: Additional Value Created to Deferring Construction for 1 year

As can be seen from Fig. 2, the option to defer the investment results in either positive, or capped to zero value. However, under the traditional present worth method, the option to wait (i.e., defer the investment) is not possible. If this traditional approach was adopted for the example case, then the value of the investment in the biofuel facility is ($V-I_2$). This value is positive if in 1 year the demand was high (i.e., $V>I_2$), and negative if the demand was low (i.e., $V<I_2$). This additional value is typically forgone in the LCC analysis that assumes that the cost of development occurs initially without taking into account the additional value due to deferring the investment until uncertainty is resolved.

CONCLUSIONS

This paper presented some preliminary results of the research being conducted to investigate the applicability of option pricing and real option theories to augment traditional life cycle cost analysis while evaluating investments in biofuel energy facilities. The last section of the paper illustrate that real options will give the owner the flexibility to postpone construction expenditures during the project planning phase until more information about the projected level of demand for biofuel is resolved. At that time a more calculated decision can be made on whether to go ahead and invest in procuring the equipment and constructing the facility, or forgoing the project for an another opportunity.

REFERENCES

Black, F. and Scholes, M. (1973). "The Pricing of Options and Corporate Liabilities." Journal of Political Economy, 81 (3), 637 – 654.

Boute, R., Demeulemeester, E., and Herroelen, W. (2004). "A Real Options Approach to Project Management." International Journal of Production Research, Taylor and Francis Group, 42 (9), 1715-1725.

BP (2008a). "Why Alternative Energy Matter."
http://www.bp.com/sectiongenericarticle.do?categoryId=9021754&contentId=7042345 (08/01/08).

BP (2008b). "How it works? The Advance Biofuel Process from Crop to Car." http://www.bp.com/liveassets/bp_internet/globalbp/STAGING/global_assets/downloads/B/bio_biofuels_animation_text.pdf (08/01/08).

BP (2008c). "Biofuels."
http://www.bp.com/sectiongenericarticle.do?categoryId=9021757&contentId=7041016 (08/01/08).

Congressional Research Service (CRS) (2007). "CRS Report for Congress- Energy Independence and Security Act of 2007:A Summary of Major Provisions." Order Code RL34294, http://energy.senate.gov/public/_files/RL342941.pdf (08/15/08).

Copland, T. and Tufano, P. (2004). "A Real World Way to Manage Real Options." Harvard Business Review, 82(3), 1-12.

Cox, C., Ross, S., and Rubinstein, M. (1979). "Option Pricing: A Simplified Approach." Journal of Financial Economics, North-Holland Publishing Company, 7, 229-263.

Dell'lsola, A.J. and Kirk, S. (2003). "Life Cycle Costing for Facilities." Reed Construction Data – Construction Publishers and Consultants, Kingston, MA.

Department of Energy (DOE) & Energy Information Administration (EIA) (2008). "Annual Energy Outlook 2008 with Projections to 2030." DOE/EIA-0383 http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2008).pdf (08/01/08).

Fichman, R. Keil, M. and Tiwana, A. (2005). "Beyond Valuation: Option Thinking in IT Project Management." California Management Review, 47(2), 74-96.

International Energy Agency (IEA) (2006). "World Energy Outlook Summary and Conclusions-2006." http://www.iea.org/Textbase/npsum/WEO2006SUM.pdf (08/01/08).

Koo, D.H. and Ariaratnam, S. (2008). "Application of Sustainability Model for Assessing Water Main Replacement Option." Journal of Construction Engineering and Management, ASCE, 134:8, pp. 563-574, Reston, VA.

Luehrman, T. (1995). Capital Projects as Real Options: An Introduction. Harvard Business School, 9-295-074, 1-12.

Ng, F. and Björnsson, H. (2004). "Using Real Option and Decision Analysis To Evaluate Investments In The Architecture, Construction and Engineering Industry." Construction Management and Economics, Taylor and Francis Group, 22, 471–482.

Novozymes and BBI International. (2005). "Fuel Ethanol: A Technological Solution." http://www.ethanolrfa.org/objects/documents/76/fuelethanol-lr-05.pdf, (08/01/08).

Ping Ho, S. and Liu, L. (2002). "An Option Pricing-Based Model For Evaluating The Financial Viability Of Privatized Infrastructure Projects." Construction Management and Economics, Taylor and Francis Group, 20(4), 143 – 156.

Renewable Fuels Association (RFA) (2008a). "Ethanol Facts." http://www.ethanolrfa.org/resource/facts/, (08/01/08).
Renewable Fuels Association (RFA) (2008a). "Renewable Fuel Standards." http://www.ethanolrfa.org/resource/standard/, (08/01/08).
Rouse, K. (2007). "Biofuel Energy Shelves Plans to Construct Ethanol Plants". The Denver Post, http://www.denverpost.com/business/ci_7315897, (04/04/08).
Trigeorgis, L. (1993). "Real Options and Interactions with Financial Flexibility." Financial Management, Financial Management Association, University of South Florida, 22(3), 202-224.
Trigeorgis, L. (1996). Real Options Managerial Flexibility & Strategy in Resource Allocation. Cambridge, Mass: MIT Press.

ECONOMIC AND ENVIRONMENTAL ANALYSIS OF RESIDENTIAL GREYWATER SYSTEMS FOR TOILET USE

Scott Glick[1], Angela Acree Guggemos[2], A.M. ASCE and Santosh Prakash[3]

[1]Assistant Professor, Department of Construction Management, Colorado State University, Fort Collins, CO 80523-1584; PH 970-491-1802; FAX 970-491-2473; e-mail: sglick@cahs.ColoState.edu
[2]Assistant Professor, Department of Construction Management, Colorado State University, Fort Collins, CO 80523-1584; e-mail: Angela.Guggemos@ColoState.edu
[3]Graduate Student, Department of Construction Management, Colorado State University, Fort Collins, CO 80523-1584.

ABSTRACT

The use of greywater for residential toilet flushing could decrease freshwater demand considerably if adopted nationally. Before this is done, a full understanding of the estimated environmental and economic impacts for greywater systems is needed. New and retrofit residential systems were studied using life-cycle assessment (LCA) and life-cycle cost (LCC). Health considerations were not evaluated as part of this study. The LCA results indicate that both systems have a net environmental benefit over their lifetimes. Based upon current potable water costs, the net present value of the LCC indicates that both systems have net costs. As water rates increase to reflect scarcity, these net costs should decrease or become net savings. Using grey water systems for toilet flushing is environmentally feasible for individual homes whether new or retrofitted. Implementing these systems on a larger scale would reduce the demands on potable water supplies and on sewage treatment facilities and may improve their economic feasibility.

INTRODUCTION

The availability and use of the world's freshwater resources are of increasing concern. On a global scale, estimates indicate that "the six billion inhabitants are already appropriating 54% of all accessible freshwater contained in rivers, lakes, and underground aquifers" (2003 International Year of Freshwater, nd). A shift from fossil fuels to biomass will add increasing pressure on freshwater supplies. In the United States (US), this increased water stress is already apparent with the growth of the ethanol industry (Institute for Agricultural and Trade Policy 2006; Renewable Fuels Association 2008). As the population grows and the demands on freshwater increase, the importance of conserving and finding new water sources will increase.

One of the ways to decrease freshwater demands in the built environment is through the use of greywater systems for toilet flushing and irrigation. Greywater is wastewater from processes such as bathing, dish washing, and clothes laundering. Notwithstanding water rights, health impacts, and public understanding issues; greywater systems can provide an important source of water conservation thereby reducing the demands on potable water supplies and on sewage treatment facilities. The residential built environment is a major untapped resource that could be exploited for water conservation. Residential water use accounts for approximately 8% of total potable water use in the US (Solley, Pierce, and Perlman 1995). Approximately 1/5 of residential water use is for toilet flushing and 1/3 is for landscape irrigation (Christova-Boal, Eden, and McFarlane 1996; Oasis Design 2008). Also, 50% - 80% of residential waste water is greywater (Oasis Design 2008).

In addition to conserving freshwater resources, greywater systems may also provide an environmental and economic benefit to property owners as well as water and sewer providers. A simulation of two greywater systems, one new and one retrofitted, in homes located in Fort Collins, Colorado analyzed these potential benefits using life cycle assessment (LCA) and life cycle cost (LCC) methodologies. LCA analyzes the total environmental impacts for a system over each phase of its existence: material mining, manufacturing, operation and maintenance, and end-of-life. LCC accounts for the total costs for a system over each phase of its existence. For the LCA portion of the study, process diagrams for greywater systems were developed for both a newly constructed residential housing unit and for the retrofitting of an existing residential structure. For the LCC portion of the study, the associated costs for the greywater system construction, use and maintenance as well as the water use and treatment costs were estimated using local prices. The results of the LCA and LCC studies of new and retrofitted systems are not meant to be compared. Instead, both systems were studied for the feasibility of greywater systems in both new and existing single-family residences. The issues of water rights, health implications, and public acceptance of greywater systems are beyond the scope of this work.

BACKGROUND

Potable water is used in domestic residential settings for drinking, food preparation, bathing, laundry, toilet flushing, and lawn and garden watering. The consumption of potable water in US residential applications for 1995 is estimated to be 98,800 Million L/d (Solley et al. 1995). Greywater is defined as all wastewater from non-toilet plumbing fixtures in a home. The breakdown for the "average" family water use by fixture type is approximately: bathroom, showers and hand basins 26%, laundry 15%, gardens 34%, kitchen 5%, and toilets 20% (Christova-Boal et al. 1996).

The two main concerns with greywater use are storage and distribution. Greywater contains several micro-organisms: fecal coliforms, total coliforms, lipids, tea, coffee, soluble starch, dairy products, and clay and glucose from kitchen sinks. In addition, water from bathrooms and laundry add several detergents, bleaches, soaps, sand, perfumes, and shampoos (Eriksson, Auffarth, Henze and Ledin 2002). Storage of greywater promotes generation of odors as the micro-organisms grow. For

this reason, greywater poses environmental and health concerns. These concerns can be mitigated or eliminated with proper secondary treatment prior to reuse (Jeppesen 1996). Once properly treated, greywater use for toilet flushing and outside irrigation could substantially reduce the demands on potable water consumption. Frieder and Hadari estimate that these savings could reduce individual in-house use by 40-60 L/d per capita (2006). The UK's Millennium Dome reclaims greywater from hand wash-basins, rainwater from the dome's roof and groundwater; supplying up to 500 m^3 per day to flush toilets and urinals on the site (Smith, Khow, Hills and Donn 2000). The Solaire, a high rise residential building in New York City, treats its wastewater to produce 94,635 Liters (L) of treated water per day: 34,069 L for toilet flushing, 43,532 L for the building's cooling towers and 22,712 L for landscape irrigation (Wilson 2008). The average single household in Sydney (3 persons per household) uses 825 L of water each day (Sydney Water, 2005). By reusing greywater for irrigation, a household has the potential to save between 50,000 and 100,000 L of drinking water per year. Also, the estimated amount of greywater that can be used for toilet flushing is 924 L per week for a full flush (one button) or 302 L per week for dual flush (two buttons) fixture type (Department of Energy, Utilities and Sustainability 2007). No LCA and LCC studies were found for residential greywater systems.

METHODOLOGY

To get a true understanding of the total environmental and economic impacts of residential greywater systems, the impacts from all life cycle phases must be studied. The main life cycle phases for greywater systems are: raw materials mining and manufacturing, construction, use and maintenance, and end-of-life. LCA and LCC are ideal methods to obtain total life cycle impacts and will be applied to two different greywater systems: a system built as part of a newly constructed single family house and a retrofitted system for an existing single family house.

Life Cycle Assessment (LCA)

LCA estimates the environmental impacts from all life cycle phases of a product or process. The LCA process involves three main steps: (1) inventory analysis, (2) impact analysis, and (3) improvement analysis (Ciambrone 1997). As part of the inventory analysis, inputs of resources and energy as well as outputs of the product, waste, and emissions are identified and quantified for each product or process component. The resulting data are used in an impact analysis to determine the associated impacts to human health and the environment. Efforts in improvement analysis can then focus on determining what steps to take in order to improve the product or process to reduce the environmental impacts.

Traditional LCA involves the creation of process models to describe the system. The study boundary only includes those elements included in the model. An alternate method, Economic Input-Output LCA (EIO-LCA) is able to estimate direct emissions from manufacturing processes as well as indirect effects from supply chain emissions using data from the US Department of Commerce's commodity-by-commodity input-output matrix augmented by various resource use, waste, and emissions factors (Hendrickson, Horvath, Joshi and Lave 1998; Carnegie Mellon

University Green Design Institute (CMUGDI) 2008). This work will be a hybrid approach of both traditional process-based LCA and EIO-LCA. Process-based LCA is used for the construction, maintenance, and end-of-life phases; EIO-LCA is used for all other phases.

Environmental impacts associated with the material acquisition and transportation from the manufacturer to the job site in Fort Collins, Colorado were obtained using (CMUGDI 2008). The calculation of the transportation costs were obtained from several sources. The manufacturing plant locations were determined through contact with the manufacturers. The mileage and shipping rates were determined through a local freight broker. Weights for the systems also came from the manufacturers. For the use phase of the systems, emissions associated with electricity and water supply were calculated using (CMUGDI 2008). The energy costs used were calculated based on amp rating, pump motor voltage, and time of use. A fill time of 1 minute was used in both cases for the toilets to determine watt hours. Water costs were calculated using expected freshwater savings of 121 L/day (Heemer Engineering, 2006).

Life Cycle Costing (LCC)

LCC is an analysis method used to determine the total cost of ownership of a product or system over its useful life (ASTM 1999). It accounts for all relevant costs over all life cycle phases of a product or process, adjusting for differences in the timing of those costs (US Department of Commerce 1980). Cost data for materials, equipment and labor associated with all phases of each greywater system were obtained from manufacturers' web sites, local wholesale houses and freight brokers while the City of Fort Collins, Colorado provided electric and water rate schedules. These costs were used to determine the net present value (NPV) of the system. End of year discounting is used with a 5% nominal discount rate (not including inflation).

Simulation Study Selection

This simulation utilized a convenience sample to choose the residence. This method of selection was necessitated by the calculation requirements of the data used in both the LCA and LCC methodologies. The residence is in Fort Collins, Colorado and has three bedrooms and two baths. The expected occupancy of this residence is 4 people. Water usage estimates for toilet flushing are based on a6.06L toilet flushed 5 times per day for each occupant for an expected water use of 121 L/day (Heemer Engineering 2006). Specifying the location of the structure allows for the determination of transportation distances as well as water, electric, and shipping costs. This study estimates the environmental impacts and life cycle costs of each system independently.

NEW RESIDENTIAL GREYWATER SYSTEM

The BRAC RGW-250 greywater system was chosen for its quality, constructability, price, expandability, ease of maintenance, aesthetics and its 250 L capacity which allows for expansion for irrigation, if desired. This allows the home designer to determine if all greywater producing fixtures in the residence should be

plumbed to the tank or only expected high-use fixtures. The upper portion of the tank houses the filter and pump systems. A bypass overflow diverts excess greywater from the storage tank into the sewer system. The lower part of the tank is storage. A greywater supply line is connected to each individual toilet. The system should last the duration of the residence (assumed to be 45 years) but the pump must be replaced every 15 years.

Process Diagram for the New System

A process diagram was created for the construction phase of the BRAC system to identify sources of pollution. Figure 1 includes the installation and testing requirements for the additional plumbing needed to isolate the bathroom sink and shower greywater from toilet wastewater (blackwater) in new residential construction.

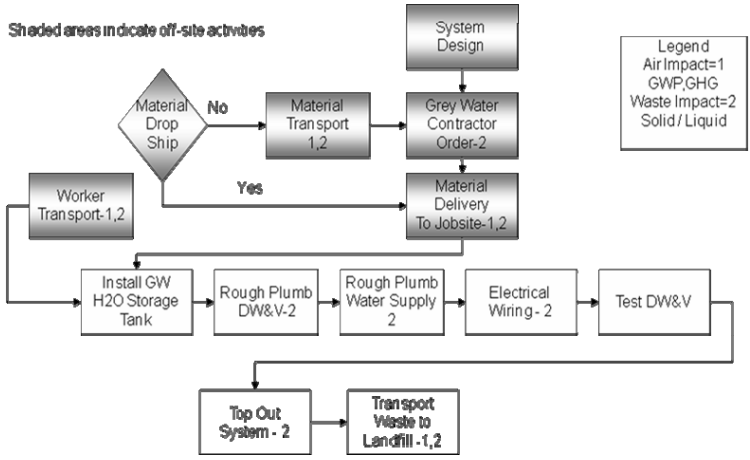


***Figure* 1.** BRAC Greywater System in a New Residential Construction Application.

Data Values for the New System

The data values in Table 1 were determined using the hybrid method of LCA. Process-based LCA was used for the construction, maintenance, and end-of-life phases; EIO-LCA was used for all other phases. Global Warming Potential Metric Tons CO_2 Equivalent (GWP $MTCO_2E$) is the standard unit of measure for environmental impacts based on green house gasses and is the sum of the remaining columns. The estimated savings of environmental emissions from reduced water consumption (<WSave>) due to greywater use in toilet flushing is also shown.

The LCC used the following parameters for the 45 year system. A new pump will be required in years 15 and 30 at a cost of $334 each with a plumber in year 15 at $125, and year 30 at $150 to replace the pumps. The initial system costs were $2,190 for the BRAC and $1,360 for the plumber ($85/hour, two day duration). The annual

electricity expense is $4.07 (50.86 KwH/yr at $0.08/KwH); annual chemical expenses are $14.80 and annual water savings are $23 (121 L/day at $1.97/3,785 L).

Table 1. Estimated Greenhouse Gas Impacts for Each Phase of the BRAC System

	GWP $MTCO_2E$	CO_2 $MTCO_2E$	CH_4 $MTCO_2E$	N_2O $MTCO_2E$	CFCs $MTCO_2E$
MFG	1.36	1.15	0.13	0.05	0.03
CONST	0.03	0.03			
USE	1.26	1.17	0.05	0.00	0.00
MAINT	0.68	0.56	0.06	0.00	0.00
<W Save>	(5.27)	(0.50)	(3.15)	(1.67)	0.00
Total	(1.94)	2.41	(2.91)	(1.62)	0.03

Data Analysis for the New System

Table 1 indicates that the BRAC system has net savings of 1.94 $MTCO_2E$ GWP over its lifetime. Although total system CO_2 increased, the overall GWP decreased due to the CH_4 and N_2O savings. Both CH_4 and N_2O are greenhouse gasses that persist longer in the atmosphere than CO_2. The NPV of this system is $4,520. This cost should be considered with the expected environmental impacts in the decision making process of installing a greywater system for toilet flushing. These costs are conservative because the analysis assumes that water prices remain low. Historically this has been the trend, but in the future it is conceivable that these prices will rise as water supplies diminish.

RETROFITTED RESIDENTIAL GREYWATER SYSTEM

The AQUS® system by WaterSaver Technologies was chosen for several reasons. The system is non-invasive in installation. It is a small self-contained under-sink unit with a 3/8" hose and a two-pair wire running through the side wall of the vanity base to the toilet. An 18.9 L greywater tank is stored under the sink for on-demand use. There is a control switch inside the toilet that operates the greywater flow and switches on the potable water supply fill feature if the greywater supply runs low. The unit and the filter are made of high impact plastic which reduces maintenance costs. The system installs in about three hours and connects into the existing sink tailpipe assembly which provides an automatic overflow into the sewer system once the storage tank fills to capacity. This system is designed for a single toilet application and has a life expectancy of 15 years.

Process Diagram for the Retrofitted System

A process diagram was created for the construction phase to identify expected pollution sources. Figure 2 shows the diagram for the AQUS® system and includes activities both on- and off-site.

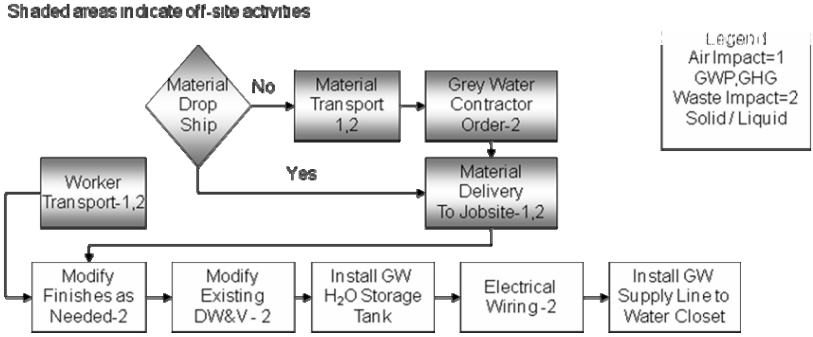


***Figure* 2.** AQUS® Greywater System in a Residential Retrofit Application.

Data Values for the Retrofitted System

The data values in Table 2 were determined using the hybrid method of LCA. Process-based LCA was used for the construction, maintenance, and end-of-life phases; EIO-LCA was used for all other phases.

Table 2. Estimated Greenhouse Gas Impacts for Each Phase of the AQUS® System in a Retrofit Application

	GWP $MTCO_2E$	CO_2 $MTCO_2E$	CH_4 $MTCO_2E$	N_2O $MTCO_2E$	CFCs $MTCO_2E$
MFG	0.25	0.21	0.03	0.01	0.01
CONST	0.02	0.02			
USE	0.05	0.05	0.00	0.00	0.00
MAINT	0.09	0.08	0.00	0.00	0.00
End-of-life	0.02	0.02			
<W Save>	(1.76)	(0.17)	(1.05)	(0.56)	0.00
Total	(1.34)	0.20	(1.03)	(0.55)	0.01

The LCC used the following parameters for the 15 year system: AQUS cost $295, installation $225 (3 hours at $85/hr), annual electricity expense $0.23 (2.92 KwH/yr at $0.08/KwH), annual chemical expenses of $5, and annual water savings of $23 (121 L/day at $1.97/3,785 L). These numbers are for each system (one for each of the two toilets) except for annual water savings which are per household.

Data Analysis for the Retrofitted System

Table 2 indicates that the AQUS system has net savings of 1.34 $MTCO_2E$ GWP over its lifetime. As with the new system, the net increase in CO_2 is outweighed by the net decrease in CH_4 and N_2O emissions. The NPV of this system is $1090 for the two AQUS units. This net cost should be considered with the expected environmental impacts in the decision making process of installing a greywater system for toilet flushing.

VALIDATION OF RESULTS

Validity and reliability are important in all research. This simulation used the accepted methodologies of the traditional LCA and EIO-LCA in a hybrid model and LCC to estimate the NPV of each investment including use, maintenance, and end-of-life. The ability to repeat and verify the results of a study are important to validity. This study used a free analysis tool found online (CMUGDI, 2008). The main concern in using databases is the disclosure of the assumptions, logic, data sources, and values used in the program. (CMUGDI, 2008) does this online. The use of databases should make the results of a LCA repeatable and verifiable (Norris & Yost, 2002). The parameters for the LCC are stated.

LCA is still in its infancy and the use of multiple tools to run the analysis may produce different results that are correct in regards to program internal logic but different in outcomes. Despite this concern, using multiple tools may be a useful process for comparative purposes given the high level of uncertainty in LCA as data capacity is built. A high level of uncertainty in the model is estimated to be between 10-20% (Hendrickson, Lave and Matthews, 2006). In both LCA and LCC, the further into the future the projected estimates are, the greater the uncertainty of the results. In this case, the new system has an expected life of 45 years and the remodel system is 15 years. In either case, the use of tools for replication is the preferred method as long the weaknesses of the methodologies are disclosed.

CONCLUSION

There are two areas in which additional research is needed. One is to validate the predicted outcomes with long term studies of installed systems to determine if the actual and predicted results are similar. This will provide important information in the capacity building of databases and possible codification of system use for water conservation. It is important to note that the location of the installation, water and electric rates, and system type are important variables in estimating both LCA and LCC results. There is a need for further system evaluation and testing in specific applications before any inferences can be made.

The second is the addition of greywater landscape irrigation supply to see if the life cycle costs are reduced significantly making a greywater system more economically feasible. The results of the life-cycle analysis can be used in conjunction with the results of ongoing studies on greywater health issues to better understand the proper level of use of this alternative water resource. Health impacts and remediation of these impacts needs to be studied to ensure that greywater use for landscape watering is safe. Research also needs to be performed on the treatment systems inside greywater storage tanks to ensure that bacteria do not flourish in this environment. Education on the benefits and special needs of greywater system owners also needs more work. To truly be sustainable, greywater systems must minimize environmental, economic, and social impacts.

Future research will not only increase our knowledge of the economic costs of installing a greywater system but it will start the dialogue of the environmental impacts associated with the widespread adoption of greywater systems in the

residential housing sector. If all existing houses in the US (127,958,000) were retrofitted with the AQUS system, household water consumption for toilet flushing would be reduced by 15,500 million L/day (calculated from Heemer 2006, US Census Bureau 2008). This would result in a savings of 171 million $MTCO_2E$ over the next 15 years which is the equivalent of removing 31 million typical passenger vehicles emitting 5.5 million $MTCO_2E$ yearly off of US roads (calculated from US Census Bureau 2008; US EPA 2005).

The full impact of the potential residential water savings attributed to greywater use both economically and environmentally is still in its infancy. As the US population increases and manufacturing is off-shored, the residential share of water consumption may increase. The potential rewards for adopting greywater use appear to be positive once the economies of scale are determined for a project.

REFERENCES

2003 International Year of Freshwater, (nd). "Wateryear2003." <http://www.wateryear2003.org/en/ev.php-URL_ID=1607&URL_DO=DO_TOPIC&URL_SECTION=201.html > (8-12-2008).

American Society for Testing and Materials (ASTM) (1999). "E917-99 Standard Practice for Measuring Life-cycle Cost of Buildings and Building Systems." Philadelphia, PA, USA.

Carnegie Mellon University Green Design Institute (CMUGDI) (2008). "Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model." <http://www.eiolca.net> (August 19, 2008).

Christova-Boal, D., Eden, R. E., and McFarlane, S. (1996). "An investigation into greywater reuse for urban residential properties." Desalination, 106, 391-397.

Ciambrone, D. F. (1997). "Environmental Life Cycle Analysis." Lewis Publishers, Boca Raton, FL, USA.

Department of Energy, Utilities and Sustainability (2007). "Guidelines For Greywater Reuse In Sewered, Single Household Residential Premises." <http://www.deus.nsw.gov.au/Publications/NSW%20Guidelines%20for%20Greywater%20Reuse%20in%20Sewered,%20Single%20Household%20Residential%20Premises.pdf > (August 31, 2008).

Eriksson, E., Auffarth, K., Henze, M.,and Ledin, A.(2002). "Characteristics of grey wastewater." Urban Water, 4, 85–104.

Friedler, E., and Hadari, M.(2006). " Economic feasibility of on-site greywater reuse in multi-storey buildings." Desalination, 190(1-3), 221-234.

Heemer Engineering, 2006. "Water Efficiencies (WE) Credit 2 – Innovative Wastewater Technologies." LEED Water Efficiency Credit Review, <http://www.watersavertech.com> (Aug. 18, 2008)

Hendrickson, C., Horvath, A., Joshi, S., and Lave, L. B. (1998). "Economic input-output models for environmental life cycle analysis." Environmental Science and Technology, 32: 184A-191A.

Hendrickson, C. T., Lave, L. B., & Matthews, H. S. (2006). "Environmental Life Cycle Assessment of Goods and Services: An Input -Output Approach." Resources for the Future, Washington, DC.

Institute for Agricultural and Trade Policy. (2006). "Water Used by Ethanol Plants: Potential Challenges." <http://www.agobservatory.org/library.cfm?refid=89449> (Aug. 12, 2008).

Jeppesen, B. (1996). "Domestic greywater re-use: Australia's challenge for the future." Desalination, 106(1-3), 311-315

Norris, G. A., & Yost, P. (2002). "A Transparent, Interactive Software Environment for Communicating Life-Cycle Assessment Results: An Application to Residential Windows." Journal of Industrial Ecology, 5(4), 15-28.

Oasis Design (2008). "Grey Water Central." <http://www.oasisdesign.net/greywater/> (June 9, 2008).

Renewable Fuels Association (2008). "Changing the Climate Ethanol Industry Outlook 2008." <http://www.ethanolrfa.org/objects/pdf/outlook/RFA_Outlook_2008.pdf> (Aug. 24, 2008).

Smith, A., Khow, J., Hills, S., and Donn, A. (2000) "Water reuse at the UK's Millennium Dome." Membrane Technology, 2000(118), 5-8.

Solley, W. B., Pierce, R. R. and Perlman, H. A. (1995) "Estimated Use of Water in the United States in 1995." <http://water.usgs.gov/watuse/pdf1995/pdf/circular1200.pdf> (Aug. 24, 2008).

Sydney Water Corporation (2005). "Water Conservation & Recycling Implementation Report 2004-2005." <http://www.sydneywater.com.au/Publications/Reports/WaterConservationAnnualReport2005.pdf > (August 31, 2008).

US Department of Commerce. (1980). "Life Cycle Cost Manual for the Federal Energy Management Program." National Bureau of Standards Handbook 135, Washinton, DC.

Wilson, A. (2008). "Toward Wiser Water Strategies." GreenSource July 2008. < http://continuingeducation.construction.com/article.php?L=5&C=421&P=2#> (Aug. 26, 2008).

SUSTAINABILITY FOR ADVANCED TECHNOLOGY FACILITIES

Allan D. Chasey, M. ASCE[1] and Atul Kumar Jain[2]

ABSTRACT

The concept of "Green" building has been heightened in significance due to concerns regarding the world's climate. This "Green" concept is increasingly accepted throughout the world and its impact is being felt in different sectors of the construction industry. Leadership in Energy and Environmental Design (LEED), developed by the U.S. Green Building Council, is a standard to rate different facility types relative to optimizing energy and environmental performance.

Semiconductor manufacturing facilities, commonly referred to as 'Fabs', are special construction projects. LEED for New Construction (LEED NC) has been used to assess performance of resource intensive facilities, but modifications and improvements to the current LEED rating system are needed to help better define and construct high performing resource intensive facilities.

This paper outlines a foundation for defining the parameters to help develop resource efficient facilities. This includes understanding the resource requirements of the semiconductors manufacturing facilities and how they differ from other facilities in terms of water and energy requirements. It identifies potential areas that need to be addressed when developing criteria to rate resource intensive facilities.

INTRODUCTION

The term sustainability originated in the 1980's when the global economy was growing rapidly. Nations were looking to grow without harming the environment. Sustainable development was defined in the The Brundtland Report, 1987, as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". (Sustainability in Construction, 2007)

The application of sustainable development in the construction industry has been termed Sustainable Construction or "Green" Construction. Although this concept is relatively new to construction, it has been adopted rapidly. This is a paradigm shift for the construction industry and has added new dimensions to the way facilities are designed and operated.

[1]Associate Professor, Del E. Webb School of Const, Arizona State University, PO Box 870204, Tempe, AZ 89287-0204; Phone (480) 965-7437, email: achasey@asu.edu
[2]Graduate Research Assistant, Del E. Webb School of Const, Arizona State University, PO Box 870204, Tempe, AZ 89287-0204; Phone (480) 965-1579, email: akjain1@asu.edu

Sustainability can take on an even wider significance when the world is considered as one system. The Trajectory of Environmentally Responsive Design proposed by Integrative Design Collaborative addresses the different stages of sustainability (Krygiel and Nies, 2006). Conventional practices are a degenerative system, the Best Sustainable Solution is neutral and Regenerative is participating with nature to improve the environmental system. It could be argued that semiconductor fabs are still operating in the first stage of the trajectory i.e. conventional practices because no organized methodology has been developed to construct a sustainable fab moving towards a more neutral position.

Sustainability for Semiconductor Fabrication Facilities

A semiconductor wafer fabrication facility (Fab) must provide an extremely controlled environment in terms of contamination, (i.e. temperature, humidity, particulates, vibration) for fabrication of integrated circuits. These requirements, along with a reliable and continuous flow of production materials, make a fab unique.

Because of the need for environmental and process material purity, the manufacturing process requires a large amount of energy and water. For example, the quantity of water required daily is enough to fulfill the water supply requirements of a small town. The energy requirement is approximately 100 million kWh per year, in some cases up to 100-times more energy intensive per square foot than a typical office building. The average energy use for a midsize cleanroom (9300 m^2, (100,000 sf)) can run around $1M dollars per month. (Shamshoian et. al., 2005)

The semiconductor industry is trying to adopt the concepts of sustainability but the lack of specific guidelines or performance measuring criteria is a major challenge. The International Semiconductor Manufacturing Initiative (ISMI) recently organized a workshop to develop a "green fab standard" to propose guidelines for the design and construction of Fabs to reduce energy and water consumption, minimize waste and air pollution, and reduce the overall cost of production. (Beasley 2007)

STRUCTURED SYSTEMS TO MEASURE SUSTAINABILITY

LEED for New Construction

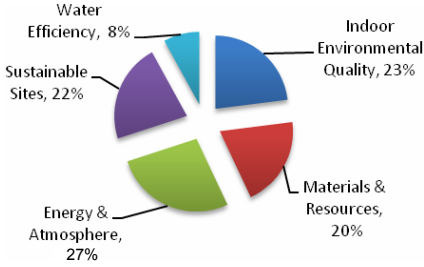
The formation of the U.S. Green Building Council (USGBC) in 1993 was a major step in development of “Green” construction. The LEED rating system, initially developed to rate office buildings, is currently available for several major categories: new construction, existing buildings, commercial interiors, and core and shell. In addition, two other major categories (LEED for homes and neighborhood development) are under development.

The LEED criteria is designed to cover energy, water and environmental aspects related to a sustainable building with the implementation of mandatory prerequisite elements and a range of optional elements. The prerequisite elements are compulsory and must be accomplished to obtain any level of certification. The optional elements help build the score for LEED certification which has four categories; certified, silver, gold or platinum. (Figure 1)

MODIFICATIONS OF LEED NC FOR FACILITY TYPES

LABs21 Application Guide for Laboratories

Labs21 was developed by the Environmental Protection Agency (EPA) to provide criteria for construction of sustainable, high performance, energy efficient laboratories. The criteria were developed from a "whole building" perspective, focusing on the facility as a system, concentrating on efficiency (Labs, 2007). All five sections of the LEED rating system were updated to cover specific lab related issues such as hazardous effluents, process energy, and process water, the same issues that need to be addressed for Fabs.



Level	Points
Certified	26-32
Silver	33-38
Gold	39-51
Platinum	52-69

Figure 1: Distribution of LEED Credits

Green Guide for Health Care

The Green Guide for Health Care (GGHC) was developed following the organizational structure of LEED NC to serve as a complete reference and rating criteria for design, construction and operation of healthcare facilities. The Green Guide is a unique example of developing a holistic approach by incorporating health-based credits, highlighting the fundamental relationship between human health and the built environment (Resource Review, 2007). Unlike the LEED rating systems, however, it does not have different levels of certifications. It also differs by introducing two integrated design prerequisites and by evaluating construction and operation separately. (Green Guide 2007)

These building specific approaches for sustainability of laboratories and health care facilities provide a basis for understanding how a facility rating should differ with respect to its function and user specific requirements.

FAB SPECIFIC APPROACH

LEED analysis for sustainable fabs

A Fab generally consists of a cleanroom (the controlled environment) where the actual wafer fabrication takes place, a facility that houses the cleanroom and an infrastructure of complex utility systems that supports the manufacturing process, as well as a site where the facility and supporting infrastructure is located. This section identifies some potential areas of improvement that can help provide long term sustainability for semiconductor facilities, focused on two key issues for fabs, i.e. water and energy.

Water Efficiency Credits

Water is a natural resource used extensively in the semiconductor manufacturing process. The major portion is used during the rinsing and cleaning steps. This water, primarily Ultra Pure Water (UPW), is produced by processes that remove nearly all the organic components, oxygen or suspended solids leaving little to no impurities. For a typical wafer fab, approximately 7600 liters (2000 gallons) of UPW is required to produce one 200mm wafer while 5300-6000 liters (1400-1600 gallons) of city water is needed to produce 3800 liters (1000 gallons) of UPW. An average size fab requires 11,400,000 liters (3,000,000 gallons) of UPW per day. The expanding semiconductor market and the introduction of 300mm technology have further increased the demand of water in Fabs. A 300mm Fab requires almost one and half times more water than a 200mm fab, meaning the water requirements of a 300mm facility equals that of a city of approximately 60,000. (Energy 2007)

Water efficiency can be approached in three ways: Reduction in use, Recycling, or Reuse/Reclamation:

Water use reduction: Most of the UPW is used for rinsing wafers between the chemical processes. The optimization of these processes results in reducing the total water usage and shorting the process time. Process optimization can result in reducing the rinse process time by 25-80% thereby resulting in UPW savings. (Chiarello 2000)

Recycling used water: Even after the UPW is used in the rinse process, this water can be cleaner than most city water (Natural Resources 2007). This rinse water can be recycled to the UPW system and potentially reused, making up 40-50% of the total UPW requirement. (Energy 2007)

Reuse/Reclamation of used water: Water reclaim from the rinse water and other waste water streams minimizes the load on the local wastewater facilities as this water can be used in other systems such as cooling towers, scrubbers or irrigation ponds (Energy 2007).

Compatibility of Water Efficiency with the current LEED NC

Water efficiency is of prime importance for sustainability of a fab. Water accounts for a major portion of a Fab's operational cost and is a key component in the final wafer cost (Energy 2007). The water efficiency credits should be restructured to place more emphasis on the fab water requirements and efficiencies.

Table 1 shows the compatibility of the current LEED NC water efficiency credits with the fab needs. Five points are available all the points are awarded for reduction in sanitary and landscape water requirement. Only 4% of the total water consumed by a fab is used in sanitation and landscaping, leaving 96% of the water used in the manufacturing process and cooling towers (Achieving Process, 2007). However, only 8% by weight (ref Figure 1) is given to the water efficiency, which is negligible for fabs considering the amount of water used daily.

Energy and Atmosphere Credits

Almost half the energy used in semiconductor fabs is wasted (Williamson, 1998).

- Process Tools: Production Equipment is a major contributor in the energy consumption, consuming up to 35% of the total energy of a Fab (Williamson,1998). Benchmarking the process equipment and facility systems and rating them based on their energy performance can result in a considerable cost savings. Addressing the equipment design criteria can also result in more cost effective, and energy efficient systems.

Table 1: Water Efficiency Section – Compatibility with the Fabs

	LEED NC	Compatibility	Remark
Credit 1.1	Water Efficient Landscaping, Reduce by 50%	Yes	Has little impact on overall water use in a fab
Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	Yes	Has little impact on overall water use in a fab
Credit 2	Innovative Wastewater Technologies	Yes/No	Process water makes a major portion of the total waste water in a fab and needs more consideration
Credit 3.1	Water Use Reduction, 20% Reduction	No	Percentage too large to obtain any credit
Credit 3.2	Water Use Reduction, 30% Reduction	No	Percentage too large to obtain any credit

- HVAC: HVAC consumes the other major portion of the total energy in a fab, consuming almost 40% of the overall energy. (Figure 2) (SEMI, 2007) Lower cleanroom make-up and exhaust air rates can save a considerable amount of energy. Low face-velocity cooling coils, higher performance air-filters, high-efficiency motors, pumps and fans are other examples of ways to optimize the HVAC system. "Optimized airflow design alone can reduce energy usage and costs in a typical fabrication facility by as much as 15%" (EPA 1997).

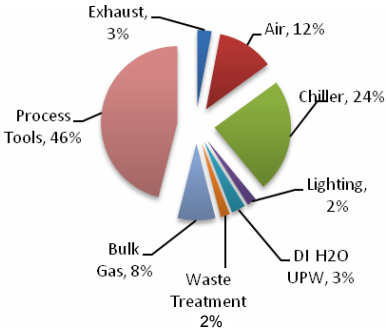


Figure 2: Energy Use Semiconductor Fabs – Average Share by Component (Source: SEMI, 2007)

Compatibility of Energy and Atmosphere with the current LEED NC

Table 2 shows the compatibility of the current LEED NC energy and atmosphere criteria with the Fab needs. For the optimized energy performance credits, process energy needs to be addressed. Energy savings is a challenging task for a Fab, but effective measures are available that can result in energy savings. LEED NC addresses the energy and atmosphere credits considering office and commercial buildings. For instance in Credit 1, Optimize Energy Performance, the first two points must be achieved with an efficiency savings of 14% to meet the prerequisite for certification. This can be achieved more easily in a commercial or office building, but on a percentage basis, this is much more difficult in a fab. The percentage criteria for achieving points in a fab needs to be reconsidered based on the effort and resources required.

Table 2: Energy and Atmosphere section – Compatibility with the Fabs

	LEED NC	Compatibility	Remarks
Prereq 1	Fundamental Commissioning of the Building Energy Systems		Required
Prereq 2	Minimum Energy Performance	No	Required
Prereq 3	Fundamental Refrigerant Management		Required
Credit 1.1-Credit 1.10	Optimize Energy Performance	Yes/No	Needs modification with inclusion of manufacturing process related energy requirements
Credit 2.1	On-Site Renewable Energy - 2.5%	No	2.5% of fab energy requirement is too large an amount of energy to produce on site in the

			form of renewable energy.
Credit 2.2	On site renewable energy – 7.5%	No	
Credit 2.3	On site renewable energy – 12.5%	No	
Credit 3	Enhanced Commissioning	Yes	
Credit 4	Enhanced Refrigerant Management	Yes	
Credit 5	Measurement & Verification	Yes	
Credit 6	Green Power	Yes/No	Amount of power needed might prevent this from being available

CASE STUDIES

Two case studies related to advanced technology facilities show how the current rating system have been applied to the resource intensive facilities. One of these case studies is a semiconductor fab and the other an advanced research laboratory. Even though these case studies are from two different segments of advanced technology facilities, each reveals that due to process material and process energy requirements, advanced technology facilities need to be addressed separately for a true sustainability rating.

Texas Instruments (TI) Richardson Fab

TI's Richardson Fab (RFab) (Figure 3) constructed in 2005 is the world's first semiconductor fab to be registered with USGBC under LEED NC v2.1 (Sustainability 2007). However, specific efforts that are not addressed by LEED were done to make it a green fab.

TI's goal was to construct a fab with less initial investment and relatively low operational cost to enable TI to remain competitive. Since the initial construction cost of a fab is high, TI focused on minimizing the initial investment. If a fab is designed to be operated at a lower cost, then it will affect the final cost of products to be released in the market. (Plata 2006)

Sustainability Approach

For this project, a special sustainability team was formed with an aim to reduce fab cost by 30% per square foot compared to previous fabs. The sustainability team developed innovative ideas addressing all five major sections of LEED NC criteria.

In addition to regular LEED measures to reduce the sanitary and landscaping water consumption, TI focused on minimizing total water consumption, including manufacturing. They approached the manufacturing water efficiency through Recycling, Reclamation, and Conservation.

- Recycling: After treatment, the UPW is recycled instead of discharged, considerably reducing the volume of feed water.

- Reclamation: Wastewater is reclaimed from rinsing and other processes and reused in scrubbers and cooling towers.
- Conservation: The de-ionized water plant successfully uses measures such as rinse optimization and more efficient tools to conserve water. (Natural Resource, 2007)

TI also took an innovative approach to minimize energy consumption by maximizing the use of available space to house the larger 300mm tools, reducing the volume of the clean space, minimizing the load on the HVAC system. (Plata, 2006)



Figure 3: TI's Richardson LEED Certified Fab

Results of Sustainability Efforts

The sustainability efforts in Texas Instrument's RFab resulted in noteworthy achievements. The lean approach in space management resulted in minimizing the total area of the fab without affecting the production capacity and in reducing the size of the support systems such as HVAC. The estimated benefits can be summarized as follows when compared to traditional fabs:

- Operational cost savings of approximately $4M per year (when fully operational)
- Energy savings of more than 20%
- Water savings of 35% (The Making 2007)

ASU's BioDesign-II

Arizona State University's project management team approached the sustainability of the BioDesign II laboratory (Figure 4) using LEED NC v2.2 criteria to ensure that the end product was green both in purpose and functionality. These efforts produced a platinum level certification. Understanding the laboratory needs and then developing a strategy for 'green' construction was a challenging task.

Although this facility received platinum certification, the ASU project management team felt that some very specific efforts in this laboratory project could not be counted towards the final score because they were lab specific issues and are not covered by the LEED NC credits.

The BioDesign II facility uses state-of-the-art technology to ensure that the process water and energy utilization is kept at a minimum. The high level of water use in the laboratory is mainly attributed to the process water requirements.

Ventilation is another challenging area for laboratories because it requires a higher ventilation rate to ensure the desired CO_2 level. This high ventilation rate is a major contributor to the overall energy use of a laboratory. A reliable energy efficient solution was accomplished by using a variable air volume system which houses seven different sensors for temperature, humidity, CO_2 level and TOC (total organic compounds), keeping the air mixture at the desired level. (McLeod, 2007)



Figure 4: ASU BioDesign II LEED Platinum Facility

Conclusions from case studies

Both Texas Instruments RFab and ASU's Biodesign II are examples that highlight the need for more specific LEED criteria for the advanced technology sector. Though Texas Instruments' RFab is a semiconductor manufacturing facility and ASU's Biodesign-II is an advanced research laboratory, both of these facility types require more process energy and process water compared to other facility types.

Even though Texas Instruments approached sustainable construction with a focus on process material and energy use, which is specific to a Fab, and the ASU Biodesign II took a lab specific approach, the actual LEED NC score cards do not reflect the real efforts employed by the design and construction teams.

RECOMMENDATIONS AND CONCLUSIONS

The ever increasing awareness towards a sustainable, healthy and prosperous world has led to the development of products like LEED to construct and rate highly efficient buildings. The products have proven successful in demonstrating how facilities can provide the necessary functions yet do so more conservation oriented. However, the need to understand the impact of different construction types and modify or develop LEED products accordingly is still a challenge.

Facilities such as semiconductor fabs, are radically different in both construction and operation. Specific areas of these facilities need to be addressed to make them truly sustainable. Process energy and process water are key contributors to the overall cost, both construction and operational, of advanced technology facilities and must be included as targets in any criteria defining high performing facilities.

Understanding the requirements and devising a holistic approach will assist in developing a sustainable model for facilities that are energy, water, and resource intensive.

REFERENCES

Achieving Process Utility Conservation and Cost Reductions in a 200-mm Fab Environment; http://www.micromagazine.com (April 2008)

Beasley, J. (2007); "The Green Fab Challenge: An ISMI-led Initiative to Explore Sustainable Manufacturing in the Semiconductor Industry", Future Fab International, Issue 22, Jan. 2007.

Chiarello P. (2000); Rinse Optimization For Reduction of Point-of-Use Ultrapure Water Consumption In High Technology Manufacturing

Energy and Water Efficiency for Semiconductor Manufacturing (2007) http://www.p2pays.org/ref/04/03271/

Green Guide for Health Care, Jan. 2007

Krygiel E, Nies B; (2008), Green BIM Successful Sustainable Design with Building Information Modeling.

Labs For 21st Century (2007); http://www.labs21century.gov/about/index.htm, 11 April 2007

McLeod M., (2007), Construction Project Manager, Arizona State University, Tempe; Phone: 480 965 7505; e-mail: Michael.McLeod@asu.edu

Natural Resources and Energy Conservation http://www.ti.com/corp/docs/company/citizen/esh/nrec.shtml July 2007

Plata, J.; (2006) "The Business Case for the Sustainable Fab: Merging Environmental Responsibility With Increased Profits Through Integrated Design" Future Fab International, Issue 21, July 2006.

Resource review: Green Guide for Health Care; http://www.aia.org/nwsltr_cote.cfm?pagename=cote_a_0701_resource April 2007

SEMI S23-0705, (2007) Guide for Conservation of Energy, Utilities and Materials Used by Semiconductor Manufacturing Equipment

Shamshoian G., Blazek M., Naughton P., Seese S., Mills E., Tschudi W., (2005) "High-Tech Means High Efficiency: The Business Case for Energy Management in High-Tech Industries", Lawrence Berkeley National Laboratory

Sustainability in Construction (2007) http://www.aggregain.org.uk/sustainability/sustainability_in_construction/index.html#anchorlink_2

The Making of RFAB; http://www.ti.com/corp/docs/rennerroadfab/ti_rfab.pdf 27 Aug. 2007

U.S. Environmental Protection Agency (1997) Proceedings of the Semiconductor Energy Efficiency Opportunities Workshop. San Jose, CA, November 13-14.

Williamson, M.C.;(1998) "Energy Efficiency in Semiconductor fabs, A Tool for Cost savings and pollution Prevention" Semiconductor Fabtech Journal 8, Feb. 1998.

Financial Model for Insuring Against Catastrophic Storm Risks

Islam H. El-adaway [1]

[1]Assistant Professor: Department of Building Construction Science, Adjunct Assistant Professor: Department of Civil and Environmental Engineering, Mississippi State University, 128 Giles Hall, Mississippi State, Mississippi 39762; Phone: (662) 325-1525; Fax: (662) 325-8872; E-mail: ieladaway@caad.msstate.edu.

Abstract

Risks and uncertainties represent an integral part of the construction process that negatively affects executed projects, contracting parties, and the industry as a whole. In fact, natural hazardous events become extremely important at construction developments that allow low or zero tolerance levels. Concerns regarding catastrophic losses have limited the commercialization of certain projects and activities. This paper proposes a financial model for insuring against catastrophic storm risks that affect construction projects through a cost-benefit analysis. The challenge with modeling such severe conditions is that they are so rare that it might take thousands of years of experimental data to ensure that all possible events have been properly measured and captured. Under this study, the historic data in relation to storm events in Mississippi between 5/31/2006 and 5/31/2008 was analyzed using Chandler *et al.* (2001) technique to estimate loss parameters. This dataset was then bootstrapped using Iman and Conover technique to impose correlation and generate simulated dataset of 5,000 points. Finally, the bootstrapped data was modeled using a Monte Carlo simulation that is based on option theory to calculate the fair-valued premium for an interrelated insurance policy. This insurance product would: (1) fund any destructive effect in connection with construction projects; (2) allow comparing catastrophic risks against benefits by putting a dollar value to such risks; and (3) solve the non linearity problem between wind speed and associated losses. It is the author's hope that the developed model could be extended to form a nationwide insurance policy against catastrophic storm risk. Furthermore, the same principles exploited under the model beforehand could be slightly modified in order to be applied on other extreme weather events such as hurricanes and tornadoes.

Introduction

The term "weather extremes" signifies individual weather events that are unusual in their occurrence that lie in the upper or lower ten percentile of a suitable probability distribution or have destructive potential, such as hurricanes and tornadoes (CCSP 2008). On the other hand, the term "climate extremes" is used to represent the same

type of event, but viewed over seasons or longer periods. Naturally, extremes can have positive or negative effects. However, on balance, because systems have adapted to their historical range of extremes, the majority of the impacts of events outside this range are expected to be negative (CCSP 2008).

There are strong indications that humans are gradually but definitely changing the climate of the earth. Emissions from fossil fuels and greenhouse gases are altering the atmosphere, leading to an uncertain future of global warming (CCSP 2008 and Linnerooth-Bayer 2000). The negative consequences of this changing atmosphere are fostered by (1) the increasing concentration of population in high-risk zones; (2) the greater susceptibility of modern industrial societies to catastrophes; and (3) the accelerating deterioration of natural environmental conditions (Linnerooth-Bayer 2000 and Kunreuther 2006). As a result, the nature of catastrophic weather events has significantly changed where the number of natural disasters has risen by a factor of three throughout the time period from 1950 and the corresponding economic losses, after being adjusted for inflation, have risen by a factor of nine (CCSP 2008). Also, hurricane rainfall and wind speeds will significantly increase in response to human-caused warming. Analyses of model simulations suggest that for each 1ºC (1.8ºF) increase in tropical sea surface temperatures, core rainfall rates will increase by 6-18% and the surface wind speeds of the strongest hurricanes will increase by about 1-8% (CCSP 2008).

The impact of weather and climate extremes can be severe and wide-ranging as they affect all sectors of the economy and the environment. The direct impact of natural geological and weather events on the U.S. economy is substantial. In addition, and on a more serious note, there is scientific evidence that a warming world will be accompanied by more changes in the intensity, duration, frequency, and spatial extent of weather and climate extremes (Linnerooth-Bayer 2000).

Goal and Objectives

This paper proposes a financial model for insuring against catastrophic storm events that affect construction projects or households through a cost-benefit analysis. That said, under this study, the historic data as well in relation to weather extreme events will be was analyzed using Chandler *et al.* (2001) technique to estimate loss parameters. This dataset was then bootstrapped using Iman and Conover technique to impose correlation and generate simulated dataset of 5,000 points. Finally, the bootstrapped data was modeled using a Monte Carlo simulation that is based on option theory to calculate the fair-valued premium for an interrelated insurance policy. This insurance product would: (1) fund any destructive effect in connection with construction projects; (2) allow comparing catastrophic risks against benefits by putting a dollar value to such risks; and (3) solve the non linearity problem between wind speed and associated losses.

Background Information

Sources of Risks

Risks can be categorized in a number of ways based on the source of risk, by impact type or by project phase (Klemetti 2006). In this regard, Artto *at al* (2003), as quoted in (Klemetti 2006), presents a four-level risk categorization which is divided into

pure risks such as *hazards and weather conditions*; financial risks including cash flow or credit risk; business risks that confines almost anything that can happen in a project; and political risks which are caused mostly by wars. Most recently, Brown (2004) indicated that construction risks would include design, construction, site, economic, political, *environmental*, and human risks.

In this regard and as a result of technological advancements and consequent global warming, weather and climate extreme events have become much more frequent. Thus, it is crucial to direct efforts towards modeling and mitigating the negative effects of such catastrophic events through innovative insurance products.

Principles of Insurance

Insurance is defined as the equitable transfer of the risk of a loss, from one entity to another, in exchange for an indemnity rate called premium (Tsanakas and Desli 2005). According to Raviv (1979), the optimal insurance premium should be based on a meaningful historic data of around 5,000 points. That said the accuracy of information is the most important element for the success of any insurance business (Gogol 1993). There are two issues that negatively affect any insurance policy, namely adverse selection and moral hazard. On one hand, adverse selection is the situation where the insured pool should not be mostly composed of high risk beneficiaries and thus, premiums are kept at a fair level (Janssen and Karamychev 2005). On the other hand, moral hazard is the setting where the insured pool should always realize that a loss will always be a misfortune and thus, the existence of the insurance will not change the behavior or due diligence of the insured party (Lee and Ligon 2001, Breuer 2005, and Doherty and Smetters 2005). According to Harrington and Niehaus (2004), an insurable risk should have: (1) large number of homogeneous exposure units; (2) definite loss; (3) accidental loss; (4) large loss; (5) measurable loss; and (6) affordable premium.

Calculation of Insurance Indemnity

The fair premium in insurance pricing is equal to the expected loss resulting from the underwritten risk. Thus, an insurance premium is simply calculated from the average payout in cases of losses (Brocket *et al.* 1986). Interestingly, this is the very same concept behind the pricing of a "put" or "call" warrants under the options theory (Hart *et al.* 2006). An option is a security giving the right to buy or sell an asset or any financial instrument, subject to certain conditions, within a specified period of time (Chance and Brooks 2007). The most known theory for options theory was developed by Black and Scholes (1973) where the value of the option will depend only on the price of the stock and time and on variables that are taken to be known constants. However, the Black and Scholes theory is only applicable for financial instruments that follow a lognormal probability distribution. Thus, the more general theory of option pricing is referred to Samuelson (1965).

The insurance indemnity for any catastrophic event can be modeled using a Monte Carlo simulation as follows where an exceedance probability curve provides the necessary information to calculate the expected loss, average annual loss, and probable maximum loss (Grossi *et al.* 2005). In this regard, E_i is defined as a catastrophic event that occurs with annual probability p_i, resulting in a loss of L_i. Moreover, such extreme weather events are assumed to be independent Bernoulli

random variables, each has a probability mass function defined as $P(E_i \text{ occurs}) = p_i$, $P(E_i \text{ does not occur}) = (1 - p_i)$. Thus, the expected loss (E) from a particular event in a given year is:

$$E[L_i] = p_i L_i \quad (1)$$

Also, the average annual loss (AAL) is the expected loss from all events in a given year:

$$AAL = \sum_i p_i L_i \quad (2)$$

Moreover, if during a given year only one disaster occurs, the exceedance probability for a given level of loss, $EP(L_i)$, is:

$$EP(L_i) = (P(L > L_i) = 1 - P(L \leq L_i) \quad (3)$$

In order to make the insured understand and accept the merit of a premium in the light of financial loss implications, we assume that x_i is the total annual loss of an insured with the annual occurrence probability p of a windstorm of a certain size. That said, the loss is covered by insurance in the range of the deductible limit to the maximum payment limit. Then, the total annual loss of an insured is expressed by:

$$X_i = X_a + X_b \quad (4)$$

where X_a *is the* retained loss (deductible) of the insured and X_b represents the financial implications of loss transferred to an insurer. Then, the expected annual total cost to the insured is expressed as:

$$E_i[X_i] = pX_a + pX_b + \alpha \quad (5)$$

where the terms pX_a and pX_b are the expected losses of the insured and the insurance company, respectively and the term α is a loading to represent the insurance expense including profit. Thus, the premium due consists of the sum of *pxb* and α

Methodology

Overview

Usually, extreme weather events might occur in one in one million years. Meanwhile, such events are of little relevance when the acceptable tolerance level is at 1%, the same events are important at extremely low or zero tolerance levels (Ripplinger *et al.* 2008). In this regard, it might take thousands of years of experimental data to ensure that all possible extreme weather events have been measured because the required weather events are so rare. Thus, and to get over the problem of scarcity of data, this research utilizes the historic information as well as interrelated data on the physics of wind movement and weather patterns to simulate the probability of occurrence of catastrophic storm events. The utilized method would make use of diversified fields of study including meteorology, climatology, and finance.

Predicting and Modeling Wind Movement

Theoretical models are used to approximate actual distributions through usage of known physical parameters and relationships. Thus, having thorough knowledge of fundamental determinants of wind movement, one can more accurately estimate the distribution of possible outcomes, especially those events that are rare in occurrence. This paper utilizes a technique similar to the one used by Chandler *et al.* (2001) in

predicting and modeling loss estimation for windstorms, with some modifications that suit the problem under investigation.

Sustained wind speeds have been found to give the best overall correlation with wind-induced damage and insured losses in windstorm events (Chandler *et al.* 2001). A key wind speed parameter is the maximum level of sustained wind speed U_m over a certain return period. Short-term wind speed records from meteorological stations over the most recent 5-year period can be used to derive the relation between wind speed and return period in the key range of 5 to 50 years. To derive the relation between wind speed and return period, Chandler *et al.* (2001) determined the annual probabilities of wind speeds that reach two key reference levels on the Saffir–Simpson scale. Then, a tri-linear plot of wind speed against the log of the mean recurrence interval (return period) is drafted to represent the mean result for hazard modeling. This plot has a unique mathematical shape defined by a cumulative Gaussian probability curve. In this regard, both the mean of this curve corresponding to the probability of exceedance (PE) for damage and its standard deviation are expressed directly in units that are related to the maximum sustained wind speed, U_m. This mathematical shape gives a best-fit match to the actual damage accumulation data and thus optimizes the reliability of the damage predictions. The two key parameters, the mean and standard deviation, are therefore sufficient to define an individual curve for the damage level. Afterwards, the windstorm loss function is represented through defining the maximum expected wind speed, U_m, and then converting the U_m values to a windstorm loss parameter, termed H_w. The loss parameter H_w is related to the square of the maximum sustained wind speed, U_m, and reflects the wind pressures leading to damage.

Design of Catastrophic Risk Insurance Policy

Based on the above, the catastrophic wind insurance policy will be designed as follows:

1) In order to avoid the issue of adverse selection, continuous care should be given so that the policy is not only insuring projects or households that are located in areas that have witnessed high risks of extreme wind exposure but should extended to locations that have no, minimal, or fewer risks. This is tough goal because people who did not witness previous experiences underestimate the negative affect evoked by natural catastrophic risks, which de-motivates any mitigation behavior. However, campaigning efforts should highlights the high costs elements associated with recovering damaged properties would hopefully let these groups interested in joining the policy;
2) The problem of moral hazards is not of concern under this policy because the insured risks are totally outside the control of the beneficiary (i.e. owners of construction projects or households);
3) The starting premium paid to insure against construction risks will be based upon past experiences with the predefined risks in a set of at least 3000 locations.
4) The fair indemnity rate (i.e. premium) paid to insure against each type of risk will be calculated as the fair rate for a put exotic option using the Monte Carlo simulation

Results and Analysis

Overview

As a proof of concept, the developed model was utilized in order to estimate the fair premium for a catastrophic storm insurance policy. Based on the outcome of such analysis, the model might be revised and then, extended to form a nationwide insurance policy against catastrophic storm risk. Furthermore, the same principles exploited under the model beforehand could be slightly modified in order to be applied on other extreme weather events such as hurricanes and tornadoes.

Date Collection

The historic data and information that serve as preliminary basis for this study were collected from the online sources of the National Climatic Data Center of the US Department of Commerce. The collected data spanned over 2 years between 5/31/2006 and 5/31/2008 in relation to storms and the associated cost of losses in relation to those events. In this regard, 997 storm events were recorded resulting in losses equal to 18.895 million US $. In addition, and out of these events, only 19 storms were recorded as being of Type F3 or higher (i.e. wind speed in excess of 137kt).Thus, it is true that extreme weather events would usually lie in the tail of distribution and which would substantiate any efforts to bootstrap such data to put hands on meaningful probability distribution for their occurrence

More importantly, a deeper look into such data would assure the satisfaction of the basic principle of adverse selection in the sense that: (1) the aforementioned storms spanned over various counties of Mississippi but not all of them and (2) not all of the storms have resulted in associated property damages. Thus, the problem of adverse selection is not of concern at all. Accordingly, the collected data would be confidently used in order simulate and bootstrap the distribution occurrence of such storms as well as the probability of such associated losses.

Model Application

In order to assign the probability of losses as result of extreme storm events using Chandler *et al.* (2001) technique, Table 1 highlights the same under various tolerance levels for a list of sample counties.

Table 1: Probability of Losses

County	Tolerance Level			
	0.001	**0.00065**	**0.0005**	**0.00001**
Greenville	0	0	0.149	0.877
Meridian	0.0002	0.034	0.261	1
Flora	0	0	0	0.721
Shivers	0	0.006	0.152	0.936

Iman and Conover (1982) procedure for inducing correlation has four attractive properties: (1) the procedure works well with any distribution function compared to other correlation techniques are aimed directly at standard distribution functions and cannot be used with other distribution functions; (2) the mathematics behind the procedure is not extremely complex and Cholesky factorization and inversion of

matrices are the most exotic steps in the procedure; (3) the procedure can be used under any sampling scheme; and (4) the marginal distributions of interest are maintained throughout the procedure and the moments of the marginal distributions are not affected at all.

The said technique was successfully used in order to bootstrap the 997 storm events towards a simulated set of storm events with their associated losses. In principle, both the original and simulated data sets should carry the same statistical characteristics including marginal distribution and correlation. In this connection, Table 2 highlights that the non-parametric Pearson's correlation value between the original and simulated datasets are nearly the same in sample counties in Mississippi that witnessed extreme storm events. In fact, this should increase confidence in the modeling and simulating credentials of the utilized model.

Table 2: Correlation Values in Original and Simulated Datasets

Counties	Spearman's Correlation Value	
	Original Dataset	Simulated Dataset
Hickory–Greenville	0.82571	0.82573
Meridian-Damascus	0.79563	0.79568
Bentonia-Flora	0.86738	0.86731
Canton-Shivers	0.77737	0.77734

Moreover, the descriptive statistics for the losses resulting from the simulated and bootstrapped dataset, as shown in Table 3, would demonstrate that the generated data is properly dispersed which helps in putting hands on the value at risk (VAR) represented by the tail of the distribution. The high value of the standard deviation is very normal because of the high dispersion of the $US associated with losses as result of extreme weather events.

Table 3: Descriptive Statistics for Simulated Dataset

Statistical Indicator	Value
Mean	51,982,663
Median	51,752,314
Standard Deviation	54,114,762

In order to decide upon the optimal way to price the indemnity rates according to the option theory, it was essential to fit the risks under investigation into suitable probability distribution. In this regard, the risk of extreme storm events followed a normal distribution, which is in line with the conjecture that in most cases the occurrence of risks happens pursuant to a normal probability distribution (Paulson 2007).

Indemnity Calculation

Indemnity rates for the proposed insurance policy was modeled using Monte Carlo simulation as described under equations (1) through (5) of this paper. Table 4 shows the calculated rates for different policy and tolerance levels.

Table 4: Indemnity Rates

Coverage	Premium in $US / US $ 100 [for various tolerance levels (TL)]			
	0.001 TL	**0.00065 TL**	**0.0005 TL**	**0.00001 TL**
100%	4.523	6.747	7.638	8.993
95%	4.297	6.409	7.256	8.543
90%	4.071	6.072	6.874	8.094
85%	3.845	5.735	6.492	7.644

Fortunately, the calculated premiums are in line with the premiums available in market for different insurance policies. Moreover, it is conjectured that insuring against catastrophic storm risks would fit into the aforementioned requirements for insurance outlined by Harrington and Niehaus (2004).

Summary and Conclusions

As a result of the increasing concerns of extreme weather events, this paper developed a model for insuring against the risks associated with catastrophic storms. That said, under this study, the historic data in relation to storm events in Mississippi between 5/31/2006 and 5/31/2008 was analyzed using Chandler *et al.* (2001) technique to estimate the loss parameters. This dataset was then bootstrapped using Iman and Conover technique to impose correlation and generate simulated dataset of 5,000 points. Finally, the bootstrapped data was modeled using a Monte Carlo simulation that is based on option theory to calculate the fair-valued premium for an interrelated insurance policy.

Meanwhile, make use of diversified fields of study including meteorology, climatology, and finance fosters and promotes the value of interdisciplinary research, it also serves two folds of benefits. First, the fair insurance premiums provides a measure of the magnitude of catastrophic storm risks which allows us to compare risks against benefits by putting a dollar value to the risk and thus, bridging between meteorologists who are concerned with risks versus benefits and economists who are more used to costs versus benefits. Second, this insurance policy solves the non-linearity problem associated with wind speed and amount of losses through insuring against losses in excess of certain tolerance level.

Based on the outcome of such analysis, this model could be extended to form a nationwide insurance policy against catastrophic storm risk. Furthermore, the same principles exploited under the model beforehand could be slightly modified in order to be applied on other extreme weather events such as hurricanes and tornadoes. Lastly, the developed model serves as the first step towards an integrated financial method for mitigation of the negative effects of catastrophic events.

References

Breuer, Michael (2005), "Multiple Losses, Ex Ante Moral Hazard, and the Implications for Umbrella", *Journal of Risk and Insurance*, Vol. 72, No. 4, pp. 525-538.

CCSP (2008), *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global

Change Research, Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA.
Chance, Don and Robert Brooks (2007), *An Introduction to Derivatives and Risk Management*, Thomson Higher Education, Ohio, USA.
Chandler, Adrian, John Jones, and Minoo Patel (2001), "Property Loss Estimation for Wind and Earthquake Perils", *Journal of Risk Analysis,* Vol. 21 No2, pp. 235-249.
Chiu, W. Henry (2000), "On the Propensity To Self-Protect", Journal of Risk and Insurance, Vol. 67, No. 4, pp. 555-578.
Doherty, Neil and Kent Smetters (2005), "Moral Hazard in Reinsurance Markets", *Journal of Risk and Insurance*, Vol. 72, No. 3, pp. 375-391.
Finnerty, J. (1996), *Project Financing: Asset-Based Financial Engineering*, John Wiley & Sons, New York, USA.
Fischer, Black and Myron Scholes (1973), "The Pricing of Options and Corporate Liabilities", *The Journal of Political Economy*, Vol. 81, No. 3, pp. 637-654.
Glasserman, Paul (2003), *Monte Carlo Method in Financial Engineering*, Springer Verlag, USA
Gogol, Daniel (1993). "The Value of Information in Insurance Pricing", *Journal of Risk and Insurance*, Vol. 60 No. 1, pp. 119-128.
Grossi, P., Kunreuther, H. and C. C. Patel (2005), "An Introduction to Catastrophe Models and Insurance in Catastrophe Modeling: A New Approach to Managing Risk", *Springer*, USA.
Hart, Chad E., Dermot J. Hayes, and Bruce A. Babcock (2006). "Insuring Eggs in Baskets: Should the Government Insure against Individual Risks" *Canadian Journal of Agricultural Economics,* Vol. 54 No. 1, pp. 121-137.
Iman, R. L., and W. J. Conover (1982), "A Distribution-Free Approach to Inducing Rank Correlation among Input Variables." *Communication in Statistics: Simulation and Computation* 11: 311-34.
Jaffee, Dwight and Thomas Russell (1997), "Catastrophe Insurance, Capital Markets, and Uninsurable Risks", *Journal of Risk and Insurance*, Vol. 62, No. 2, pp. 205-230.
Janssen, Maarten C. W. and Vladimir A. Karamychev (2005), "Dynamic Insurance Contracts and Adverse Selection", *Journal of Risk and Insurance*, Vol. 72, No. 1, pp. 45-59.
Klemetti, Ann (2006), "Risk Management in Construction Project Networks", *Report 2006/2, Laboratory of Industrial Management, Helsinki University of Technology*, Finland.
Kunreuther, Howard, (2006), "Disaster Mitigation and Insurance: Learning from Katrina", *ANNALS, AAPSS*, Vol. 604.
Lee, Wondon and James A Ligon (2001), "Moral Hazard In Risk Pooling Arrangements", *Journal of Risk and Insurance*, Vol. 68 No 1, pp. 375-390.
Linnerooth-Bayer, J. (2000), "Global Change, Natural Disasters, and International Aid, *Foresight and Precaution*, 1:667–672.
National Climatic Data Center (2008), < http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms>, accessed on July 10, 2008.

Raviv, Artur (1979), "The Design of an Optimal Insurance Policy", *American Economic Review*, Volume 69 No 1, pp. 84-96.

Ripplinger, David, Dermot J. Hayes, A. Susana Goggi, Kendall Lamkey (2008), "Insuring Against Losses from Transgenic Contamination: The Case of Pharmaceutical Maize", Working Paper: Center for Agricultural and Rural Developments, Iowa State University.

Paulson, Nicholas (2007), *Risks and Uncertainty in Agriculture,* PhD Dissertation, Economics Department, Iowa State University.

Samuelson, Paul (1965), "Rational Theory of Warrant Pricing", *Industrial Management Review,* Volume 6 Number 2, pp.13-39.

Tsanakas, Andreas and Evangelia Desli (2005), "Measurement and Pricing of Risk in Insurance Markets", *Journal of Risk Analysis*, Vol. 25, No. 6, pp. 1653-1668.

DEVELOPMENT OF THE STAR TOOL FOR THE MANAGEMENT OF SHUTDOWN/ TURNAROUND/OUTAGE PROJECTS

Donald A. Whittington[1], P.E. and G. Edward Gibson, Jr.[2], P.E., F. ASCE

Abstract:
Renovation and revamp projects are ubiquitous in the construction industry. Shutdowns/turnarounds/outages (STO) are a subset of renovation and revamp projects in the industrial sector. These events typically occur when planned disruptions to normal use or operation of a manufacturing facility take place to facilitate maintenance, enhancements, or tie-ins. It is common to have several construction projects executed during an STO and the integration of the activities is often problematic. Little research has been performed studying the integration of these multiple projects, work-scopes and maintenance activities into a single STO. Based on a Construction Industry Institute research study, this paper will provide a discussion of STOs, including unique challenges, describe a new tool/ management approach developed to aid industry professionals in planning and coordinating the multiple projects within an STO, and provide guidance to practitioners.

Keywords: Front End Planning; Program Management; Multi-Project Coordination and Integration; Shutdown/Turnaround/Outage Management;

INTRODUCTION

As defined by the Construction Industry (CII), a renovation or revamp project is focused on an existing facility and includes the act, process, or work of replacing, restoring, repairing, or improving this facility with capital funds or non-capital funds. It may include additional structures and systems to achieve a more functional, serviceable, or desirable condition, including improvement in: profitability; reliability; efficiency; safety; security; environmental performance; and/or compliance with regulatory requirements (CII 2008b).

Shutdown/Turnaround/Outage (STO) "projects" are a subset of renovation and revamp projects. These projects are generally a combination of one or many smaller projects or discrete activities. Each STO is typically unique and can be small to very large in terms of construction costs, although almost always constrained to relatively

[1] Graduate Research Assistant, Dept. of Civil, Const. and Environ. Engrg., University of Alabama, Box 870205, Tuscaloosa, AL 35487, 205-348-6550
[2] Professor and the Gary Neil Drummond Endowed Chair, Dept. of Civil, Const., and Environ. Engrg., University of Alabama, Box 870205, Tuscaloosa, AL 35487, 205-348-6987, egibson@eng.ua.edu

short schedule durations. STOs are typically focused in the industrial construction sector (although not always) and have specific time constraints for performance, and large business cost drivers for successful completion on a tight schedule. These cost drivers include such things as significant losses of production or sales opportunities resulting from any delays. For these projects, coordination of effort between multiple projects, each with their own unique issues, with facility maintenance and operations activities is extremely important. Unforeseen conditions and work requirements often come up during the work.

STOs are known by many different aliases such as shutdowns, outages, turnarounds, tie-ins, overhauls and so forth. As discussed herein, an STO refers to the management actions overseeing a project(s) or portion of a project(s) that are executed during a planned disruption in normal use or operation of an existing facility where return to service is a priority. It is a common occurrence that several projects are executed concurrently during an STO. This is due to the requirement for facility to be in a condition other than its normal operating mode to facilitate project tie-ins or normal maintenance activities. When multiple projects or discrete activities are overseen in an STO, the management team is effectively providing program oversight. Because of the concurrent projects and maintenance activities during this period, execution is complicated and requires intensive planning and management. Many organizations treat STOs as a project even if they contain only maintenance activities. This is done in order to bring project management discipline to the large investment in the facility asset. During an STO, timelines are a major constraint, activity intensity tends to be higher, focus is much broader than one project or contractor and project risk levels are typically higher. This paper will only focus on STOs in the industrial sector. Some of the critical issues that set STOs apart will be briefly examined later in the paper.

A literature review revealed few references dealing with this critical industrial process. This fact and subsequent discussions with the research sponsor lead to the direction of this exploratory research effort. This paper will provide a discussion of STOs, including unique challenges, describe a new tool/management approach developed to aid industry professionals in planning and coordinating the multiple projects within an STO, and other research activities.

DESCRIPTION OF RESEARCH

In late 2006, the CII membership was surveyed concerning processes related to front end planning of renovation and revamp (R&R) projects with 41 organizations responding. One specific finding of note from the survey was that the majority of the respondent organizations manage their R&R projects differently from greenfield projects because these projects typically contain more risk in such areas as safety, unknown site conditions, interface with existing operations and so on. Further investigation via 25 detailed R&R project case studies, performed by both owner and contractor organizations, showed that STO projects require intensive management activities in order to be successful. These cases constituted both large and small renovations efforts, mostly from the industrial sector, with the combined cost of the sample being greater than $1.4 billion. The case study sample write-ups were analyzed using pattern matching software (Howard et al. 2008).

The CII research team overseeing this research effort was made up of 20 experienced industry professionals from 10 contractor and 10 owner organizations. Based on the input from the survey and case studies described in the previous paragraph, the authors and the research team decided to focus a large amount of effort on understanding the characteristics and key success factors of STOs. Using these previous results, the team's collective experience and subsequent workshops involving 67 individuals from 39 organizations (as discussed later in this paper), the authors identified STO mitigation strategies and critical issues as described in the next sections. The authors, in conjunction with the research team, also lead the development of a STO management tool and approach for practitioners to address s as outlined later in the paper based on the input of these research efforts. The materials presented in the next two sections have been vetted extensively with industry and are exploratory findings based on subjective input from over 80 individuals.

STO RISK MITIGATION STRATEGIES

STO's require extensive planning to minimize the risks imposed by interfacing with existing facility systems. With STOs posing a large number of risks, the first level of risk mitigation should be to design for minimizing the amount of work required to be performed during the STO. This may not be the easiest or the cheapest solution for an individual project but it may be the best for the STO and the facility overall. The risk imposed by executing construction during an STO needs to be considered during the design review process and later during constructability reviews. The potential risks of excessive work done in the STO, manifest in increased project complexity and often result in the potential for increased costs, schedule delays, or in the worst case scenario, failure of the project to meet complete project objectives. Planning and coordinating efforts during the pre-construction phases of the project or STO can help to alleviate the prospective for problems.

For activities that must be executed during the STO, effective early planning will improve the STO performance in terms of both cost and schedule. CII shows that planning for STO activities often result in limited durations with schedules showing tight tolerances and minimal slack time (CII 1991). If similar STOs will be executed over a period of time, the development of a standard STO schedule template that incorporates optimized best practices is desirable.

During the STO, specially empowered individuals from operations, maintenance, engineering, procurement, and other support staffs may be put in place to facilitate communications and quick resolution of issues. Protocols should be in place to ensure issues are quickly communicated to the STO management. Detailed STO metrics may also be routinely used to track STO preparations, progress, and other key issues (e.g. material availability, engineering product availability, low level safety incidents, etc.). Finally, specialized maintenance crews may be established to address highly complex jobs that are critical to resolving STO issues. Previous research conducted and detailed in another CII publication indicates that the coordination between critical maintenance work and planned activities helps overall project effectiveness (2001).

STO CRITICAL ISSUES

Approaching an STO using only greenfield project management techniques will most likely not lead to success. The following unique and critical success factors where identified as requiring additional care during front end planning of an STO; each needs to be considered when planning an STO (CII 2008a).

- **Alignment:** During planning for most projects, there is one project to be executed during a specific period. In the case of an STO, there typically are many individual projects and maintenance activities to be executed in the same period. From a overarching management perspective there is no longer a single focus, however staff or contractors working on individual projects may not see the overall vision and may maintain their individual focus. The organizational hierarchy and goals of the STO need to be understood by the various project teams.
- **Safety Management:** The nature of STOs imposes unique safety challenges in particular regarding work near existing operations and in close proximity to multiple projects and contractors. Such periods of intense activity, with possibly competing objectives, may compromise safety if not actively managed. Consideration needs to be given during the STO to an overall safety program, and an enhanced emergency response capability.
- **Contracting Strategies:** Multiple contractors working on an STO with different contracting strategies may drive individual behavior that is not aligned with the overall objectives and priorities of the STO. Interfaces between projects, contractors, and the facility need to be planned and managed.
- **Availability of Resources:** Since the STO is characterized by a relatively short period of intense activities, availability of the required trades, engineering staff, procurement personnel, specialized contractors or pieces of equipment such as cranes may be in short supply. In these periods of high demand, productivity or quality can suffer, negatively impacting cost and/or schedule. Additionally, resources to provide site training or orientation prior to and during the STO may be taxed during these periods. In some cases, input from these training resources may be required in the front end planning stages of the STO.
- **Logistics:** Due to competing priorities between the individual projects and maintenance activities making up the STO, there is a need for detailed, integrated plans that correlates the various activities. Coordination of lifts, swing space requirements and other logistical issues must be understood prior to the STO. Material movement and staging prior to and during the STO must be coordinated.
- **Space Allocation:** With intensive activity during the STO, available space will often become constrained for equipment staging, part staging, work areas, lay down areas, as well as pedestrian and traffic flow, and so on. A common, space allocation process for the STO is required, integrating all projects.
- **Fixed Resources:** Demands from various groups for the fixed resources of the facility can negatively impact the STO. Competition for the use of bridge cranes, service air, water, power, and so on can result in cost or schedule impact delays. Availability of these services can be affected by the work scope of the STO, as systems are taken out of service for maintenance or project tie-ins.

- **Control of Work Zone:** It is common to have multiple work zones controlled by multiple contractors during an STO. Consideration needs to be given to how these work zones will be controlled to ensure safety and efficiency, including pedestrian traffic, material movement, work space availability, and so on across these boundaries.
- **Lock Out/Tag Out Requirements:** STOs can be very complex, with diverse work in many locations on many different process systems. Some of these activities may not normally occur during online maintenance activities. This may increase the complexity of the lock out/tag out requirements. Periods of intense activity levels during an STO may strain the management of the lock-out/tag-out process. Older facilities may have degraded conditions that will render the most efficient or planned lock-out isolation points unavailable. The accessibility and condition of critical project lock-out/tag-out isolation points should be confirmed prior to the STO.
- **Unknown Site Condition:** Accurate knowledge of site conditions is critical to maintaining schedule and cost. Project interfaces to the existing facility may turn out to be different than planned and project schedules may need to be adjusted with little notice. Accurate inventories of designated substances (asbestos, lead paint, etc.), accuracy of drawings and contractor knowledge of site operations, maintenance and safety procedures are some of the site conditions that may impact the STO.
- **Unplanned/discovery work:** Maintenance activities are usually also conducted during an STO. The possibility of unplanned/discovery work as a result of maintenance or project activities is great and can impact the overall scope of work to be conducted during the STO. Risk mitigations plans should be in place and procurement and contract strategies should be aligned to effectively anticipate and manage such situations.
- **Environment Management:** Special precautions may be necessary to ensure the STO does not adversely affect the environment. Such items as noise, dust and hazardous material control need to be managed. The scope of the STO needs to be understood to ensure that environmental control systems are not inadvertently taken out of service.
- **Permit Requirements:** Permits required by the local, regional or federal regulatory bodies required to construct, maintain and operate the facility need to be obtained, in most cases, prior to the start of construction. Since several projects making up the STO may have specific permitting requirements, an integrated plan generally is required.
- **Security:** The intense nature of the STO may influence or tax site security arrangements. Additional resources may be required to process personnel, tools, and equipment in and out of the facility.
- **Traffic Control:** Consideration needs to be given to traffic control entering and on the site, material and equipment delivery, staging and conveyance as well as employee and contractor parking during these periods of intense activities.
- **Communication Strategy:** Effective communication strategies from the workforce to management levels are required prior to the STO. These include protocols for routine workforce communication, STO progress reporting, work

group handoffs, and urgent item resolution (e.g., delays, unforeseen conditions, labor or material shortages, etc.).

- **Project Controls:** Reporting processes for controlling cost, schedule and scope need to be flexible enough to supply the required information at the required time intervals for the overall STO and for individual projects as required.
- **Procurement Plan:** The fixed return to service date and the interdependencies imposed by projects and maintenance activities require a well-functioning procurement plan that is aligned with the integrated schedule, and be adaptable to unforeseen events. The procurement organization needs to be able to deal with urgent material requests and changes to contracts during the STO to effectively deal with discovery work. To the extent possible, potential material discovery risks (e.g., spare parts that are likely to be required) should be evaluated and actively managed prior to the STO.
- **Commissioning Plans:** The sequencing of the commissioning and start-up / return to service activities needs to be integrated and supported by a single plan.

NEW STO PLANNING TOOL

A new and novel tool, called the **S**hutdown **T**urnaround **A**lignment **R**eview (STAR) Tool, for the planning and risk mitigation of STOs has been developed based on this research effort. The STAR Tool provides a means to assess key planning attributes unique to STOs, leading to earlier risk identification and mitigation. It provides an umbrella evaluation method to test the alignment and preparedness of multiple projects to move forward into detailed design and execution of an STO. As previously discussed, an STO is a unique event where multiple projects and maintenance activities converge to a constrained period of time. Individual projects or activities conducted during the STO must compete in a 'one to many' relationship as they vie with others for resources, space, or equipment. The Tool provides insight, management guidance and common ground for communication between the multiple project teams as they work together to meet the expectations during an STO.

The STAR Tool would normally be used by the STO Manager or an individual who is intimately knowledgeable with the scope and objectives of the STO. The objective of this assessment is to provide a venue or forum where multiple projects can be reviewed collectively in the early stages of planning, leading to identification of problem areas, potential conflicts in priorities, and, hopefully, win-win solutions involving the key stakeholders. It would be most effective when a team of representatives for all the work that will be executed during the STO get together to complete the STAR assessment. Representation of contractors would be considered essential input to the assessment. The STAR assessment also serves as a good alignment exercise for the STO team to ensure the objectives of the STO are communicated to the individuals involved. As illustrated in another CII study (2001), projects with involved management groups in the planning and execution of the activities result in superior performance when compared with other projects.

STAR TOOL DEVELOPMENT

Based on the STO critical issues as identified and described above, the STAR Tool was initially developed by a sub-team of ten CII research team members who

specialize in the planning and implementation of STOs. Nine summary categories (given in Table 1) and 94 elements were refined for a joint assessment of the multiple projects that will eventually converge during the STO.

Once the initial tool was drafted, a series of four external workshops were held to prioritize the tool as well as provide input and suggestions for refinement. The structured workshops allowed interaction between the industry professionals while also improving the STO planning tool. These suggestions included a detailed vetting of the individual elements within the STAR Tool as well as assessment of tool appearance, ease of use and overall usefulness. The workshops included a total of 67 participants representing 39 separate organizations with combined project management experience of over 1,300 years (Whittington et al. 2008).

Each of the respondents was asked to indicate the relative importance (priority) of each of the nine categories to the planning process for STO projects (on a scale of 1 to 100, with 100 total priority points assigned). The respondents used recent or existing STOs as a basis for the prioritizations totaling approximately $5.5 billion in total installed costs (Whittington et al. 2008). Gibson and Whittington (2008) describe the method used to develop the prioritizations using research charrettes and a structured data survey, which is beyond the scope of this paper.

The nine STO categories are listed in Table 1 along with some relevant statistical results from the four workshops. Based on input from the 67 respondents, the priorities of each category are listed along with the standard deviation. The table includes the total number of respondent outliers from each category. The authors classified the value of a priority outlier as plus or minus 1.5 standard deviations. The validity of the individual respondents were then scrutinized. Any participant whose responses included three or more priority outliers were classified as respondent outliers. Of the 67 total participants, seven were determined to be respondent outliers and were excluded for final prioritization calculations (Whittington et al. 2008).

In the final state of the tool, each of the nine categories has been assigned a transformed ‘value’ or ‘prioritization’ based on a total score for all categories of 1000 points as shown in Table 1. This transformation was done to provide tool users a simple method of assessing the readiness of their projects during the planning process. This overarching assessment score gives a subjective method for determining areas which need additional planning and risk mitigation effort. A higher total score indicates poorer definition of planning preparedness.

Table 1: STAR Tool Categories and Statistics

Category	Prioritizations (%)	Standard Deviation	Priority Outliers (Exceeding +/- 1.5 std dev)	Relative Importance (0-1000) Scale
1. Design for Constructability Analysis	13.4	5.94	5	134
2. Permit Requirements	6.3	3.55	4	63
3. Equipment and Material Status	14.0	5.48	7	140

4. Procurement Procedures and Plans	8.8	3.62	10	88
5. Project Control Requirements	12.0	4.99	8	120
6. Engineering/Construction Plan and Approach	14.2	5.74	9	142
7. Shutdown/Turnaround/ Outage Requirements	16.3	6.66	6	163
8. Commissioning	7.3	4.29	8	73
9. Startup Requirements	7.7	3.57	7	77

Identified within each of these categories are sub-tasks or elements for evaluation that, when reviewed together, provide an overall summary of risks. With this assessment, informed decisions can be made, needed actions for improvement can be identified, and identification of overlaps between competing projects can be discovered. An example of one category, Procurement Procedures and Plans, from the STAR Tool is shown in Figure 1. Note the description of the category and its four basic elements in the figure. The complete STAR Tool and corresponding electronic assessment spreadsheet are available from CII (2008a).

The STO management team would conduct a review of the projects involved in the STO and determine the corresponding readiness level of each specific element by placing a check (√) in its corresponding level of readiness. Once all of the elements in an individual category have been rated, an overall priority for the category can be identified considering all projects to be executed during the STO. The assessment will be continued for each category and a completed prioritization for the STO will be developed. The total priority out of 1000 potential points will give a preliminary level of preparedness of the team to enter the STO. A state of readiness in Columns 1-3 may be acceptable to management depending on the importance to the STO. A state of readiness in Columns 4 and 5 need definite improvement or may risk poor execution of the STO depending on the importance of the line item to the STO. One or more line items in this column could be grounds for a “no-go” decision. Based on a comparison of the readiness levels, repeated STAR Tool assessments will show changes in STO preparations and alignment and will guide STO management in future STO planning.

STAR Tool (cont.)							
Categories/Elements for Review:	N/A	High Performing	Meets Most	Meets Some	Needs Improvement	Not Acceptable	Comments:
4. Procurement Procedures and Plans		1	22	44	66	88	
Specific guidelines, special requirements, resources, or methodologies for accomplishing the purchasing, expediting, delivery, and security of equipment and materials required for the project. Evaluate each of the line items below based on a collective impact of the multiple projects involved. Evaluation criteria should include:							
A. Procurement guidelines (including expediting processes) to support planned, unplanned, or 'discovery' work during STO are in place with appropriate time constraints							
B. Procedures and accountabilities to allow for real-time contract change controls are in place							
C. Potential for leveraged contracts across multiple projects for common commodities (i.e., piping, conduits, valves, cable, consumables, etc.) has been reviewed							
D. Staff resources available to support procurement procedures and plans							
E. Other							

Figure 1: Example STAR Tool Category

After development, the tool was tested on several actual projects, including both ongoing and completed STOs. In all cases the tool showed its value in STO planning activities (Whittington et al. 2008).

RECOMMENDED STAR TOOL TIMELINE

The STAR tool can be employed at various times in the front-end planning phases of the individual projects and as an overall review of all projects and activities involved in the STO. Various projects that comprise an STO are often at varying degrees of preparation and a STAR assessment can be implemented across the individual project front-end planning period. The STAR Tool can be used to assess the risks and readiness of the overall STO.

The STO manager will decide when to undertake the overall STAR Tool assessment, generally 12 to 18 months prior to the STO. Each STO is unique and the assessment must be scheduled in accordance with the experience of the STO manager, reviewing each project and work scope in terms of its impact to the overall STO readiness. Actions can be taken to bring the projects into alignment with STO preparations and objectives.

CONCLUSIONS

This exploratory research project has focused on STOs, which are an important subset of renovation and revamp projects in the industrial sector. STOs are typically very complicated efforts, with the potential to adversely affect the owner of the affected facility. STOs are very common in the oil and gas, power, heavy manufacturing, pulp and paper, and pharmaceutical industry sectors, but until this

study, few published resources have been focused directly on the planning process of these efforts.

For STOs, coordination and alignment between the multiple projects and activities making up the effort, each with its own unique concerns, is critical. STO planning efforts must integrate with existing facility maintenance and operations activities. Unforeseen conditions and work requirements often come up during the STO work and should be mitigated if possible and anticipated. Safety must be addressed.

Because of a lack of publicly available information concerning STOs, a CII research investigation looked at the unique, critical success factors of these types of endeavors. Based on input from over 80 individuals representing over 50 organizations, a list of 19 issues of concern for STOs is given in this paper. The authors, in conjunction with the CII research team, have developed a new STO planning and alignment resource called the STAR Tool as described briefly in this paper. This tool provides nine categories made up of 94 individual elements that can be used to determine the overall readiness of the STO project team for entering the outage. For practitioners approaching an STO, the issues identified in this paper and the STAR Tool will provide a good basis for beginning their planning activities. For academic researchers, this exploratory study will provide a basis for further work in understanding the dynamic and complicated planning and execution processes tied to STOs.

REFERENCES

Construction Industry Institute (CII) (1991), *Manual for ~~Small~~ Special Project Management,* Special Publication 13, Austin, TX, June.

Construction Industry Institute (2001), "Small Project Execution," Research Summary 161-1, Austin, TX, November.

Construction Industry Institute (2008a), *Front End Planning of Renovation and Revamp Projects* Implementation Resource 242-2, Austin, TX.

Construction Industry Institute (2008b), "Front End Planning for Renovation/ Revamp Projects: A Different Animal," Research Summary 242-1, Austin, TX, October.

Gibson, G. and Whittington, D. (2008). "Charrettes as a Method for Engaging Industry in Best Practices Research," *Journal of Construction Engineering and Management, in review,* 2008.

Howard, S., Gibson, G., Whittington, D. and Cui, Q. (2008). "Analysis Supporting Front End Planning for Renovation and Revamp Projects, Part 1," Research Report 242-11, Construction Industry Institute, Austin, TX.

Whittington, D., Gibson, G. and Cui, Q. (2008). "Analysis Supporting Front End Planning for Renovation and Revamp Projects, Part 2," Research Report 242-12, Construction Industry Institute, Austin, TX.

INTEGRATING PRODUCTIVITY AND SAFETY ANALYSIS WITH THE TASK DEMAND METHODOLOGY: A CASE OF CONCRETE PAVING

Panagiotis 'Takis' Mitropoulos[1] and Manoj Namboodiri[2]

[1]Assistant Professor, Del E. Webb School of Construction, Arizona State University, Email: takism@asu.edu
[2]Former graduate research assistant, Del E. Webb School of Construction, Arizona State University. Email: manoj.namboodiri@asu.edu

Abstract
This paper presents a new methodology to measure at the same time the safety risk and productivity of an operation and assess how changes in operation parameters affect both productivity and safety. The methodology is based on a cognitive approach to safety and considers two key factors for assessing the likelihood of accidents: (1) the exposure to a hazard, and (2) the 'task demand' during the exposure, which reflects the difficulty to do the work safely with respect to a particular hazard. The task demand indicates the probability that there will be an error during the exposure to the hazard that can lead to an accident. The paper describes the methodology, and presents a case study that analyzes the likelihood of accident and the productivity of a paving operation. The case illustrates how this methodology can be used to evaluate the effect of production variables on both productivity and safety. The conclusion discusses the strengths and limitations of the approach.

INTRODUCTION

The long term goal of this research is to increase the ability to design operations that are at the same time highly productive and highly safe. This requires the ability to quantify the effect of the production variables and measure how changes in the relevant variables influence productivity and safety risk. Towards this goal, this study develops a methodology for measuring at the same time the productivity and safety risk of an operation, based on operation-specific variables.

Productivity analysis methods (Oglesby, et al 1989, Howell 1999) and simulation techniques such as CYCLONE and STROBOSCOPE (Martinez and Ioannou 1999) provide the ability to analyze the productivity of an operation and the effect of different variables on productivity. However, there is no methodology to evaluate the effect of operations variables on the safety risk of an operation. Methods

for safety evaluation used in behavior based safety focus on frequency of safe behaviors but such assessments are independent of operational variables.

Methodologies for evaluating the potential for injury based on characteristics of the operation have been developed in ergonomics. Such methods evaluate the demands on workers only due to physical loads, based on specific characteristics of the activity (posture, weights, etc.). These methods do not calculate the likelihood of injuries (as injuries depend on many other factors), but provide a way to quantify the ergonomic task demands, which indicate the potential for ergonomic injury.

To measure the safety risk of an operation, this research developed the 'Task Demand' methodology. This method is based on a cognitive approach—it is based on the premise that the attributes of the task and the environment affect the likelihood of errors and consequently the performance of the operation. The task demand methodology takes an approach similar to the ergonomics and quantifies the potential for accident due a particular hazard.

The paper provides an overview of the methodology, and uses the method to analyze the productivity and safety of a concrete paving operation under different production scenarios. The discussion summarizes the strengths and limitations of the method and the contribution to research and practice.

OVERVIEW OF THE 'TASK DEMANDS' METHODOLOGY

An integrated analysis of the productivity and safety of an operation requires two components: (1) measurement of productivity and (2) measurement of the safety risk, or potential for accident. With regards to productivity, the methodology proposed in this paper uses the established concepts and techniques for analyzing and measuring productivity as a ratio of output over input. The specific metrics and units depend on the particular operation. To measure the safety risk the researchers developed the 'task demand' methodology. In this method, the safety risk (or potential for accidents) for a particular hazard is calculated as follows:

Safety Risk = [Exposure to the hazard] x [Task Demand]

Exposure to the hazard. The exposure to a hazard is determined as the percentage of the time that a worker is exposed to the presence of the particular hazard. The percentage of time is used to normalize and compare different operations.

Task demand. The task demand reflects the difficulty to do the work safely with respect to a particular hazard. The task demand during the exposure indicates the likelihood that there will be loss of control (e.g. worker's error) which has the potential to lead to an injury. The likelihood of loss of control also depends on factors related to the workers' capacity (skills, fatigue, etc) which are not considered currently by the method. The method quantifies the potential for accident (safety risk) independent of the capabilities of the worker, similar to the ergonomic methods that calculate the load, but do not account for the strength of the worker. The task demand methodology also measures the safety risk independent of the safety measures applied—for example, with regards to 'fall from elevation' hazard, the the safety risk of losing balance is independent of the use of a fall arrest system.

A central issue in the methodology is the identification of the factors that determine the task demand. These factors are specific to the hazard and the operation, and they are determined by observing and analyzing the operation and interviewing the activity participants. The case study in the section that follows discusses how the task demand factors were identified and quantified.

The methodology was developed empirically based on observation and analysis of three concrete operations: (1) a concrete paving operation, (2) a formwork operation for concrete diaphragm walls on a bridge, and (3) a concrete wall formwork operation. The research approach used a comparative analysis of similar operations. Each case analyzed and compared different instances of the same operation (the same operation at different locations and in different days) to understand if and how changes in production variables affected the productivity and the safety risk.

For each operation studied, the research included the following steps:

- Interview participants (manpower, estimated productivity, planning, preparation, work distribution and tasks, coordination needs, etc.)
- Observe/videotape the operation (layout, tasks performed, durations, quantities completed)
- Analyze the operation for productivity and identify the factors affecting productivity (calculate productivity, develop crew balance charts, analyze time use, task dependencies)
- Analyze the operation for safety risk
    - Identify the most significant hazards as identified by the crew.
    - Identify the factors that determine exposure to the hazards
    - Identify the factors that determine the task demand

The concrete paving case study illustrates the use of the task demand method for quantifying the safety risk. The case analyzes different production scenarios and calculates the productivity and the potential for accidents for each scenario.

CONCRETE PAVING OPERATION

This case study analyzes a concrete paving operation at an airport facility. The project involved upgrading of airport taxiways from Asphalt concrete (AC) to Portland cement concrete pavement (PCCP). The taxiway was divided into smaller sections to be replaced. Most of the preparatory work was done in the day, and operations such as hauling dirt and paving were done at night. The project included removing the existing AC pavement, rerouting underground utilities, placing crushed aggregate base course (CABC), and paving with PCCO.

This study analyzed the paving operation of one section that was paved during one night shift 8 hours long. This section was 300-350 feet long, 37.5 feet wide and 19.5 inches deep. This section was between two paved sections with dowel bars extending from both sides of the concrete pavement. The estimated productivity for this section was 135 Cy/hr. A batching plant at the airport supplied the PCCP according to the approved mix design. Eight trucks were used to deliver the concrete.

Preparations

The preparatory works took about 2-3 hours and included the following: (1) Clear the area to be paved of any foreign materials. (2) Divide the area in 2 lanes using safety cones to make dump truck routes visible. (3) Mark the expansion and

construction joints locations on the paved sides. (4) Arrange the dowel baskets along the sides of the section. The dowel baskets were required per the design of the pavement joints. After the operation started, the baskets were placed across the section and fixed into the ground using a nail gun. (5) Prepare the equipment (paver and cure bridge) and tools (vibrators, hand shovel, wheel barrow, etc.)

The foreman, superintendent and quality control inspector reviewed a pre-pour checklist before the start of the operation. The superintendent inspected all areas of the work while the foreman coordinated with the batching plant for the delivery of concrete. Just before the start of the operations, the foreman discussed the method of work with the crew members. Safety issues were identified by the site superintendent and the site foreman and reported in a task hazard analysis form (THA). These issues were discussed with the crew. The most significant hazards identified were (1) getting hit by the moving truck, and (2) getting hit by the paver.

Operation overview

The paving operation involved three activities: (1) placing the concrete in front of the paver, (2) paving, and (3) concrete finishing behind the paver. Figure 1 illustrates the layout of the paving operation and the labor involved. The section was divided in 2 lanes where the trucks backed up and dumped the concrete. Each truck load provided concrete for approximately 4 feet. The paving crew consisted of ten workers (not counting the superintendent, the paver operator, and the mechanical foreman). The general foreman supervised the entire crew and was in constant communication with the batching plant.

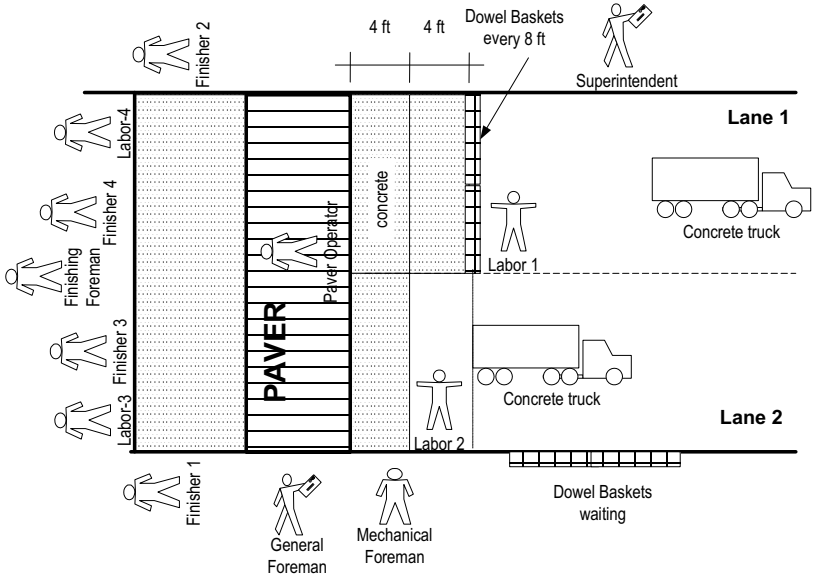


Figure 1. Layout of paving operation

During the operation, the paver reached and maintained a speed of 1 foot per minute. The concrete delivery rate was one truck every 2.5 minutes in each lane. The finished pave rate was 9 feet in 17 minutes (the paving crew started at minute 7). The three activities (concrete placing, paving, and finishing) needed to stay relatively close to each other, so that the speed of the paver and the workability of the concrete were not affected.

Placing concrete in front of the paver

Two laborers and the superintendent performed the following tasks:

(1) The laborers guided the concrete trucks to back up to the right location, opened the truck gate and guided the truck to dump the concrete. The cycle time of dumping the concrete varied from 52 to 72 seconds (average of 62 sec). Each laborer was assigned one lane in which to guide the delivery trucks.

(2) Set the dowel baskets every 8 feet (every 2 truckloads for each side). The cycle time was 72 seconds. Setting the baskets (14 seconds) required two crew members (the two laborers or one laborer and the superintendent). Fixing the baskets (60 seconds) required one laborer.

Every two trucks of concrete, the laborers set down the next row of dowel baskets. The dowel baskets were approximately 7.5 feet long and 9.75 inches high. Two baskets were placed on each side. It took both laborers to set down the dowel baskets—if one laborer was busy guiding a truck, the other laborer had to wait or the superintendent was helping. After setting the dowel baskets, one laborer fixed the dowel basket onto the ground with a nail gun.

The superintendent supervised this activity. His primary concern was to maintain the smooth and continuous delivery of concrete so that the paver, once started, did not stop. If the paver stopped, that portion of the concrete would settle and bumps would occur in the concrete after finishing. The superintendent also took care not to overload the paver, as this could slow the paver down. The delivery rate of trucks was decided by the superintendent and communicated to the general foreman, who in turn communicated with the batching plant. In addition to supervising, the superintendent helped guide the trucks and helped place dowel baskets.

Paving

The mechanical foreman was constantly checking the paver and communicating with the paver operator. The operator communicated with the superintendent and the two laborers in front of the paver. The operator took instructions from the superintendent regarding the speed of the paver. The speed was adjusted to the concrete delivery to maintain a smooth and steady flow of concrete.

Finishing behind the paver

The finishing crew vibrated and finished the concrete. The crew included 4 finishers, 2 laborers and a finishing foreman and performed the following tasks: vibrated and troweled the concrete, checked concrete workability, checked paver alignment and concrete edge, checked surface and added or removed concrete, and operated the cure bridge.

PRODUCTIVITY AND SAFETY ANALYSIS

The analysis quantifies the productivity and the safety risk for the observed operation and then examines the productivity and safety risk for different scenarios.

Productivity analysis

The contractor measured the productivity of this operation in cubic yards per hour. Because of the linear nature of the project in the study the productivity was expressed in linear feet per minute. The actual speed of the operation was one ft per minute.

Safety risk analysis

The analysis included the following steps:

1- **Identify key hazards.** The review of the task hazard analysis performed by crew, and the interviews with the crew and supervisors, identified two key hazards: (1) hit by the paver, and (2) hit by the truck. Thus, the analysis focused on the two laborers working in front of the paver.

2- **Determine exposure to hazard(s)**

For the hazard 'hit by paver, we considered that exposure exists 100% of the time, as the paver is moving continuously. Although the workers may not be standing in front of the paver all the time, but only when the trucks approach, this approach provided the 'worst case scenario.

For the hazard 'hit by truck', the exposure to the hazard starts from the moment when the truck starts backing up, to the point when the truck leaves. The rest of the time, the workers are not exposed to this hazard.

3- **Determine factors affecting task demand**

For the hazard 'hit by paver,' it was determined that the task demand depended on the distance between the worker and the paver. Thus, the smaller the distance, the greater the task demand. Table 1 shows the task demand depending on the distance from the paver. The task demand score (1 low, 3 moderate, and 9 high) was based on a subjective assessment of the 'potential to be hit by the paver'.

To calculate the workers' distance from the paver, it was assumed that the workers were standing at the end of the concrete buffer in front of the paver. This was the case when the worker was guiding the truck. For the rest of the time, this was a conservative estimate of the safety risk. The amount of concrete in front of the paver was calculated based on the truck delivery rate and the paver speed (Figure 3a).

Table 1. Hazards, exposures, and task demands

Hazard	Exposure	Task demand (TD)
Hit by paver	Option 1: 100% of the time Option 2: When truck present	Distance from paver: 0-2 feet → TD = 9 (high) 2-4 feet → TD = 3 (moderate) 4-6 feet → TD = 1 (low) >6 feet → TD = 0 (none)
Hit by truck	% of time a worker is exposed to moving truck. From the moment when the truck starts backing up, to the point when the truck leaves.	Laborer guides truck→ TD=1 (low) Laborer behind truck, third party guides → TD = 3 (mod) Laborer behind truck Truck backs up → TD = 9 (high)

For the hazard 'hit by truck,' the task demand was determined as follows, based on observations of the operation and discussion with the superintendent. When a laborer guided the truck, the worker's full attention was at the truck, and the worker and the driver are in direct communication. In this case, the task demand was considered the lowest (1). If the truck was backing up while the laborer behind the truck was performing another task (setting the dowel baskets), and a third party was guiding the truck, the task demand was considered moderate (3). In a couple of such cases, the superintendent stopped the truck until the laborer finished. Finally, if the truck was backing up while the laborer behind the truck was performing another task but there was no one else to stop or guide the truck, this was assigned high potential for accident (9). Table 1 summarizes the factors determining exposure and task demands for each hazard

4- Calculate the safety risk

Figure 2a illustrates the tasks for the laborers in front of the paver for 10 minutes period of time. At each lane, a trucks arrives every 2.5 minutes. The laborer at that lane guides the trucks to position. Every two trucks the laborers set the baskets together and then one laborer fixes the basket, while the other one returns to his lane. Based on this information, the task demand for the 'hit by truck' hazard can be calculated for each laborer, as shown in Figure 2b.

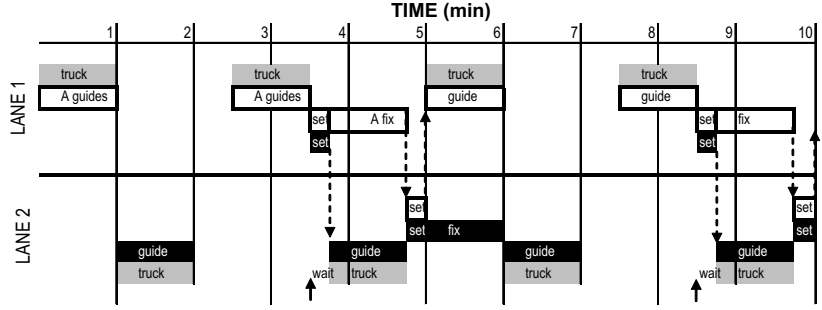


Figure 2a. Tasks performed by laborers in front of paver.

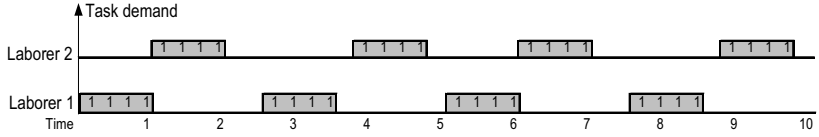


Figure 2b. Tasks demand over time for hazard "hit by truck'

The safety risk for the hazard 'hit by truck' is calculated as the exposure (percent of time) multiplied by the task demand.

Laborer 1:	Safety risk for 'hit by truck' = 40% x 1 =	0.40
Laborer 2:	Safety risk for 'hit by truck' = 40% x 1 =	0.40
Total:	Safety risk for 'hit by truck' =	0.80

The safety risk for 'hit by paver' depends on the workers distance from the paver. This was considered equal to the concrete in front of the paver. Figure 3a shows the concrete buffer in front of the paver for the actual production parameters (Paver speed=1ft/min, and truck delivery every 2.5 each lane). Based on this information, we can calculate the task demands for each worker with regards to the 'hit by paver' hazard, as shown in Figure 3b.

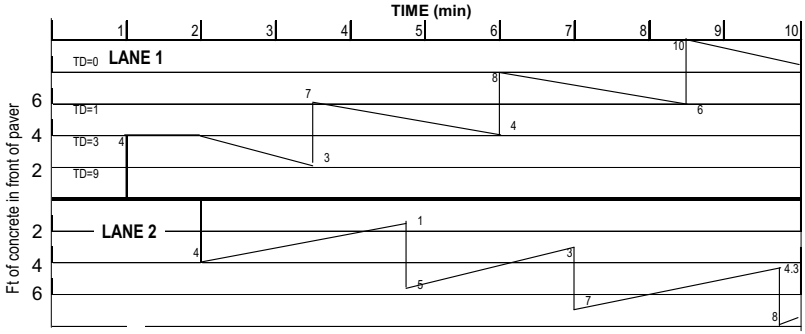


Figure 3a. Amount of concrete (in LF) in front of the paver

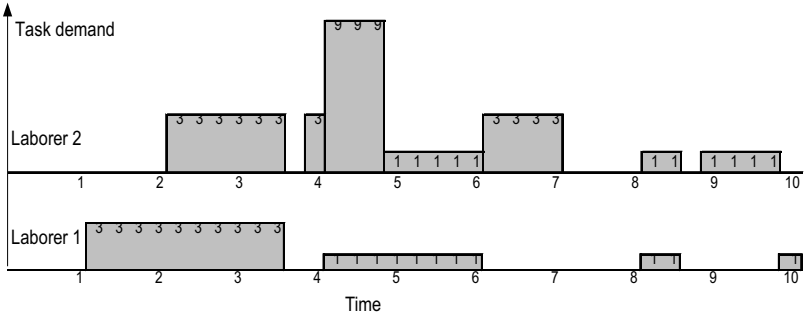


Figure 3b. Task demand for 'hit by paver hazard.'

The safety risk for the hazard 'hit by paver' is calculated as follows:

Laborer 1: Safety risk for 'hit by paver'	= 25%x3 + 27.5%x1 =	1.025
Laborer 2: Safety risk for 'hit by paver'	= 27.5%x1 + 27.5%x3 + 7.5%x9 =	1.775
Total safety risk for 'hit by paver'	= 1.025 + 1.775 =	2.80

In principle, the safety risk score reflects the probability that an accident will occur during the operation. However, the metric has not been correlated to actual

probabilities of accidents. Furthermore, the safety risk may be better indicated by the frequency of peaks—that is, percent of time with high task demands, rather than the total task demand. Although these issues are not resolved at this time, the value of the methodology is that it brings all these safety issue into focus.

Productivity and safety

Using the same methodology and steps, the safety risk was calculated for the additional scenarios shown in Table 2.

Table 2. Scenarios analyzed and summary of results

Scenario	Paver speed	Truck arrival & action	Safety risk 'Truck'	Safety risk 'Paver'	Safety risk Total
Actual	1 ft/min	2.5 min	0.80	2.80	3.60
Scenario 2	1.5 ft/min	2.5 min	0.80	6.075	6.875
Scenario 3a	1.5 ft/min	2 min & wait for worker	0.95	3.850	4.80
Scenario 3b	1.5 ft/min	2 min & no wait	2.20	2.875	5.075

Scenario 2 indicates higher safety risk due to increased risk by paver. The reason is that the greater speed of the paver results in a smaller concrete buffer in front of the paver. In Scenario 3a, trucks arrive more frequently. As a result, the safety risk increased due to increased exposure to trucks. Often the trucks arrive while the laborers are setting or fixing the dowel baskets. However, the trucks wait for the worker to guide them to position. Thus, the task demands due to trucks did not increase. In Scenario 3b, the truck arrival and paver speed are the same as in Scenario 3a but the trucks do not wait for the workers to guide them. As a result, there is increased safety risk due to trucks. The matrix in Figure 4 summarizes the productivity (paver speed) and safety risk of the different scenarios.

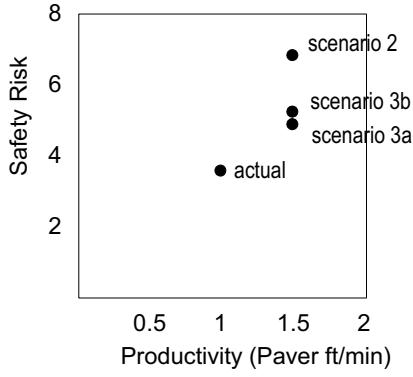


Figure 4. Productivity and safety risk for the scenarios examined

DISCUSSION

The task demand methodology provides a new way to measure the safety risk of an operation based on the operation's parameters. This enables analysis of alternative scenarios to identify ways to increase productivity and reduce the safety risk. The contributions of this method are the following:

- Quantifies the safety risk with regards to the different hazards.

- Provides a new ability to measure the safety risk based on operation parameters
- It accounts for the factors that actually affect the difficulty of the operation
- Enables simulation and comparison of operations under different production variables.

A key element of the methodology is the identification of the operation parameters affecting the task demand for each hazard. These factors were not predetermined, but were 'discovered' through observations and interviews. This leads to a deeper understanding of the operation, the key safety variables and the trade offs between productivity and safety. By identifying (1) the exposure to the hazards, and (2) the parameters that determine task demands, the task demands methodology can quantify the safety risk of other hazards (e.g., fall from elevation, struck by objects, etc.). These parameters differ depending on the hazard; for example, in the case of fall from elevation, the task demand parameters may include distance from the edge, support conditions (roof slope), action performed (e.g., moving heavy objects), etc. The method is very similar to methods for measuring ergonomic load.

The methodology also has limitations and areas of difficulty:

- The assignment of task demand values is subjective. It is recommended that this is performed with input from the crews and the supervisors.
- The task demand score for different hazards may not reflect the same probability. Thus, it may be incorrect to simply add the safety risk score for different hazards. However, the method can be used to compare the safety risk for the same hazard between variations of the operation.
- Validation using actual statistic is very unlikely. One way to validate the method's calculations is to compare them with experts' assessments.

Despite its limitations, the task demand methodology provides a useful tool that researchers and practitioners can use to measure and improve both the productivity and safety risk of an operation. The method helps the user develop better understanding of the important variables for safety and productivity. It also enables the user to evaluate how changes in production variables affect productivity and safety risk. Overall, this ability enables design of operations that increase productivity as well as eliminate, reduce, or more effectively manage the hazards.

ACKNOWLEDGEMENTS

The authors would like to thank the management and personnel of the participating crews for taking the time to explain their work. The research described in this paper is conducted with the support of NSF and the CAREER Award Grant # 0645139.

REFERENCES

Martinez, Julio C. and Ioannou Photios G. 1999, General-Purpose Systems for Effective Construction Simulation, J. Constr. Engrg. and Mgmt. **125**, 265.

Howell, G., Laufer, A., and Ballard, G. 1993. "Interaction between Subcycles: One Key to Improved Methods." J. Constr. Engrg. Mgmt. **119**, 714.

Oglesby, C. H., Parker H., & Howel, G. 1988. "Productivity improvement in Construction**"** McGraw-Hill College.

THE VALIDITY OF DATA DEPENDENT SYSTEM MODELLING TO PREDICT RELATIVE PHYSIOLOGICAL WORKLOAD DURING CONSTRUCTION WORK

Tariq Abdelhamid[1], Lili Xi[2], and John G. Everett[3]

[1]Associate Professor, 116 Human Ecology, Construction Management Program, Michigan State University, East Lansing, Mi 48824-1323, email: tariq@msu.edu

[2]Teaching Assistant, Business School, Oakland University, Rochester, Mi 48309-4401 MI 48824-1323.

[3]Senior Lecturer, 2352 G. G. Brown, Dept. Of Civil And Environmental Engineering, University Of Michigan, Ann Arbor, MI 48109-2125

ABSTRACT

The measurement of oxygen uptake during physical work activities is considered a good measure of the physiological workload experienced by construction workers. Many work physiologists advocate reporting the measured oxygen uptake as a percentage of maximum oxygen uptake, a ratio commonly known as relative workload. The main advantage of this ratio is the subject-specific workload it provides. This enables the tailoring of work demands to the ability of individual workers. Determining relative workload is arithmetically simple once maximum oxygen uptake is known. However, finding exact maximum oxygen uptake requires intricate and complicated laboratory procedures that may be dangerous for unfit individuals. Therefore, despite sacrificing accuracy, maximum oxygen uptake prediction techniques offer an attractive alternative. This paper presents a large scale validation of a maximum oxygen uptake prediction method that uses in-situ collected sub-maximal oxygen uptake data. The methodology, developed using twenty subjects and verified on eight construction workers, was based on the use of time series analysis techniques and the hypothesis that oxygen uptake data are serially dependent. The validation results using 100 subjects arrived at a ± 0.65 liter $\cdot$ min^{-1} standard error of prediction for VO_{2max}. The findings indicate that the assumptions of the original model hold but with less prediction accuracy. Improvement of the prediction accuracy will require the utilization of a multiple regression model that can incorporate more subject-specific results.

INTRODUCTION

In lean construction, similar to lean manufacturing, workflow unreliability causes downstream workers to be idle resulting waste. Workflow refers to the release of work from one production process (not activity) to another. A fluctuation in the release of work, as committed to by one production process to another, is an indication of workflow unreliability (Ballard 1999). This unreliable workflow is a result of variability stemming from single or multiple causes that need to be targeted separately or collectively.

Under a lean paradigm, variability is controlled through the use of material and plan buffers, and/or flexible capacity (Ballard and Howell 1998). Material buffers could be in the form of raw and/or processed material. Plan buffers refer mainly to having a backlog of work for crews. Flexible capacity is the third way of combating the effects of variability and refers to the ability of using a resource in multiple ways. A common example of flexible capacity is cross-trained workers. Other examples of flexible capacity can be found in Hopp and Spearman (2000). The common element between these three approaches to tackle production process variability is that they are all attempts to combat the effects of variability and not to eliminate variability altogether. Eliminating or reducing the variability that plague production processes requires the removal of the root causes of variability –a difficult but not impossible task.

While variability has many causes, in construction or other industries, it manifests itself mainly in the form of poor intra-process and inter-process performance. Intra-process performance refers to the ability of a production process to meet its ***assigned*** work. Inter-process performance refers to workflow reliability between production processes. Clearly, a poorly performing intra-process will affect inter-process performance. In turn, inter-process performance will affect overall project performance.

In the construction industry, sources of variability include late delivery of material and equipment, design errors, change orders, equipment breakdowns, tool malfunctions, improper crew utilization, labor strikes, and environmental effects. Another important indirect source of variability in construction is the physical demand of work. Physically demanding work leads to physical fatigue which in turn leads to decreased productivity and motivation, inattentiveness, poor judgment, poor quality work, job dissatisfaction, accidents, and injuries (Brouha 1967, Janaro 1982, Injury Facts 2007).

The main focus of this paper is to present a work physiology perspective on workflow reliability and propose that worker physical performance degradation is an indirect source of workflow unreliability. It is suggested that this degradation is caused by long-term physical fatigue arising from physically demanding work. Abdelhamid and Everrett (2002) have demonstrated the results of a field study, conducted on 18 randomly selected construction laborers while they were engaged in actual construction work. The results revealed that some workers routinely exceeded one or more published guidelines for acceptable levels of physiological demands. The research pointed to the need to promote concepts of work physiology at the workplace to better the occupational safety and health of the construction workforce

while simultaneously reducing performance variability and enabling lean conversion efforts.

The research findings of Abdelhamid and Everett (2002) also indicated that the use of any one physiological measurement does not present the entire story regarding the physical workload affecting an individual worker. Wide differences were noted among individual workers' response to strenuous work. Abdelhamid and Everett (2002) concluded that:

"Future research should investigate not only the absolute energy expenditure, oxygen uptake, or heart rate for individual workers, but how these values relate to the individuals' maximum values for each measure. Maximum values are difficult, if not dangerous, to measure, but would lead to a better prediction of physical fatigue."

Abdelhamid (1999) and Abdelhamid and Everett (2006) developed a new method capable of such prediction. This new prediction methodology was based on the hypothesis that oxygen uptake data are serially dependent, and that by exploiting this dependence, using time series analysis techniques, a regression model between relative workload ($\%VO_{2max}$) and a statistical characteristic of collected oxygen uptake data can be developed.

In Abdelhamid and Everett (2006), a time series-based metric called the Energy of Green's function (E_G) was found to be strongly linearly correlated to relative workload ($\%VO_{2max}$). Based on this finding, a simple linear regression model was developed using data from 20 subjects. The regression model had a standard error in predicting $\%VO_{2max}$ and VO_{2max} of $\pm 3.4\%$ and ± 0.5 liter $\cdot$ min^{-1}, respectively. Using data from five validation subjects, the standard error in predicting $\%VO_{2max}$ and VO_{2max} was $\pm 3.3\%$ and ± 0.43 liter $\cdot$ min^{-1}, respectively. The closeness of these errors to those of the regression model indicated that the mean square error of the regression equation is not seriously biased and that it provided an appropriate indication of the predictive capability of the developed regression model. The resulting regression model was named the Relative Workload Prediction (RWP) model. These initial results are quite promising and established a starting point for further investigations.

This paper presents research conducted to establish the validity of the simple linear regression model developed by Abdelhamid (1999) for a larger subject pool. The paper begins with a brief background on work physiology. A description of the experimental set-up and methods adopted to accomplish the research goal follows. Finally, the results and findings of the research are presented.

Background

Work physiology is the scientific discipline that is concerned with understanding metabolic and physiological responses to manual work. The main objective of work physiology is to make it possible for individuals to perform their work tasks without developing objective or subjective feelings of physical fatigue resulting from physiologically demanding work (Astrand and Rodahl 1986). As stated by Astrand and Rodahl (1986), the basic tasks in measuring and evaluating physiological demands of work as follows:

"A basic task for the work physiologist must be that of measuring the rate at which the work is being done, i.e., the workload, and matching this rate with the worker's ability to perform the work."

When work exceeds the ability of the worker to perform work, physical fatigue begins to set in. A decrease in performance due to physical fatigue is widely accepted, but no agreement has been reached in trying to quantify this decrease, or in setting acceptable limits for it. This disagreement is due to the fact that physical fatigue is multifaceted and may arise due to different causes. In general, physical fatigue arising from manual work is classified as long term and/or short term.

Long term fatigue is attributed to a state of disturbed homeostasis that occurs due to work and/or the work environment. Very little is known about the dynamics and nature of the disturbed homeostasis, but there is agreement that it causes subjective symptoms and objective signs of long term fatigue. Subjective symptoms may range from mild to severe feeling of exhaustion and have been observed at the end of an 8-hr workday. Objective signs of long term fatigue have been typically based on blood lactate levels, blood sugar levels, muscle glycogen, and respiratory quotient values (Astrand and Rodahl 1986).

Short term fatigue, or "local muscular fatigue", refers to decreased strength capacity of a muscle to maintain either static or dynamic muscular work. Short term fatigue attributed to static muscular exertions is investigated from a biomechanical perspective. Investigating short term fatigue arising from static muscular exertions is outside the scope of this paper and will not be addressed.

Workloads or absolute physiological workloads of work have been measured by directly measuring mean oxygen uptake and/or heart rate during the performance of actual work activities. Matching measured absolute workload with worker's ability to perform work refers to expressing mean oxygen uptake ($\dot{V}O_2$) and individual work capacity expressed as maximum oxygen uptake ($\dot{V}O_{2max}$) as a ratio, commonly known as relative workload or $\%\dot{V}O_{2max}$ (Kamon 1979, Astrand and Rodahl 1986). This percentage is especially important for occupations with intense physical demands and various demographic groups (old, young, male, and female workers) such as Construction. Christensen (1962) has concisely summarized the importance of this percentage as follows:

"The determination of oxygen uptake or caloric output and a parallel determination of maximal oxygen uptake of the worker can be valuable tools in our effort to avoid overstrain of the worker at a given job."

Once a subject's VO_{2max} is known, the determination of relative workload becomes a simple arithmetic exercise. Determining VO_{2max} is accomplished through the use of direct (exact) measurement or prediction techniques. Exact measurement of VO_{2max} is an intricate laboratory-intensive procedure making it impractical for applied research and may even be dangerous for unfit subjects. Prediction techniques offer an attractive alternative with numerous linear and non-linear regression techniques available.

Notwithstanding which method is used to determine VO_{2max}, subjects are required to participate in one or more test sessions, in addition to the data collection

session, which inconveniences and discourages many subjects from participating in the study or research. This is a real threat to the success of applied research efforts performed in real-world scenarios conducted with the intent of having higher ecological validity compared to lab tests.

As previously mentioned, Abdelhamid (1999) developed a method capable of directly predicting relative workload from in-situ collected sub-maximal oxygen uptake data without the need to determine maximum oxygen uptake. A statistical analysis technique called time series analysis was used to model oxygen uptake data. The methodology is based on the hypothesis that oxygen uptake data are serially dependent, and that by using time series analysis techniques, a regression model between relative workload and statistical characteristics of collected oxygen uptake data can be developed.

Data exhibiting serial dependence is usually analyzed using a special statistical analysis technique called time series analysis. Time series analysis is a statistical technique used to model a set of serially correlated and ordered data resulting in a special kind of regression models termed AutoRegressive Moving Average models, ARMA(p,q). A general discrete Autoregressive Moving Average model, ARMA(p,q), has a linear stochastic difference equation of the form:

$$X_t - \phi_1 X_{t-1} - \phi_2 X_{t-2} - \ldots - \phi_p X_{t-p} = a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \ldots - \theta_q a_{t-q} \qquad (1)$$

The variables p and q describe the order of the ARMA(p,q) model to be used. The value of p represents how many preceding observations does a value at time t, termed X_t, depends on, and the value of q represents how many preceding disturbances affect X_t.

Controlled laboratory experiments were performed on twenty subjects while oxygen uptake and heart rate were measured. Each subject performed three different experiments, in addition to a maximum oxygen uptake test using an exact technique termed the Harbor protocol (McArdle, Katch, and Katch, 1996). Hence, the exact relative workload for each subject could be determined at each level of effort. Time series analysis was then performed for each subject's oxygen uptake data set, and the energy of the Green's function obtained and related to the relative workload through regression analysis.

The resulting model is a special kind of regression models termed AutoRegressive Moving Average model, ARMA(p,q). After arriving at an adequate ARMA(p,q) for the observed time series, the Green's function "G_j" was derived and used to make inferences about the system that produced the data – the human body in this case. The Green's function "G_j" was the strongest candidate, because, by definition, it quantitatively summarized how a system responded to disturbances and described the system's resistance to change from equilibrium.

Using the time series analysis package ITSM 2000 version 7.0 (Brockwell and Davis 1996) on the data collected from subjects doing exercises on the treadmill, values of the Green's function were obtained and the value of E_G was determined (based on the sum of squares of the individual G_j values). The relation, shown in Figure 1, between the Energy of Green's function (E_G) and VO_{2avg}/VO_{2max} exhibited a strong correlation. It was analyzed using linear regression to formally characterize their relation and resulted in a simple regression model

$$(VO_2/VO_{2max} = 0.0936 + 0.1361(\ln(E_G)) + \varepsilon) \quad (2)$$

, where where E_G stands for the energy of the Green's function and is obtained using $E_G \cong \sum_{j=0}^{n} |G(j)|^2 ; \text{for } j = 1, 2, ..., n$

(3)

RESEARCH METHODS

The goal of this research was to validate the simple linear regression model developed in Abdelhamid (1999). To attain this goal the following are the objectives needs to be achieved:

- Measure relative physiological workload for subjects performing a specified exercise regimen.
- Reconstruct and validate the linear regression model used in Abdelhamid (1999) to predict the relative workload from sub-maximal oxygen uptake (VO_2).

For the first objective, measurements were conducted on subjects performing the same treadmill experiment protocol that was performed in Abdelhamid (1999). The VO2000 Portable Metabolic System was used to measure oxygen uptake. With this system, the subject wore a face mask and breathed ambient air. The subject also wore a chest vest on which the measuring device was mounted. The Polar Vantage XL was also used to measure heart rate. The target number of subjects for this study was set at 100 subjects.

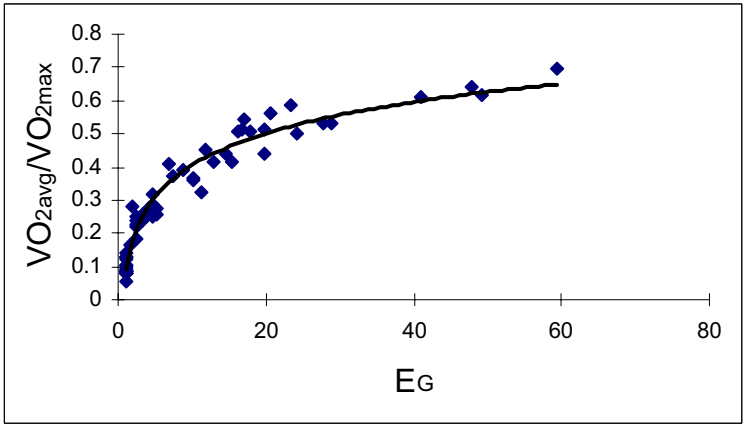


Figure 1. Energy of Green's function versus VO_{2avg}/VO_{2max}

The experimental protocol involved four sessions. All sessions were designed such that all subjects were subjected to the same work intensity. During all sessions, oxygen uptake and heart rate data were collected at 10-second intervals. The detailed description of the sessions can be found in (Xi 2005). The statistical properties of the

reconstructed model such as the SEE, coefficient of determination r-value and inferences about prediction of VO_{2max} were investigated.

RESULTS AND FINDINGS

In this research, the same experimental protocol performed in Abdelhamid (1999) was used on 100 subjects. The resulting data were analyzed to develop and validate a simple linear regression model between $\%VO_{2max}$ and the Energy of the Green's function. Descriptive physical data and exercise data for the 100 experimental and validation subjects are presented in Xi (2005). Around 80% the subjects are 24-32 years old.

Model Developments

The simple linear regression model using the relationship between the Energy of the Green's function and $\%VO_{2max}$ was used in the development of the single linear regression model using data from the 100 experimental subjects. This simple regression model is based on the relation between the Energy of the Green's function and relative workload ($\%VO_{2max}$), which is the method advocated by Abdelhamid (1999). However, in the research of Abdelhamid (1999), the relation was developed based on data for 20 subjects and validated on 5. Therefore, this research redeveloped this simple linear regression relationship on 100 experimental subjects.

Values of the Energy of the Green's function and $\%VO_{2max}$ for each experimental subject are plotted in Figure 2. As shown, the relation between the Energy of the Green's function and relative workload are strongly correlated. The solid line in Figure 2 represents the best-fit curve (logarithmic) between the Energy of the Green's function and VO_{2avg}/VO_{2max}. This verifies that a non-linear relation exists between the two variables for a larger pool of subjects.

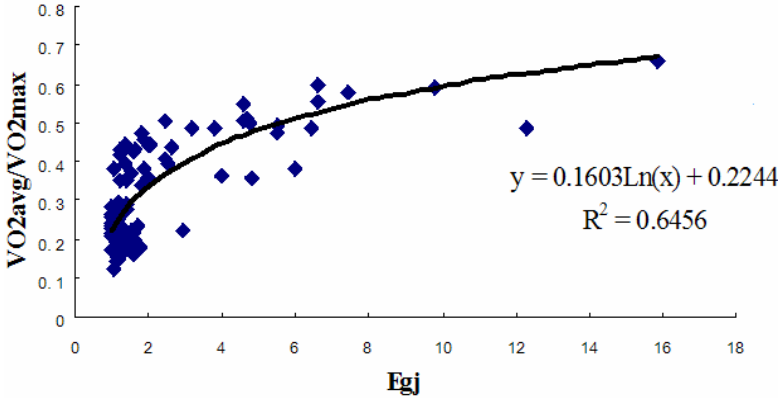


Figure 2. Energy of the Green's function and VO_{2avg}/VO_{2max}

Table 1 presents the running output from the Minitab software for the regression of $\%VO_{2max}$ based on the Energy of the Green's function. Therefore, the following single liner regression model results:

$$\%VO_{2max} = 0.224 + 0.160\ Ln(E_G) + \varepsilon \quad (4)$$

The intercept and slope for the linear regression model are estimated as 0.224 and 0.160 respectively, and standard deviation $\sigma$is estimated as ±0.076. The coefficient of determination for equation 4 is r^2=0.646 and the coefficient of correlation is r=0.80. This means that 64.6% variation in relative workload ($\%VO_{2max}$) can be explained by $Ln(E_G)$, indicating that E_G and $\%VO_{2max}$ are highly correlated.

In order to check the significance of the predictors in the model, two other reference values can be checked: t-value (T) and p-value (P). The t-value for testing the regression coefficients is obtained by dividing the estimates by their standard errors. The bigger the absolute value of the t-value, the more likely the predictor is significant. For the relation depicted here, between E_G and $\%VO_{2max}$, the t-value for the $Ln(E_G)$ was 13.70, indicating the significance of the predicator and the p-value was equal to zero, indicating that that the null hypothesis that linear regression of $\%VO_{2max}$ on $Ln(E_G)$ is of no value of predicting $\%VO_{2max}$ is rejected. This verifies that the correlation between the Energy of the Green's function and relative workload exists and is valuable. In other words, using the simple linear regression model is expected to have reasonable prediction accuracy of relative workload ($\%VO_{2max}$).

Table 1 Regression output for the $\%VO_{2max}$ by Minitab

Regression Analysis: $\%VO_{2max}$ versus $Ln(E_G)$					
$\%VO_{2max} = 0.224 + 0.160\ Ln(E_G)$					
S = 0.0760997 R-Sq = 64.6%					
Predictor	**Coef**	**SE Coef**	**T**	**P**	
Constant	0.224405	0.00968	23.18	0	
$Ln(E_G)$	0.1603	0.0117	13.7	0	
Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	1	1.0868	1.0868	187.66	0
Residual Error	103	0.5965	0.0058		
Total	104	1.6833			

Table 2 displays a sample Minitab confidence and prediction interval analysis for specific values of $Ln(E_G)$. For example, for all individuals with $Ln(E_G)$=0.06 the predicted mean $\%VO_{2max}$ is 0.23442 (practically 23%) with a standard error of

0.00923 (approximately 1%). The 95% confidence interval is (0.22,0.25). In other words, for subject with $Ln(E_G)$ at 0.06, we are 95% confident that the $\%VO_{2max}$ falls between 22% and 25%. And it is predicted with 95% confidence that the $\%VO_{2max}$ would fall between 8.24% and 38.65% for a new observation of $Ln(E_G)$ is 0.06.

Table 2. Sample of Minitab Output on CI &PI for subpopulation means

New Obs	$Ln(E_G)$	Fit	SE Fit	95% CI	95% PI
1	0.06	0.23442	0.00923	(0.21612, 0.25272)	(0.08239, 0.38645)
2	0.11	0.24218	0.0089	(0.22452, 0.25984)	(0.09022, 0.39413)
4	0.1	0.24073	0.00896	(0.22296, 0.25851)	(0.08876, 0.39270)
5	0.09	0.23852	0.00905	(0.22056, 0.25647)	(0.08653, 0.39051)
6	0.21	0.25821	0.00832	(0.24172, 0.27470)	(0.10639, 0.41004)
7	0.12	0.24431	0.00882	(0.22682, 0.26180)	(0.09237, 0.39624)

CONCLUSIONS

In this paper, time series analysis techniques were used to determine the Green's function values, from which the Energy of the Green's function was calculated as the sum of squared values of individual Green's function values. A linear regression equation was constructed between the Energy of the Green's function and relative workload ($\%VO_{2max}$). The standard error of prediction for $\%VO_{2max}$ and VO_{2max} are ±7.6% and ±0.6523 liter $\cdot$ min^{-1}, respectively. In Abdelhamid (1999), this equation was termed Relative Workload Prediction equation - RWP equation. In this paper, the reconstructed RWP for 100 subjects indicated that the regression model produces acceptable prediction values for the relative workload from sub-maximal oxygen uptake data.

Future research should consider the development of a multiple linear regression model to improve prediction accuracy by incorporating factors that better capture inter-subject variability. It is expected that a multi-regression model will improve the predication accuracy of relative workload from sub-maximal oxygen uptake data collected in-situ. One reason behind this is that the multi-regression model will include the Energy of the Green's function, which captured the responses to physical exertions quite well, and other factors that affect oxygen uptake such as age, body dimensions, and heart rate.

As demonstrated in this paper, the use of time series analysis to predict relative workload proved promising and established a foundation for more future investigations. This new technique will be valuable in identifying excessively demanding construction tasks so the work can be better matched to the abilities of subjects abilities of subjects. Further validation and development of the RWP equation is needed to assess its applicability and accuracy on an even larger population. Additional research is needed to assess the physical demands of other

types of work and investigate other aspects of occupational ergonomics as they apply to construction work.

The research points to the need to promote concepts of work physiology (and occupational ergonomics) as part of construction research. In particular, the focus of work physiology enables lean-based Work Structuring as defined in the Lean Project Delivery System (Ballard 2001). Work structuring means thinking production during the design process, with an overarching goal to make on-site work flow more reliable. This paper calls for human-oriented work structuring which will better the occupational safety and health of the construction workforce while simultaneously reducing workflow unreliability and enabling lean conversion efforts.

REFERENCES

Abdelhamid, T. S. (1999). Measuring and Evaluating Physiological Demands of Construction Work. Ph.D. Dissertation, University of Michigan, Ann Arbor, Michigan.

Abdelhamid, T. S., and Everett, J. G. (1999). Physiological demands of concrete slab placing and finishing work. Journal of Construction Engineering and Management, ASCE, 125(1), 47-52.

Abdelhamid, T. S., and Everett, J. G. (2002). "Physical demands of construction work: A source of workflow unreliability". *Proceedings of the 10th Annual Conference for Lean Construction*, 6-8 August 2002, Gramado, Brazil, 75-86.

Abdelhamid, T. S., and Everett, J. G. (2006). "Relative workload prediction using data dependent systems (DDS) modeling". *Journal of Occupational Ergonomic,* 5(4), 249-263.

Astrand, P., and Rodahl, K. (1986). Text book of work physiology, physiological bases of exercise. McGraw-Hill, New York.

Ballard, G. (1999). Improving Work Flow Reliability. *Proceedings of the 7th Conference of the International Group for Lean Construction*, Berkeley, California, USA, 26-28 July 1999.

Ballard, G. and Howell, G. (1998). What Kind of Production Is Construction? *Proceedings of the 6th Conference of the International Group for Lean Construction*, Guaruja, Brazil, August 13-15.

Ballard, G. (2000). Lean Project Delivery System. White Paper #8, Lean Construction Institute (www.leanconstruction.org).

Brockwell, P. J., and Davis, R. A. (1996). Introduction to Time Series and Forecasting. Springer-Verlag, New York.

Christensen, E. H. (1962). "Speed of Work. Ergonomics, 5(1), 7-13.

Hopp, W. J., and Spearman, M. L. (2000). *Factory Physics.* McGraw-Hill, New York.

Injury Facts (2007). National Safety Council, Itasca, Illinois.

Janaro, R. E. (1982). *The development and implementation of optimal multi-rest break scheduling models.* Ph.D. Dissertation, Florida State University, Florida.

Kamon, E. (1979). Scheduling cycles of work for hot ambient conditions. Ergonomics, 22(4), 427-439.

McArdle, W. D., Katch, F. I., and Katch, V. L. (1996). Exercise physiology. Williams & Wilkins, Baltimore.
Xi, L. (2005). Predicting Relative Workload During Construction Activities Using Multiple Regression Techniques. Masters Thesis, Michigan State University, East Lansing, MI.

CATASTROPHE RISK MANAGEMENT FOR PRIVATE-PUBLIC PARTNERSHIP (PPP) INFRASTRUCTURE PROJECTS

Qian, Qiyu[1] and Tiong Lee Kong, Robert[2]

[1]PHD student, Blk N1-B4-R5, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore, 639798; e-mail: qian0012@ntu.edu.sg
[2]Associate professor, Blk N1-01c-72, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore, 639798; e-mail: clktiong@ntu.edu.sg

Abstract
Globally, there is an increasing trend in adopting a Public-Private partnership (PPP) scheme to develop infrastructure systems. At the same time, the frequency and severity of losses from catastrophes have increased dramatically. In order to keep the infrastructure projects sustainable, catastrophe risk management as one necessary component of risk management must be taken into consideration.

Combined with the special properties of PPP projects, a pro forma cash flow model would form a useful basis for quantifying catastrophic risks and measuring the dynamic financial gap of the project. A catastrophe risk management strategy will be developed based on an in-depth understanding of the project's risk exposure, a good understanding of the timing in the needs for resources and project's internal financial capacity to retain the risk, cost tradeoffs between different types of risk financing instruments and mitigation efforts, and last but not least, layered risk-transfer portfolio setup.

1. Introduction

Catastrophe risk is a broad topic that must be viewed holistically, as it can impact many facets of society. Since the early 1990s, natural catastrophes, especially weather-related events, are increasing dramatically in number and magnitude (Munich 2007). In 2007, a total of 335 natural catastrophes led to overall economic losses of USD 64 billion across the globe. Asia, the most densely populated continent, suffered the greatest impact (Sigma 2008). Most recently, in 2008 economic losses from Sichuan earthquake and Cyclone Nargis are estimated to be US$ 73 billion and US$ 10.7 billion (ReliefWeb 2008).

Evidence indicates that, apart from the weather-related events associated with global warming and geopolitical issues related to terrorism, the frequency of catastrophes

has not increased, but the scope of social and financial impact has increased dramatically. This is mostly attributable to growing vulnerabilities, which often expand without any progress in risk mitigation or management behavior. Loss growth is largely, if not exclusively, a function of vulnerability growth.

Unsustainable urbanization is increasing the city's vulnerability because most of new growth in the Asian region has been generated by its urban economies. From 1950 to 2000, Asians lived in urban areas had increased five times to 1.22 billion and urban proportions of the total population increased from 17.1 to 34.9 percent. In the next two decades Asia will pass the threshold of having more than half their population living in urban areas. Along with the population growth, infrastructural spending also developed greatly with urbanization. For example, US$16.65 billion of direct investment will be generated in Beijing for hosting the 2008 Olympic Games. (Ryrie 2007)

It's easily to conclude that the huge catastrophe losses origin from the increasing catastrophe events as well as growing vulnerability. Since infrastructure facilities and systems are pillars supporting economic growth and sustaining the daily life of human being, it is therefore important to study catastrophe risk management of infrastructure projects.

2. Catastrophic risk of PPP infrastructure projects

2.1 Special property of PPP infrastructure projects

Since PPPs are increasingly viewed necessary as a concerted effort to respond to catastrophe risks, this paper would propose to start with analyzing infrastructure projects that are funded under PPP schemes, especially those that are utilizing the BOT financing scheme. This proposition is founded on the following factors:

Contractual obligations of both the government and the concessionaire are generally well specified in the concession contract. Risk partnership is vital for sustainable risk management of catastrophe events. All the stakeholders of the PPP projects are risk partners. The existence of these contract details provides a good basis for quantifying the expected risks and returns for each party. Moreover, in some cases, the level of tariffs that could be collected by the concessionaire is well defined (as in a Power Purchase Agreement). Clear projection of annual cash flows (or social benefits) will undoubtedly help to assess the impact of catastrophic risks.

The concession period defined in the contract serves a finite and realistic time for catastrophic risk assessment, rather than keeping the problem open-ended. The contract period (as stated in the concession contract) is at least around 20 years, sometimes may exceed 30 years. In order to compensate for the largely unknown risks involved over such a long period, the private sector will inevitably demand high risk premiums, as will the financial institutions and members of supply chains which serve them. Substantial evidence shows that it is difficult to predict the extent of risk in such projects, of inappropriate risk distribution between the pubic and private sectors and of overly optimistic businesses cases and ending up with revenues less than investment costs.

Most infrastructure projects provide low returns in the beginning of the operation

period. If catastrophe happens during this period or even in the construction period, the private sectors may ask for more compensation of the recovery of the project and more financial stress will be faced by both parties. In this case, contractual arrangement and pre-disaster financing planning would be necessary.

Since the infrastructure projects may have social, cultural and ecological impact on the region even the country, it can not be easily abandoned even after being destroyed heavily. That is to say, the recovery works must be conducted regardless of huge costs, and the complex negotiation and appropriate collaboration between different stakeholders are also needed.

2.2 Force majeure in PPP contract

In a PPP contract, catastrophe risk has no clear definition and is mainly included in force majeure risk. The term "force majeure", a phrase originating in Napoleonic law, refers to certain circumstances and events which are recognized as being above and beyond the control of contracting parties and which could not reasonably have been foreseen or avoided by the due care of either of the parties (Powell 2001). Some unexpected circumstances that occur beyond the control of a project stakeholder and prevent stakeholder from fulfilling his obligations incorporated in the contract are usually included. (Xenidis and Angelides 2005)

A force majeure event grants an extension to the completion date but does not normally provide the financial compensations due to damages resulting from the delay caused by the event to the contractors. The traditional arrangement industry-standard language goes like this: “The contractor will be entitled to extensions of time equal to delays on the Project’s critical path arising from unforeseeable causes beyond the contractor’s control and arising without the contractor’s fault or negligence.” (Shumway, Richard et al. 2004) It is important to note that not every "force majeure event" excuses performance. Force majeure provisions only provide relief when there is a specific and direct connection between the event and the impact on the performing party.(Gentile 2004)

For a PPP infrastructure project, such initiatives can be structured inherently as part of the concession contract, except for transferring the risks to the insurance sector as a default solution. This may turn out to be more cost effective, since design can be customarily modified to mitigate the risks at the early stage of the project lifecycle. Depending on the insurance loading, the subjective loss of the insured and other insurance contractual details (e.g. deductibles and maximum payment limit), it is sometimes more effective to absorb rather than transferring the risks to the insurance sector (Hoshiya, Nakamura et al. 2004). This explains the importance of contractual arrangement, but it doesn’t mean that insurance is of no use.

2.3 Summary

Catastrophic risks are not included in the typical risk analysis and management process during the course of infrastructure project development. One reason for this is the assumption that catastrophic risks, as a form of force majeure risks, can be readily transferred to the insurance industry. However, this should not be taken lightly as a

default option, since insurance cover: may not be available for certain types of catastrophes (e.g. terrorism) in some countries; available only at a very high cost, particularly during the aftermath of an event; or available but subject to various exclusions, thus rendering the purchase such coverage economically inefficient. Catastrophe risk management is important for PPP infrastructure projects.

3 Risk exposure--Catastrophe impact on cash flow of PPP infrastructure projects

The basic cash flow model of a PPP infrastructure project usually captures the following characteristic components:

- Revenue, RN (usually comes from user charges, tariffs specified in the concession contract or agreement between concessionaire and government);
- Initial engineering and construction costs, CAPEX;
- Annual operating and maintenance costs, OM;
- Major replacement and/or expansion costs, RE;
- Interest and principal payments of debt, PI;
- Taxes, TX

The impact of catastrophic risk can be superimposed onto the pro forma cash flow model and modeled as potential disruptions to the realization of this set of cash flows. In addition to the potential loss of revenues and any savings gained from non-occurring cost items during the period of disruption, there will also be recovery cost (RC) incurred during the recovery period (e.g. maintenance and rebuilt costs). Thus, the impact of catastrophe, from the concessionaire's viewpoint, can be quantified as follows:

NPV of project free cash flows to equity (FCFE) without catastrophe (NPV^0) =
-Equity drawdown+ Debt drawdown

$$+\sum_{t=0}^{a}\frac{-CAPEX_t}{(1+r_e)^t}+\sum_{t=a+1}^{T}\frac{(RN-OM-RE-PI-TX)_t}{(1+r_e)^t} \quad (1)$$

NPV of project free cash flows to equity (FCFE) with catastrophe (NPV*) =
-Equity drawdown + Debt drawdown

$$+\sum_{t=0}^{a}\frac{-CAPEX_t}{(1+r_e)^t}+\sum_{t=a+1}^{T}\frac{(RN^*-OM^*-RE^*-PI^*-TX^*)_t}{(1+r_e)^t}-\sum_{t=b}^{b+c}\frac{RC_t}{(1+r_e)^t} \quad (2)$$

Where t denotes the timing of the cash flow components;
t=a marks the end of construction period;
t=b denotes the year when catastrophe strikes;
c denotes the duration of recovery period;
t=T marks the end of the concession period;
r_e is required rate of return-on-equity.

So, financial impact due to catastrophe event= NPV^0—NPV* (3)

Obviously, different kinds of catastrophe events will result in different damages to the system. Even for the same type of catastrophe event, degree of damages varies with magnitudes changes. This may in fact lead to different recovery periods, and each scenario would bear a different impact on the cash flows of the project combined with the different vulnerability.

In Equation 2, it is assumed that the private concessionaire will shoulder the full cost of recovery RC. In practice, this is subject to the contractual terms and post-disaster negotiation. Infrastructure systems are closely linked to social and economic welfare, thus public sector may support a speedy recovery of the facility affected. Normally speaking, recovery costs will be shared between the concessionaire and government. Adjustments can be accordingly made in the cash flow model to reflect variations from the above basic assumptions.

Equation 1 and 2 are set up from the private sector's standpoint. Similar equations can be derived from the public sector's viewpoint. For example, an additional component to capture the economic value of the infrastructure component to capture the economic value of the infrastructure facility (or the loss of it after an event) may be included. (Ergonul 2005)

One should realize that Equation 2 is deterministic in which the probability of earthquake occurrence is not reflected. The temporal uncertainty of earthquake occurrence can be incorporated in an influence diagram with the annual cash flow components of Equation 2 as the input. This is illustrated in a simplified model as Figure 1 shows (take earthquake as an illustrative example), which provides more details than the one appeared in Condomin et al. (2006).

In Figure 1, the "Earthquake occurrence" variable is derived from the combination of damage state and temporal uncertainty. The "Impact" variable is based on the vulnerability assessment which attempts to quantify the level of exposure of a particular region subjected to the peril intensity and frequency. In this case, vulnerability assessment consists of "magnitude" "site-to-source distance" "type and materials of the structure" "year of construction" etc. The present value of earthquake losses would be equivalent to financial impact in Equation 3. This is related to the extent of damage, which in turn is related to spatial and magnitude uncertainty. For a simplified model, a specific magnitude may be assumed and the extent of damage/impact can be narrowed to a few discrete scenarios. More sophisticated engineering models would link the "earthquake occurrence" variable. In addition, the effects of Bayesian updating can be introduced (i.e. the future outlook of earthquake occurrence is constantly updated depending on what has happened recently). This can be achieved by introducing additional links among the "Earthquake" variables from one year to another. Alternatively, the temporal uncertainty of earthquake occurrence can be easily modeled through Monte Carlo simulation. Choice of models for damage state combined with the temporal uncertainty will determine the actual seismic impact on cash flow items.

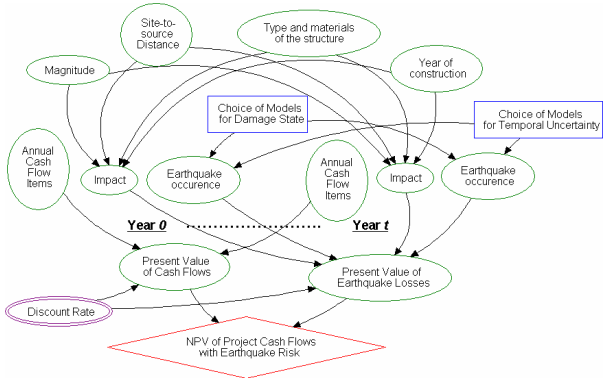


Figure 1 Influence Diagram for Analysing Financial Impact due to Earthquake

4 Risk management

The risk exposure resulted from cash flow of the PPP projects during a certain period provides basis for catastrophe risk management. It is vital to realize that catastrophe risk cannot be totally eliminated and the probability of losses cannot be reduced to zero. The mitigation measures and investment in risk financing instruments helps reduce risk, whereas, the marginal return from each dollar in investment decline with the reduction of risk. Hence, careful examination on the tradeoffs of various instruments and measurements is important.

Along with costs, a good understanding of the timing in the needs for resources is necessary for the strategy development. Combined with the internal financial capacity of the project, it is easy to obtain static liquidity gap. Both risk exposure and financial capacity vary with the different periods; therefore dynamic liquidity gap should be taken into consideration.

Benefits and cost tradeoffs of mitigation measures & financial instruments

Respective mitigation measures can cut down the potential losses effectively; however, it is hard to decide to what extent the mitigation should be because of restriction of costs. An example from Oakland shows that bracing the crippled wall and bolting pre-1940 houses to their foundation can reduce the worst case losses due to earthquakes by approximately 40% irrespective of reinsurance and/or cat bonds (Kunreuther 2001).

Catastrophe risk financing instruments can ensure availability of funds during the aftermath of catastrophic events and sustain the operations of the facility or system. However, their costs may greatly exceed expected losses, so it is important to closely examine their benefits and alternatives. Insurance and cat bond as two of the most popular risk financing mechanisms are compared as below. The principal of the combination is introduced in the following equation:

Coverage provided by (Insurance + Cat bond + Other financial instruments) = liquidity gap ─ resources needed reduced by mitigation measure;

Min [costs of (Insurance + Cat bond + Other financial instruments + Mitigation measure)]

Table 1 summarizes the difference between insurance and cat bonds in terms of their pricing and credit capacity.

Table 1 Insurance versus cat bond

	Benefits	Shortcomings
(Parametric) Insurance	Quick pay-out	Credit risk; sometimes may be uninsurable
Cat Bond	No credit risk	High costs; low liquidity

Dynamic liquidity gap

Although losses due to catastrophic events may occur in a very short time, maintenance and reconstruction operation can spread over several years. That is to say, losses may be immediate, but the resulting financing needs can spread over a very long period. In order to develop more efficient catastrophe risk financing strategy for infrastructure projects, time variable need to be incorporated into the analysis.

When comparing estimated resource needs with estimated resource available in each phase of the post disaster operation, it is easily to find out the difference between resources needed and available at a specific time in the aftermath of a potential disaster event. Table 2 shows an illustrative example. In this example, the short term resource gap is estimated at US$10 million and the long term resource gap is estimated at US$100 million in the case of a 1-in-100 year catastrophe event.

The project manager may start with the most frequent events, and gradually build up the financial capacity through risk financing strategy to an acceptable return period. Decision on this return period can be made based on the different scenarios and internal financial capacity of the project.

Table 2 Matrix of project financial vulnerability (illustrative example)

Dynamic funding gap (US$ million)			
Return period (years) of the catastrophic event	20	100	500
Short term (1-3 months)	-	10	20
Medium term (3-9 months)	-	-	50
Long term (over 9 months)	10	100	1000

The understanding of potential liquidity gap based on timing at which resources will be needed can greatly influence the design/improvement of a catastrophe risk financing strategy aimed at reducing funding gap at a given period of potential post catastrophe events. When combined with timing of financial instruments and

dynamic liquidity gap, the risk financing strategy could be developed more reasonably. Table 3 shows an illustrative example of risk financing instruments based on the availability of funds in the different post-disaster periods. The timing may vary with the financial capacity of a specific project and the economic policy of the host country.

Table 3 Availability of financial instruments over time

	Short term (1-3 months)	Medium term (3-9 months)	Long term (over 9 months)
Ex-post financing			
Government aid			
Debt/Equity issued			
Ex-ante financing			
Reserve fund			
Cat bond			
Parametric insurance			
Traditional insurance			

Layered risk-transfer portfolio

An example of a layered risk-transfer portfolio is illustrated in Figure 2. In this case, risk exposure of the project will be derived from the combination of catastrophe impact and physical vulnerability. After dynamic liquidity gap is decided, it is necessary to develop risk financing strategy to fill up the resource deficit during maintenance and rebuilding operation.

In Figure 2, the box with border in double line shows the risk financing strategy developed. The lower threshold refers to a catastrophe event of more frequency (e.g., a 1-in-10 year event) with losses of x, and the upper threshold refers to an event of less frequency (e.g., a 1-in-200 year event) with losses of y. The two thresholds are determined by the project manager, and project's internal financial capacity is one of the most important considerations. As Figure 2 shows, in the lower layer, if losses are no more than x, the risk will be shared among those stakeholders (such as decreasing the dividend, extending the repayment period, decreasing the interest rate, extending the delivery date, etc.) through contractual arrangements. When compared with dynamic financial analysis, it is easily to find out this part is usually used to fill up short term liquidity gap. In the middle layer, if losses are no more than y and more than x, insurance and cat bond (other financial instruments may be involved in future research) will be combined to transfer risk. Medium term liquidity gap is mostly bridged through this layer. The upper layer covers losses which are more than y. It may not be cost-efficient to insure or transfer through cat bond. Negotiation with government may be helpful because infrastructure as pillar of the country is important for the national economy. Long term liquidity gap is normally financed by this layer.

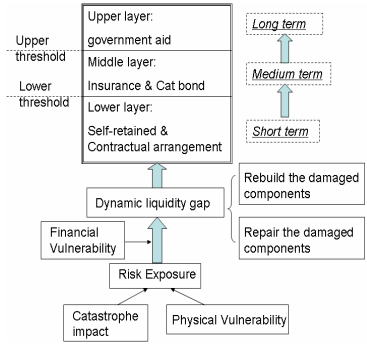


Figure 2 Layered risk-transfer portfolio

5 **Conclusions**

Catastrophe risk management of infrastructure projects is challenging for project managers and other stakeholders involved. It is not only due to the difficulty of the quantification of the exposed risk but also the restrictions of the various risk financing instruments. Except for the contractual arrangement which may ask for sharing risk among the stakeholders involved in the project, the natural reaction for the project manager is to utilize insurance. However, the growing scope of impact means that there is simply not enough insurance-based capital to provide coverage for all of those seeking protection and it may be not cost effective. Accordingly, alternative solutions must be factored into the process, including ex ante measures such as loss control/mitigation, and ex post loss financing via capital markets securitizations, and government/public funding. Based on a thorough analysis of special properties of PPP projects, this paper provided some clues for catastrophe risk management strategies development of PPP infrastructure projects. Due to the limitation of this paper, only preliminary analysis on cat bond and insurance is involved. Future research may extend to other approaches, and seek for a properly combined strategy for the infrastructure projects.

References

Condomin, L., L. J-P, et al. (2006). Risk quantification. West Sussex, John Wiley & Sons.

Ergonul, S. (2005). "A probabilistic approach for earthquake loss estimation." Structural Safety **27**: 309-321.

Gentile, M. (2004). "Terrorism - Who Bears the Risk?" Southeast Construction **4**(12): 69.

Hoshiya, M., T. Nakamura, et al. (2004). "Transfer of financial implications of seismic risk to insurance." Natural Hazards Review **5**(3): 141-146.

Kunreuther, H. (2001). "Mitigation and financial risk management for natural hazards." The Geneva papers on risk and insurance **26**(2): 277-296.

Munich, R. (2007). Risk management. 2006 Report, **:** 5-12.

Powell, K. (2001). "What is force majeure?" Heavy Construction News **45**(6): 44.

ReliefWeb (2008). China allocates 95 bln yuan for post-quake effort so far, Xinhua News Agency.

Ryrie, S. (2007). Asian Megacities & Catastrophes. 6th Conference on Catastrophe Insurance in Asia, Beijing.

Shumway, R., A. Richard, et al. (2004). "New trends and bad results in construction conracts, Part 1." Leadership and management in engineering: 93-98.

Sigma (2008). Natural catastrophes and man-made disasters in 2007: high losses in Europe, Swiss Re**:** 5.

Xenidis, Y. and D. Angelides (2005). "The legal risks in Built-Operate-Transfer projects." Journal of construction research **6**(2): 273-292.

APPLYING INSURANCE PRICING THEORY FOR PRICING ADR AS AN INSURANCE PRODUCT

Xinyi Song[1], Carol Menassa[2], Feniosky Peña-Mora[3] and Robert F. Conger[4]

[1]PhD student in Construction Management, Civil and Environmental Engineering Department, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL 61801, USA, Phone 217/819-1088, FAX 217/265-8039, xsong5@illinois.edu
[2]PhD Candidate in Construction Management, Civil and Environmental Engineering Department and Masters of Science in Finance Student, College of Business, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL 61801, USA, Phone 217/333-2071, FAX 217/265-8039, menassa2@illinois.edu
[3]Edward W. and Jane M. Gutgsell Endowed Professor of Construction Management and Information Technology, Civil and Environmental Engineering Department, University of Illinois at Urbana-Champaign, Urbana-Champaign, IL 61801, USA, Phone 217/244-0187, FAX 217/265-8039, feniosky@illinois.edu
[4]Consulting Actuary, the Tillinghast business of Towers Perrin, 71 S. Wacker Drive, Suite 2600, Chicago IL 60606, USA, Phone 404-791-9375, Fax 312-201-6333, bob.conger@towersperrin.com

ABSTRACT

As litigation is recognized as a costly and time-consuming method to resolve disputes, alternative dispute resolution (ADR) techniques are being adopted in construction projects to help handle disputes in a more effective way. However, there are potential costs related to ADR implementation as it requires expenditures to cover the expenses incurred by the owner's/contractor's employees and third party neutrals. Normally those costs are determined during the project planning phase prior to the actual occurrence of disputes. In this paper, the possibility of pricing ADR as an insurance product will be explored. It is similar to the concept of "premium" in insurance industry, although it may be structured more like a self-insurance program. The objective is to provide project participants with an economic advantage by investing a certain amount of premium in the beginning of the project in exchange for compensation from the insurance company in the uncertain event of an unknown ADR cost that may be incurred during the construction phase. Insurance pricing theory's underwriting concepts will be utilized to develop similar concepts in ADR pricing. A conceptual model will be presented to perform the ratemaking process by drawing an analogy from health insurance. An example of a construction project is used to illustrate the mathematical calculations required to determine the premium of the proposed ADR techniques.

INTRODUCTION

The construction industry in the United States plays a powerful role in sustaining economic growth. It provides job opportunities for 7.6 million people, more than 5% of the total nonfarm workforce and makes a large contribution to the gross domestic product (GDP), totaling $1.2 trillion or 9% of GDP in 2006 (AGC 2008). The intricacy and magnitude of the construction work often result in complex contract documents, which furthermore lead to complex disputes (Harmon 2003). In the construction industry, disputes are almost inevitable in each and every project due to poorly prepared and/or executed contract documents, inadequate planning, financial issues, and communication problems, etc. (Harmon 2003). The increasingly costly and time consuming court proceedings (Treacy 1995) indicate a great need in the construction industry to find a more effective method to resolve disputes.

Alternative Dispute Resolution (ADR) is a general term for a number of methods by which conflicts and disputes are resolved privately other than through litigation in the public courts (Kovach 2004). A Dispute Resolution Ladder (DRL) was proposed by Findley (1997) where a broad spectrum of ADR techniques is organized in a stepped manner. It includes six steps from the lower stage of prevention, negotiation, to middle stage of standing neutral, non binding, and finally to the upper stage of binding resolution and litigation. When disputes escalate from lower stage to upper stage, the expenses and hostility also increase (Peña Mora et al. 2003). Compared to the general dissatisfaction with litigation, the implementation of ADR has proven to be faster, more effective, less formalistic, cheaper and often less adversarial (Treacy 1995). Questionnaire results in a study by Chau (2007) show that the top two reasons for project participants in Hong Kong to experiment with mediation or adjudication in construction disputes are ”time and cost savings; desirability to continue amicable business relationship.”

As mentioned above, ADR techniques are used to overcome the ineffectiveness of litigation in providing a fast and amicable settlement of construction disputes. However, it is not without cost. Neither time nor money is infinite and the implementation of ADR requires a certain amount of each, from both the owner’s/contractor’s employee and third party neutrals (Menassa 2007). According to Gebken II and Gibson (2006), while engaging in litigation is often more costly, resolving a dispute in the construction industry is an expensive endeavor no matter which dispute resolution methodology is selected. Moreover, although ADR techniques are implemented when disputes arise during the construction phase, the decision about the budget account for management and staff time spent on dispute resolution is usually undertaken during the project planning phase. Thus, people who make managerial decisions of investing in an ADR technique in exchange for the perceived savings in the project face the uncertainty of the exact amount of ADR cost in the future. Also, a contractually-agreed dispute resolution methodology may not be the best one once disputes have arisen (Harmon 2003). If this is the case, the project will incur an even higher cost to adapt new approaches in the dispute resolution process. Given that most construction projects operate on tight budgets, how to transfer this uncertainty of an unknown potential ADR cost to a third party is the question this paper will address.

In the insurance industry, the uncertainty about whether a particular loss will occur is referred to as risk. To reduce their risk, businesses and individuals transfer the potential financial consequences of their loss exposure to an insurer by purchasing an insurance product (Myhr and Markham 2003). For example, a family purchases health insurance to cover medical costs they might incur in the future. The risk transfer process does not eliminate the possibility that a loss will occur, but it does reimburse the costs associated with that loss. In return for this transfer, an insurer receives a premium (Myhr and Markham 2003). In the construction industry, because of the uncertainty of the frequency and magnitude of disputes and the potential disruption they could cause to the project, it would be important to think about the possibility of pricing dispute resolution methods---ADR techniques as an insurance product and transferring the uncertain potential cost of ADR implementation to a third party by paying a certain amount of premium at the project planning phase and throughout the project.

PROBLEM STATEMENT

In applying the basic concepts of risk management and insurance pricing models to an ADR pricing model, this paper will focus on the following questions, while being mindful of the overriding objective of promoting ADR techniques in the most possible effective and cost saving manner.

1 Why it is useful to consider treating ADR techniques as an insurance product?
2 How can ADR be priced as an insurance product?

An analogy between general insurance products and ADR techniques may prove to be an answer to the first question and an ADR pricing model based on the insurance pricing model will be proposed later.

ADR CONSIDERED AS INSURANCE PRODUCT

In risk management process in the insurance industry, insurance products have served as both risk control and risk financing techniques. The first function is designed to eliminate or reduce the likelihood or amount of loss (Myhr and Markman 2003). For example, as part of most health insurance plans, routine visits to a doctor's office or periodic physicals provide ways to reduce the likelihood of getting sick. Similarly, keeping ADR experts on the project can help identify potential conflict items before the actual occurrence of disputes and thus provide opportunities for preventing these issues from becoming the basis of a future dispute (Gebken II and Gibson 2006). Moreover, even if disputes do occur, consultants and experts who have close association with the project would be able to quickly identify conflict resources and help keep the dispute resolution process on the lower, less contentious and less costly stages of the dispute resolution ladder.

On the other hand, as a risk financing technique, an insurance product also provides a mean to pay for losses that do occur (Myhr and Markman 2003). Again, taking health insurance as an example, the insurance company will compensate customers for their medical expenses wholly or partially, in return for payment of a specified premium. In dispute resolution, typical ADR implementation cost may include fees and expenses paid to lawyers, accountants, claims consultants and other experts; salaries and associated overhead of in-house lawyers, company managers, and other employees who have to assemble the facts, serve as witnesses and otherwise process

the dispute, etc. (Gebken II and Gibson 2006). If ADR techniques can be priced as insurance products, project participants could expect to substitute a certain expense–the premium–for a potential unknown ADR implementation cost.

In addition, we see the potential for cost savings by applying the insurance concept of In-Network/Out-of-Network Coverage to ADR implementation. Outside counsel fees account for over 62 percent of the entire transactional cost in dispute resolution and are larger than the next most costly subcategory by almost four times (Gebken II and Gibson 2006). In health insurance, coverage and cost saving are greatest when an in-network medical care provider is chosen. In the same way, parties involved in construction disputes could seek outside counsel within a network pre-agreed with the insurance company and realize project savings.

INSURANCE PRICING THEORY

The pricing methodology used in insurance industry depends significantly on the variable (product, person, organization, activity) to be priced and the statistical data available (Myhr and Markman 2003). However, the basic principles of pricing methods are common across many types of insurance. The process of determining what loss exposure will be insured, for what amount of insurance, at what price, and under what conditions is called underwriting (Myhr and Markman 2003). Underwriting is common in all forms of insurance (Merlis 2005). For example, medical insurers will charge higher premiums to old people who have a smoking habit; property insurers may offer reduced premiums for safety features such as smoke detectors.

In insurance pricing, ratemaking refers to the process by which an insurance company calculates the price it seeks to charge its customers for the insurance it provides (BISHCA 2008). The ratemaking process is challenging because the amounts of fortuitous future loss and their associated expenses are unknown when the insurance prices are developed at the beginning of an insurance contract period (Myhr and Markman 2003).

ADR pricing, analogously to insurance pricing, should take into account of the amount needed to pay potential ADR costs, and expenses as well as the targeted profits by the insurance company (which, if achieved, compensates the capital invested by the insurer in support of the process and the risk of uncertain financial outcomes that is shouldered by the insurer).

There are three categories of ratemaking methods insurers commonly use for insurance products such as medical insurance or property/casualty insurance that we have been examining as analogies for ADR: pure premium methods; loss ratio methods; and judgment methods (Myhr and Markman 2003). Pure premium methods are used to develop rates from past claims experience; loss ratio methods are used for modifying existing rates; judgment methods rely heavily on the experience and knowledge of an actuary (Myhr and Markman 2003). This paper will use a pure premium method to illustrate how one might calculate premium rates for an insurance-like approach to funding ADR in the construction industry.

Pure premium methods calculate indicated insurance rates using estimates of future claims and expenses, typically based on an examination of historical claims and expense experience, and also include a profit loading factor (Myhr and Markman

2003). The following formula uses several terms of art (Myhr and Markman 2003): Exposure units are the persons or items of property that are insured for a specified period of time; Pure premium means the amount included in the rate per exposure unit required to pay claims; Expense loadings include the insurer's acquisition and operating expenses plus premium tax and possibly loss adjustment expenses (i.e., the administrative costs of handling claims), as well as a provision for profit; Gross premium is the final premium indicated to be paid to the insurance company and equals to Pure premium plus Expense loading.

In pure premium methods,

$$\text{Gross Premium} = \text{Pure Premium} / (1\text{-Expense Loading Factor}) \quad \text{Eq. (1)}$$

where,

$$\text{Pure Premium} = \text{Loss Frequency} \times \text{Loss Severity} \quad \text{Eq. (2)}$$

and where loss frequency is the average number of claims per exposure unit, and loss severity is the average cost incurred per claim. Because insurance is a mechanism of sharing, or averaging, financial risk across a population of insured, these concepts specifically do not imply that each insured has, or is expected to have, the same number of claims per year, or that all claims involve similar costs.

AN ANALOGY BETWEEN HEALTH INSURANCE & ADR TECHNIQUES

To explain more clearly how to apply this formula to calculate the premium of ADR techniques, the process of ratemaking in health insurance is used as an analogy in this paper. There are several parallels between health insurance and ADR. First, both deal with unique objects. In health insurance, the exposure unit is individual human beings while ADR deals with individual projects. The ratemaking process in health insurance considers each customer's unique features such as age, gender and life style, etc. Similarly, the likelihood, nature and cost of disputes in construction projects is influenced by each project's unique features such as site condition, contract type and construction methods. The types of disputes that may arise, in turn would affect the implementation of ADRs. Second, both health insurance and ADR reflect various methods for addressing the underlying issue. In health insurance, there are many choices to deal with sickness, such as taking medicine, visiting a doctor's office, or visiting a hospital, and the related outcomes and medical cost may be different depending on which method the customer chooses. Similarly, in dispute resolution there are many combinations of ADR methods. Third, the results of health care, like ADR, are not guaranteed. In health insurance, despite the measurements taken and medical expense incurred, the insurer does not guarantee to completely cure the disease. Likewise, using ADR techniques does not guarantee a satisfied settlement of disputes. The implementation might escalate to litigation eventually.

Basically, health insurance provides protection against the possibility of financial loss due to health care use (Fernandez 2005). The insurance company obtains information on an applicant's current health status, medical history, and other indicators of potential future costs. Then it estimates the overall risk of healthcare expenses and develops a routine finance structure such as a monthly premium (Claxton 2008). In the ratemaking process, pure premium refers to the total amount of financial obligation due to injury and illness that the insured is expected to incur over a certain period (Chen 2004). The pure premium can be separated into two aspects: frequency and severity. Frequency is how often a loss occurs during a defined time period;

Severity is the average amount of loss (Chen 2004). In a construction project, if considering the use of ADR as analogous to an insurance claim (as ADR costs both time and money), then loss frequency is analogous to the possibility of dispute occurrence, which is also the possibility of ADR being utilized. In health insurance, loss frequency is related to each customer's unique features such as age, gender, life style, etc., and can be estimated once the insurer knows those characteristics of the insured. In construction projects, the possibility of disputes occurring and ADR being applied varies with the project characteristics, and can be estimated by knowing those characteristics of a particular project (Peña-Mora et al. 2003). Table 1 illustrates twenty-five potential sources of disputes in construction projects:

Table 1 Sources of Conflict and dispute (adopted from Peña-Mora et al. 2003)

Area	Discipline	Sources of Dispute
Organizational issues	Structure	Internal/ external organizational structure, delivery systems, inappropriate contract type, contract documents, contract terms, and law
	Process	Performance, quality, tendering pressures, payment, delays, disruption, acceleration, administration, formal communication channels, information sharing, reports, and poor communication
	People	Misunderstanding, unrealistic expectations, culture, language, communications, incompatible objectives, management, negligence, work habits, and lack of team spirit
Uncertainty	External	Change, variations, environmental concerns, social impacts, economics, political risks, weather, regulations, uncertainty, and unpredictability
	Internal	Incomplete scope definition, errors in design, unforeseen site conditions, construction methods, and workmanship

Based on past experience and statistical data, project participants should be able to identify and weight the possible indicators of dispute occurrence from the above categories. For example, an international design-build commercial building project may have higher likelihood of disputes arising from problems in communication channels (i.e., organizational-process) and changing political environment (i.e., uncertainty-external). In the model explained later, each identified source will be given a weight to show its anticipated impact on the probability of dispute occurrence. In health insurance, loss severity, or the estimated medical cost is influenced by the kind of medical service the customer is likely to seek, such as visiting a doctor's office or hospital. Different medical services result in different costs. For example, average expense per outpatient visit and average expense per hospital stay are significantly different. Similarly, the estimated cost for ADR implementation is determined by the different combinations of ADR techniques (such as DRLs) the project participants decide to incorporate into the contract documents, the likelihood of the different techniques being used, and the effectiveness and cost of these techniques. For example, in an airport project, the project participants decide to

implement a DRL which goes through an Architect/Engineer or Supervising Officer to mediation, then arbitration if the first two fail to provide a satisfactory settlement. Then the "loss severity" can be calculated as the product of the daily expense and the estimated days for dispute resolution. (Normally there is a time limit before parties escalate the dispute to the next stage.) Moreover, in health insurance, the medical service the customer first seeks might not guarantee to cure the disease. For example, patients infected with an influenza that cannot be cured in a clinic may later be hospitalized. In dispute resolution, the first step of the contractual DRL might not achieve a satisfactory settlement. Thus, the ADR cost may escalate as the resolution process is brought to a higher stage. This further illustrates the merits of considering managing ADR techniques through an insurance product that transfers some of the risk to the insurance company.

INSURANCE PRICING MODEL

The application of the insurance pure premium pricing model to ADR is illustrated in this section through two simplified examples. The figures used in the examples are totally hypothetical, significantly over-simplified and are only used for explanation.

Suppose that Mike wants to purchase private heath insurance for himself. The insurer, based on Mike's characteristics (40-year old, male, using tobacco regularly), estimates that he has a 10% chance of becoming severely ill during a policy period of one year. Based on past experience of similar people, the insurer estimates that the average healthcare expenses per illness will be $10,000. In this case, the estimated Loss Frequency (LF) for insureds similar to Mike is 10%, Loss Severity (LS) is $10,000. Thus according to Equation (2), the estimated Pure Premium (PP) is: $10,000 X 10%= $ 1,000. For our representative health insurance company, add an Expense Loading Factor (ELF) of 20% to cover the expenses and the target profits. Then according to Equation (1), the indicated Gross Premium (GP) is: $ 1,000/ (1-0.20) =$ 1,000/0.80= $ 1250. Thus, $ 1250 is the premium the insurance company calculates to be an appropriate price for Mike to pay for his health insurance[1].

In ADR for construction projects, the ratemaking process could be similar. For example, a homebuilder is considering constructing three new houses in a local subdivision. Assume that we have identified four sources of conflicts and evaluated them using a 0~1 rating system (Table 2) to weight the loss frequency based on the past experience of this builder, the past experience of other builders, and the project characteristics. Here, Loss Frequency refers to the probability of dispute occurrence P(c) during the project. (The use of a maximum value of 1.0 in Table 2 corresponds to the highest frequency dispute type occurs on average per contract period.)

Table 2 Loss Frequency Rating System (adapted from Peña-Mora et al. 2003)

Very low	Low	Medium-Low	Medium	Medium-High	High	Very high
≈0	0.1	0.25	0.5	0.75	0.9	≈1

[1] The actual price charged for insurance may, and often does differ from the indicated price due, for example, to competitive pressures in the marketplace, legal and regulatory constraints, insurer objectives of growth and customer retention. And, the customer may choose not to pay the price quoted by the insurance company, instead choosing different coverage, a different insurance company, or no insurance at all.

Suppose that the builder is considering including a DRL in the contract document. In this DRL, once the dispute occurs, it goes through Architect/Engineer or Supervising Officer (ADR1) to mediation (ADR2), then arbitration (ADR3) if the first two fail to provide a satisfactory settlement. Then the "loss severity" is the product of the daily expense and the estimated days for dispute resolution. More specifically, when the dispute resolution process starts, the dispute is first turned to Architect/Engineer or Supervising Officer. To cover this expense, assume for this illustrative calculation that the unit cost is $ 500 per day for this step. If the initial attempt fails to achieve the settlement within the maximum allowable time, the dispute escalates to the next level with mediation between the owner and contractor representative; assume the cost at this level also is at a unit cost of $500 per day. Additionally, if the dispute is not resolved at the previous levels, it is turned to the final step of arbitration. Assume for this illustration that the cost at this level is $1000 per day. The builder then evaluates the impact of each source of conflict based the estimated duration of each dispute resolution process. As the builder lists various sources of conflicts and relates the probability that they will occur and the impact of each, he/ she develops a combined risk exposure table like Table 3.

Table 3 General Conflict Exposure

Sources of Conflicts	Probability of Occurrence P(ci)	Duration of dispute resolution process (days)			Expected total cost of ADR implementation i(ci)
		ADR1	ADR2	ADR3	
Miscommunication	High (0.9)	20	-	-	$10,000
Performance/ Quality	High (0.9)	20	20	-	$20,000
Management	Med (0.5)	30	20	-	$25,000
Contract type	Low (0.1)	30	20	20	$45,000

From this analysis, the builder and the insurance company are able to get a sense about the level for the estimated premium. According to Equation (2), the estimated pure premium (PP) is:

$$PP = \sum_{i=1}^{4} P(ci) \times i(ci) = 0.9 \times 10{,}000 + 0.9 \times 20{,}000 + 0.5 \times 25{,}000 + 0.1 \times 45{,}000$$
$$= \$44{,}000$$

Add an Expense Loading Factor (ELF) of 20% (illustrative value, assumed for this example) to cover the expenses and the target profits of the insurance company, and then according to Equation (1), the Gross Premium (GP) should be: $ 44,000/ (1-0.20) =$ 44,000/0.80= $ 55,000. Thus, $ 55,000 is the indicated premium for the builder needed to pay the insurance company for his ADR implementation insurance. (As noted earlier, actual premiums in the marketplace may vary.)

CONCLUSIONS

The objective of this paper was to explore the possibility of transferring the potential cost of construction project ADR implementation to a third party. It appears that there are both risk management and risk financing benefits potentially available to builders if such a process can be devised. The risk is susceptible to analytical risk

transfer pricing techniques similar to those used in pricing traditional insurance coverages such as health insurance, specifically pure premium methodologies. Given the relatively simple example, the model proposed in this paper is by no means an encompassing system for ADR pricing. While the approach illustrated in this paper is easy to understand and apply, it is likely that much more sophisticated pricing structures will be needed in practice to reflect the wide variations of construction projects, parties, disputes, and the dispute resolution processes.

For future research, more data must be collected regarding construction projects, and dispute resolution, particular the frequency and cost of relevant events. Additional data will allow for analyses that are more detailed and relevant, while remaining practical. In addition, future research should attempt to perfect the model in a more systematical way. While this paper provided a framework of the pricing method, the details of how to use it directly in a construction project still need more work.

To next generation of pricing model for ADR might contain four modules: Information, Modeling, Results and Decision. Information includes the input of exposure data such as project location, engineering characteristics, contract type, etc. and policy information such as coverage value, deductible, limits. Then all the information will go through the Modeling process producing the Results of indicated Gross Premium. Finally, the calculated Gross Premium enters a decision making module in which the participants may consider the marketplace conditions regarding actual premiums, the effects of any risk management programs on the dispute frequency or cost, and the other financing alternatives available to the participants. If the marketplace allows for a fair profit, the insurance company may be willing to sell the product in the marketplace. If the risk transfer allows for a useful reduction of the builder's risk and the marketplace allows for a reasonable premium level, the builder may also be interested in paying a premium to transfer that risk to an insurer.

REFERENCES

Associated General Contractors of America (2008). "Foreward to the 2007 CFMA Construction Industry Annual Financial Survey." AGC, <http://www.agc.org/galleries/econ/ ConstructionDataandSources.pdf> (May 5, 2008).

Associated General Contractors of America (2000). "Enlightened Risk Allocation – The 21st Century Owner's Guide to Cost Effectiveness." AGC, <http://www.agc.org/> (Jan. 15, 2006).

D'Arcy S. P. and Gorvett R. W. (1998) "A Comparison of Property/Casualty Insurance Financial Pricing Models." Proc. Casualty Actuarial Society - Arlington, Virginia: LXXXV,1-88, <http://www.casact.org/pubs/proceed/proceed98/980001.pdf> (Aug 22, 2007)

Department of Banking, Insurance, Securities & Health Care Administration of Vermont (2008). "Medical Malpractice Issues and Insurance Study." BISHCA, < http://www.bishca.state.vt.us/InsurDiv/medmal_studygroup/Sept29meeting/milliman_exh2.pdf > (Jul 22, 2008)

Chen, T. (2004). "Pricing Private Health Insurance Products in China" IAAHS Online Journal. Issue 2004/1-30 June 2004. <http://www.actuaries.org/IAAHS/Colloquia/Dresden/Tao%20paper.pdf> (May 15, 2008)

Claxton, G. (2008). "How Private Insurance Works: A Primer." Institution for Health Care Research and Policy, Georgetown University, on behalf of the Henry J. Kaiser Family Foundation<http://www.kff.org/insurance/upload/How-Private-Insurance-Works-A-Primer-Report.pdf > (Jan 22, 2008)

Fernandez,B. (2005) "Health Insurance: A Primer." Congressional Research Service Report for Congress. February 3, <http://www.law.umaryland.edu/marshall/crsreports/crsdocuments/RL3223702032 005.pdf > (Jan 12, 2008)

Findley, D. (1997). "Construction Claims Preparation under ADR." AACE International Transactions C&C.01.1-C&C.01.4

Gebken II, R. J. and Gibson, G. E. (2006) "Quantification of costs for dispute resolution procedures in the construction industry." J. Professional Issues in Eng. Education and Practice, 132(3), July, 264-271

Harmon, K. (2003). "Resolution of Construction Disputes: A Review of Current Methodologies." J. Leadership and Management in Engineering, ASCE, 3(4), 187-201.

Kovach, K. K. (2004). "Mediation: Principles and Practice." Thomson West, St. Paul, MN.

Menassa, C. and Peña-Mora, F. (2007) "An Option Pricing Model to Evaluate ADR Investments in AEC Construction Projects under Different Scenarios." Proceeding of the 2007 ASCE International Workshop on Computing in Civil Engineering. July 24–27, 2007, Pittsburgh, Pennsylvania, USA.

Merlis, M. (2005). "Fundamentals of Underwriting in the Nongroup Health Insurance Market: Access to Coverage and Options for Reform". The National Health Policy Forum Background Paper. April 13, 2005.<http://www.nhpf.org/pdfs_bp/BP_Underwriting_04-13-05.pdf >

Mhyr ,A. E. and Markham J. J. (2003). "Insurance Operations, Regulation, and Statutory Accounting." American Inst. Chartered Property Casualty Underwriters (AICPCU)/Insurance Institute of America, Pennsylvania. Second Edition.

Peña-Mora, F., Sosa, C., and McCone, D. (2003). "Introduction to Construction Dispute Resolution." Prentice Hall, New Jersey.

Treacy, T. (1995). "Use of Alternative Dispute Resolution in the Construction Industry." Journal of Management in Engineering, ASCE, 11 (1), 58-63.

A PREDICTION MODEL FOR CONSTRUCTION PROJECT TIME CONTINGENCY

Dalia Mohamed[1], Florida Srour[1], Wael Tabra[1], and Tarek Zayed[2]

[1] M.A.Sc. Student, Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada.
[2] Associate Professor, Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec, Canada.

ABSTRACT

Construction projects often suffer from high level of uncertainty in many fronts: time, cost, quality, safety, etc. Most of the conducted research focuses on estimating cost contingency. Even though construction project scheduling has received extensive attention of researchers, time contingency was not treated well in the literature. In order to meet the deadline of a project, an accurate scheduling should be sought. Due to the nature of construction projects, scheduling should be flexible enough to accommodate changes without negatively affecting the overall duration of the project. As such, the objectives of the research presented in this paper are to assess the factors that affect scheduling contingency and to develop a simple model that can be used in estimating the expected time contingency of a construction project. A survey was conducted on sixteen construction companies in Montréal, Québec, Canada. The data obtained from the survey was then processed using Analytic Hierarchy Processes (AHP) to develop a time contingency model. Results show that the predicted time contingency matches with 87% the estimated contingency for real projects. The developed time contingency model showed robust results.

INTRODUCTION

The main goals of any successful construction project management system(s) are to complete the project on time, within the planned budget, and with the required quality limits. The three goals are inter-related where each of them is affecting, and being affected by, the others. In order to meet the time deadline of a project, an accurate scheduling should be sought. Due to the unique nature of construction projects, time contingency and project uncertainty are essential for accurate scheduling, which should be flexible enough to accommodate changes without negatively affecting the overall duration of the project. It is essential to allocate a contingency value to both cost and time (Touran, 2003). Yet, there are situations where there could be delays in activities that result in a delay in the overall project duration. These delays will

consequently have a negative impact on the quality and budget of the project. Therefore, estimating time contingency is seen as a major factor for achieving a successful construction project. Although several industrial sectors developed and used software for estimating time and cost contingencies in order to minimize delays and over budget, yet limited efforts are reported in the literature in the area of predicting time contingency in the construction sector. Therefore, the objective of the presented research in this paper is to identify the factors that affect schedule (time) contingency and develop a model that predicts the expected contingency of a construction project.

LITERATURE REVIEW

There is no standard definition of contingency in which it could mean different meanings to different estimators, contractors, and owners' organizations (Moselhi, 1997). Contingency is probably the most misunderstood, misinterpreted, and misapplied word in project execution (Patrascu, 1988). It is an amount of money or time (or other resources) added to the base estimated amount to achieve a specific confidence level or allow for changes where experience shows obligation (AACE, 2000). It can also be defined as the budget that is set aside to cope with uncertainties during construction (Touran, 2003) or the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to an acceptable level to the organization (PMI, 2000). Treasury (1993) identified two major categories of contingency for construction projects:

(i) *Design Contingency* – it addresses the changes during the design process for factors, such as incomplete scope definition and inaccuracy of estimating methods and data (Clark & Lorenzoni, 1996).
(ii) *Construction Contingency* – it addresses the changes during the construction process. Under a traditional procurement arrangement, the contract typically contains a variation clause(s) to allow for changes and provide a mechanism for determining and valuing variations (Staugas, 1995).

There are many definitions for contingency in the literature; most of them focused on cost contingency. Contingency has different meanings to different people. Despite its importance, estimating time contingency was not thoroughly addressed in the literature. Prior to reviewing the estimating methods for project contingency, there are different attributes that affect contingency. Yer and Jha (2006) identified 55 factors affecting the performance of the project schedule. They observed seven factors that have the most significant impact on the schedule outcome and divide them into two main categories. The first include factors that posses the capability to improve performance level, such as owner's competence as well as commitment and conflict among project members. The second include factors that tend to retain the schedule at its existing level, such as coordination among project members, lack of knowledge and skills for the project managers, hostile socioeconomic environment, and uncertainty of project members. In addition, Touran (2003) indicated that the effect of change orders increased the original cost and schedule since they modified the original contract.

There are many factors that impact time contingency. Sukumaran *et al.* (2006) stated that it was not only important to identify the factors but evaluate their impact on the project duration as well. They developed a model in highway work zones that

identified different factors, which influence the construction schedule. Most engineers, planners, and agencies depend on their experience to estimate cost and time contingency (AbouRizk 2005, Touran 2003). The contractor's contingency was represented as a fixed percentage of the contract value (Smith, and Bohn, 1999) or as a percentage of total project cost or duration (Touran 2003). Smith and Bohn (1999) estimated the contingency as 5-10% of the contract value. On the other hand, Touran (2003) estimated two values of cost contingency: (1) 15% for underground construction activities and tunneling and (2) 7.5% for the rest of the project. Time contingency has been used to assure the completion time of a project and provide a degree of confidence that the planned duration can be accomplished successfully (Park, and Peña-Mora 2004, Mulholland and Christian 1999). The completion date of a project was often missed due to uncertain events, which their impacts were difficult to predict because of the uniqueness of construction projects (Thompson and Perry 1992). Kanoglu (2003) stated that overruns of the project time is common in the construction projects. Despite this fact, the construction industry did not recognize the criticality of the problem. Arif (2005) studied an alternative way to estimate the contingency by using other methodologies, such as correlation, regression analysis, and neural networks. Park and Peña-Mora (2004) estimated time contingency as 20% of the project duration. AbouRizk and Boskers (2005) presented a methodology that incorporates network analysis and duration uncertainty in project time analysis. They studied the effect of various factors on time contingency using a linear equation. Illsley (2006) stated that in the industrial sector, there are several project scheduling software such as Primavera and Microsoft Project; however, the most popular is Risk Expert. This is because it provides quantitative and qualitative analyses of project information, which is used to give a clearer picture of the true cost and time scale of any project considering risk, penalties, and complex scheduling variables.

RESEARCH METHODOLOGY

Factors that affect time contingency were identified through literature review as shown in Figure 1. A survey was conduct to collect the impact of each factor on time contingency. The research methodology was performed using two different approaches: deterministic and stochastic. In the deterministic approach, the impact and likelihood for each factor were obtained from the survey results. Using the AHP method, the weight of each factor was obtained and time contingency can be determined. The stochastic approach is not presented in this paper because of size limitations. The developed deterministic AHP model was validated and a sensitivity analysis was conducted to determine the effect of these factors on time contingency.

FACTORS AFFECTING TIME CONTINGENCY

Based on literature and practitioners, several factors that are thought to have a direct effect on time contingency were determined. These factors were divided into three major categories: project, management, and environmental conditions. Table 1 shows the description of these categories and factors.

DATA COLLECTION

A survey was developed in the form of a questionnaire to collect project data from Montréal contractors. The questionnaire was designed using the significant factors identified from the literature as shown in Table 1. The factors were identified by analyzing several research works, such as Moselhi (1993), COBRA (2004), Method

Engineering (1996), COBRA (2006), www.interface-consulting.com, and Iyer and Jha (2006). The questionnaire included three parts. Part one included the respondent person general information: years of experience, total value of completed works, type of company partnership, type of the projects, project duration. In part two, a comparison between criteria and sub-criteria was developed to obtain the ratio among parameters of time contingency.

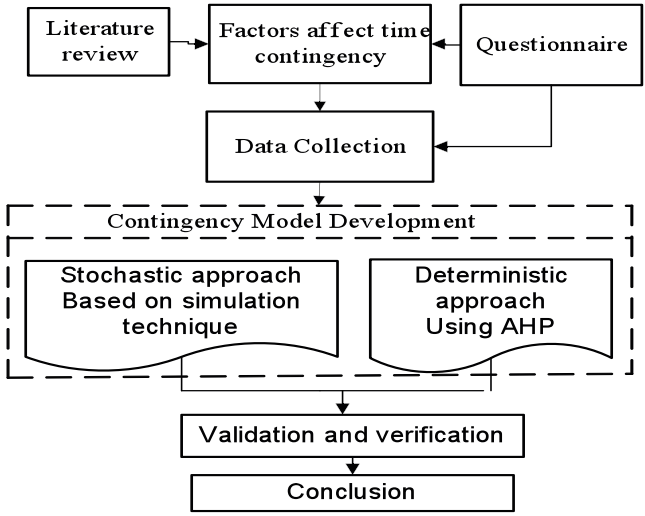


Figure 1. Research methodology

Part three included 13 questions mainly regarding the impact of factors on time contingency. In order to facilitate the answers for the reviewers, a scale consisting of numbers from 1-9 is used in which 1 means extremely ineffective and 9 means extremely effective. Physical and telephone interviews, with senior managers of sixteen construction management teams, were conducted. The construction projects were located in Montréal, Quebec, Canada. The surveyed companies had an experience history ranged from 3 to 60 years. They worked in variety of projects, such as buildings, hospitals, university, and bridges' rehabilitation. The budget values of these projects ranged from $25 to $500 Million Canadian dollars and the duration ranged from 6 months to 3 years.

DEVELOPMENT OF TIME CONTINGENCY MODEL

Analytic hierarchy process (AHP) has been widely used and applied in different fields of theory and practice (Al-Barqawi, 2006; Saaty, 1982 & 1991). It has been applied in multi-criteria decision making, planning and resource allocation, conflict resolution, and prediction problems (Saaty, 1982 & 1991). Therefore, the AHP is used in the presented research to assess the weights of various factors that affect time contingency through pair-wise comparison matrices. These matrices have several important characteristics as shown in Table 2.

Table 1. Factors Affecting Time Contingency

Criteria	Factor	Description
Project Conditions	Project Location	Location may influence the amount of risk and therefore the level of contingency.
	Project size (Design complexity)	It affects planned schedules negatively. In the large projects there are many various activities that required many different resources and involved many parties. All of these variables are interfering together which may cause delay in the project duration.
	Equipments availability (Construction technology)	Technology requirements comprising of method of construction "equipments" Issue of renting equipments, damages that may occur will increase contingency.
	Material availability (Market)	This factor is related to the site condition and storage area. Transport material from the supplier to the site is time consuming which required a prior arrangement.
Management Conditions	Amount of interference (Skills)	Any project could have stop work order because of the owner or engineer interference, this is happened due to lack of knowledge and experience from all the participants. If the amount of interference increased the delay of schedule will be increase until they make their decision.
	Number of change orders	Change of orders or extra work order usually requires long process of redesigning or modifying specification. In addition the extra work may force the contractor to accelerate work which could cause loss of the labour productivity and then caused the delay.
	Payments (Delays)	Any delay of payment may cause delay of supplying resource to the project which will affect the planned schedule.
	Time to make a decision	Owner is the main responsible in this case until he/she makes the decision of change or not. The contractor should record this delay against the owner in case of claim.
	Productivity of labor and equipments	Losing of labor productivity that caused by acceleration or extra work will affect the project schedule. Any damage of equipment will cause serious delay on the current activity consequently causes delay in project schedule.
Environmental Conditions	Weather condition	Weather in some countries has the highest impact on the schedule delay.
	Soil condition	Some unforeseen soil conditions in the site cause delay in the schedule.
	Labor strike	This stoppage will cause delay in project schedule.
	Shortage of human resources	Some unforeseen events like work accident, sickness, social, psychological and other unpredicted event may cause labor pain, or absenteeism. Hence, this factor will cause delay in the activity and schedule.

Table 2. Typical Pair-Wise Comparison Matrix for Different Factors

Factors	a_1	a_2	a_3	a_4
a_1	1	a_{12}	a_{13}	a_{14}
a_2	a_{21}	1	a_{23}	a_{24}
a_3	a_{31}	a_{32}	1	a_{34}
a_4	a_{41}	a_{42}	a_{43}	1

$a_{11,}$ i =1, j = 1

1. The diagonal elements are all equal to one because they represent the comparison of a criterion against itself.
2. The lower triangle values are the reciprocal of the upper triangular values (i.e. $a_{ij} = 1/a_{ji}$).
3. All numbers in the matrix are positive.
4. Square matrix (i.e. number of rows equal to number of columns)

The weight of each factor is determined using Equation (1) as follows:

$$W_x = \sum_{j=1}^{j=n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \Big/ \qquad (1)$$

Where, a_{ij} represents the matrix elements for i row and j column; n represents the pair-wise comparison matrix dimension; and W_x represents the weight of factor x.

After determining the weights of each factor in the hierarchy, the time contingency (C_D) is developed using the model shown in Equation (2):

$$C_D = \sum_{i=1}^{n} W_i * S_i * P_i \qquad (2)$$

Where, W_i represents the general weight of factor i; S_i represents the score of each factor in a specific project; P_i represents the probability of occurrence of factor I; and C_D is the time contingency.

TIME CONTINGENCY MODEL IMPLEMENTATION

The following are the steps that were used to develop time contingency model using the collected data.

1- Determine the relative weight of each major category; i.e. project conditions, management conditions and environmental conditions.
2- Determine the weights (W_i) of the sub factors relative to the weight of its category.
3- Calculate the factors score (S_i) for each of the thirteen factors (using a 1 - 9 scale) in which one represents the most ineffective and nine represents the most effective to the contingency value.
4- Calculate the Probability of occurrence average (P_i) for each of the thirteen factors.
5- Multiply the three values $W_i * S_i * P_i$.
6- Sum all the values of multiplication, which constitute the time contingency value C_D.

After implementing the abovementioned steps to the collected data, Table 3 shows the weights and relative weights of categories and factors, respectively. In addition, it shows the time contingency calculation based upon average values of scores and probabilities. It also shows that time contingency represents 36.78% of project duration. Therefore, the time estimator has to consider almost 36% increase in project duration due to the effect of the contingency factors. This value accounts for the occurrence of all factors; however, the case might be different if only few of them are expected to occur. In this case, the contingency value might be lower.

Sensitivity Analysis

Sensitivity analysis was performed to determine the most sensitive factors that affect time contingency rate using @Risk software. The sensitivity analysis was done based on the change in percentile of distributions 1%, 5%, 25%, 50%, 75%, 95% and 99%. After the analysis was done, the factors were put in order of their effect on time contingency as shown in Figure 2. It is clear from the chart that materials availability factor is the most sensitive factor, followed by project size and 3 resource availability. Therefore, the developed model proved to be sensitive to all considered factors.

Table 3. Time Contingency Calculation

Criteria	Weights	Factors	Weights	Relative Weights (W_i)	Score (S_i)	Probability (P_i)	Time Contingency (C_D)
Project Conditions	0.3238	Size	0.2348	0.0760	0.638	0.533	0.0258
		Location	0.2198	0.0712	0.613	0.542	0.0237
		Equipment availability	0.2749	0.0890	0.750	0.550	0.0367
		Materials availability	0.2704	0.0876	0.750	0.583	0.0383
Management Conditions	0.3673	Amount of interferences	0.1841	0.0676	0.775	0.567	0.0297
		Number of change orders	0.1601	0.0588	0.656	0.675	0.0260
		Time required for decisions	0.1642	0.0603	0.600	0.600	0.0217
		Payments (delays)	0.1773	0.0651	0.750	0.458	0.0224
		Equipments condition	0.1428	0.0525	0.520	0.400	0.0109
		Productivity uncertainty	0.1714	0.0630	0.700	0.617	0.0272
Enviro ument	0.3089	Soil condition	0.2209	0.0682	0.613	0.592	0.0247

		Weather conditions	0.2644	0.0817	0.738	0.533	0.0321
		Strike	0.2644	0.0817	0.738	0.267	0.0161
		Site shortage of resources	0.2503	0.0773	0.700	0.600	0.0325
$C_D = \sum_{i=1}^{n} W_i * S_i * P_i$							**0.3678**

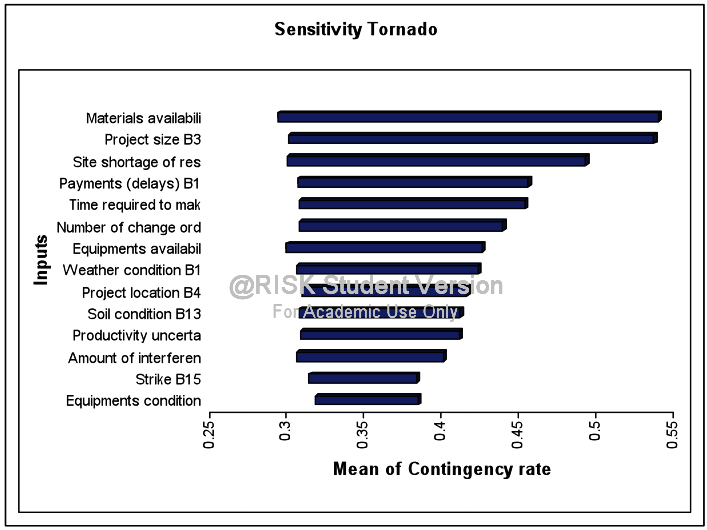


Figure 2. Sensitivity Analysis for Time Contingency Model

MODEL VERIFICATION

In order to check the accuracy of estimated average time contingency (0.3678), data were collected from experts through telephone calls regarding the actual delays in their previous projects, which include the starting and planned finish dates in addition to actual dates. Delays for the project, in months, were calculated by subtracting the planned from actual finish dates, then, divide this delay over the planned project duration to obtain time contingency. Table 4 includes the collected data and its analysis for seven projects. It is noticed that time contingency ranged from 0.167 to 0.778 out of project duration. Thus, the average time contingency of the seven projects is 35.4%, which is close to the value obtained from the developed model. Based on Zayed and Halpin (2005), two equations are used to verify the developed time contingency model as shown in Equations (3) and (4).

$$AIP = \{\sum_{i=1}^{n} 1 - (E_i/C_i)\}/n * 100 \quad (3)$$

$$AVP = 100 - AIP \quad (4)$$

Where, AIP = Average Invalidity Percent
AVP = Average Validity Percent
E*i* = Estimated/Predicted Value
C*i* = Actual Value

Applying these equations to the collected cases shows that AIP = 0.127 and AVP = 0.87. The values of AIP and AVP show that the developed model is robust in predicting the values of time contingency.

Table 4. Delay and Contingency Analysis for Several Construction Projects

Project	Start date	Scheduled end date	Actual end date	Planned project duration	Delays in months	Contingency
1	Aug-06	Feb-07	Mar-07	6	1	1/6=0.167
2	Sep-04	May-05	July-05	8	2	2/8=0.200
3	Aug-05	April-07	Sep-07	20	5	5/20=0.250
4	Feb-05	Feb-07	Aug-07	24	6	6/24=0.250
5	July-03	Oct-04	Mar-05	15	5	5/15=0.330
6	Feb-02	Feb-04	Feb-05	24	12	12/24=0.500
7	Sep-01	Mar-03	May-04	32	14	14/32=0.0.778
Average						**0.354**

SUMMARY AND CONCLUSIONS

Estimating scheduling (time) contingency is a major factor in achieving a successful schedule for construction projects. In this research, a survey was conducted on many construction companies to assess the factors that affect time contingency. The data obtained from the survey was then processed using Analytic Hierarchy Process (AHP) in order to evaluate the weight of each factor and estimate the time contingency value. The results show that the average time contingency value is estimated as 36.78%. The developed model is verified using seven cases studies, which shows robust results (87%). This value shows that the obtained results are fairly good and acceptable.

REFERENCES

AACE (American Association of Cost Engineers) (2000). "AACE International's Risk Management Dictionary," Cost Engineering, 42(4), pp. 28-31

Al Barqawi, H. A. (2006). "Condition Rating Models for Underground Infrastructure: Sustainable Water Mains," M.A.Sc. thesis, Concordia University, Montreal, Quebec.

Brinkkemper, S., Lyytinen, K., and Welke, R. (1996). "Method Engineering: Principles of Method Construction and Tool Support," Kluwer Academic Publishers, MA, USA.

COBRA (2006). "The construction and Building Research," Conference of the Royal Institution of Chartered Surveyors, University College London, September 7-8.
Clark, F. and Lorenzoni, A. (1996). "Applied Cost Engineering," M. Dekker, CRC; 3rd edition, New York, USA.
Dikmen, I., Birgonul, M., and Kiziltas, S. (2005). "Prediction of Organizational Effectiveness in Construction Companies," J. of Construction Engineering and Management, ASCE, February, 131(2), pp. 252-261.
Illsley, R. (2006). "Business Intelligence Pretmaster," Risk Expert, v7.8, Butler Group Subscription Services, New Jersey, USA.
Interface Consulting International Inc. (2007). "Interpreting Force Majeure in the Wake of Disaster," <www.interface-consulting.com> (Surfed in November 2007)
Iyer, K., and Jha, K. (2006). "Critical Factors Affecting Schedule Performance: Evidence from Indian Construction Projects," J. of Construction Engineering and Management, ASCE, August, 132(8), pp. 871-881.
Kanoglu, A. (2003). "An Integrated System for Duration Estimation in Design/Build Projects and Organizations," J. of Engineering, Construction and Architecture Management, Emerald Group Publishing Limited, 10(4), pp. 272-282.
Moselhi, O. (1993). "Applied Earned Value for Project Control," CIB W-65 conference Proceedings, Trinidad, WI, USA.
Moselhi, O. (1997). "Risk Assessment and Contingency Estimating", Transactions of the American Association of Cost Engineers, 41, A.06.1.
Park, M., and Peña-Mora, F. (2004). "Reliability Buffering for Construction Projects," J. of Construction Engineering and Management, ASCE, September/October, 130(5), pp. 626–637.
Patrascu, A. (1988). "Construction Cost Engineering Handbook," M. Dekker, New York, USA.
Saaty, T. (1982). "Decision Making for Leaders: The Analytic Hierarchy Process for Decision in a Complex World." Lifetime Learning Publications, Belmont, California, USA.
Saaty, T. (1991). " Decision Making with Dependence and Feedback: The Analytic Network Process." RWS Publications, Pittsburgh, PA, USA.
Staugus, J, (1995). "Variations, Building and Construction Law," 11(3), 156-158.
Sukumaran, P., Bayraktar, M.E., Hong, TH., and Hastak, M. (2006). "Model for Analysis of Factors Affecting Construction Schedule in Highway Work Zones," J. of Transportation Engineering, ASCE, June, 132(6), pp. 508-517.
PMI (2000). "A Guide to the Project Management of Knowledge (PMBOK Guide)," Project Management Institute, PA, USA.
Treasury, H. (1993). "CUP Guidance: No.41–Managing Risk and Contingency for Works Projects," Central Unit on Procurement, London, UK.
Zayed, T. and Halpin, D. (2005). "Pile Construction Productivity Assessment," J. of Construction Engineering and Management, ASCE, June, 131(6), pp. 705–714.

PROJECT RISK IDENTIFICATION METHODS FOR CONSTRUCTION PLANNING AND EXECUTION

Robert G. Batson, M.ASCE[1]

Abstract

Risk identification is the often neglected first step in the risk management process: potential problems specific to the project must be identified before quantification of the magnitude of the risk, or consideration of prevention or mitigation actions. This paper presents two research conclusions: systematic project risk identification during the transition from the design to construction (planning) phase benefits from a taxonomy of risk areas/potential problems for the specific type of construction involved; during construction execution, earned value analysis is an effective method to identify emerging risks from readily available project data bases. A taxonomy was developed from published references for infrastructure construction projects, validated by construction managers, and is the main contribution of this paper. Fifteen "risk areas" were used to organize 96 potential problems.

Introduction

In the context of project management, a risk area is a collection of potential problems. For example, a risk area might be "long lead time structural elements" and a potential problems associated with this risk area might be "cannot meet planned quantity on delivery date." Potential problems in the construction business may impact any or all of quality, quantity, schedule, or cost. Project risk is the probability that the actual quality, quantity, time, or cost of work fails to match project specifications and plans, along with the associated consequences of such failures.

Project risk management is an iterative process for identifying, assessing, and mitigating the uncertainties associated with complex projects. Once risk elements are identified, and their threat to project success is assessed, options are developed to reduce risk to levels deemed acceptable by the organization. In the author's experience performing risk management studies on large-scale defense and space projects, the risk identification activity was the most difficult. Maytorena, et al (2007) state "the risk identification phase has been the subject of little research" and that "over the past decade, checklists (taxonomies), brainstorming, and interview sessions have been the most commonly used risk identification tools." We agree that

[1]Professor, Department of Civil, Construction, and Environmental Engineering

The University of Alabama, Tuscaloosa, AL 35487-0288; e-mail: rbatson@eng.ua.edu

industry-specific taxonomies of risk areas/causes are useful prior to the start-up of construction, but during project execution it is more effective to go directly into a project management information system to extract the true risk elements of a particular project. The interpretation of the project MIS output is the responsibility of humans, either staff members or the project manager. Personal judgment, intuition, and experience are applied in integrating the calculated results, and drawing meaning from them. When human expertise is in short supply, one approach is to automate the interpretation expertise for risk identification into the project management software. No one had ever done this until Moynihan, Kalra, and Batson (2000) succeeded in constructing an expert system that accessed NASA International Space Station (ISS) project management systems, and employed Earned Value Analysis (EVA) heuristics taken directly from the project management literature to evaluate massive volumes of project data. This system successfully produced "risk alerts" for the NASA ISS project management office.

Risk identification is the first step in the risk management process; potential problems specific to the project must be identified before quantification of the magnitude of the risk, or consideration of prevention or mitigation actions. *During construction planning (the transition from design to construction),* the accepted approach used in other industries (e.g., aerospace) is to present the planning team with a taxonomy of risk areas/potential problems, then through systematic discussion and investigations to identify the risks specific to the project at hand. "Lessons learned" on projects similar in character are sometimes used, but are less comprehensive than the taxonomy method. To demonstrate, a taxonomy has been developed from published references for infrastructure construction projects, and will be the main contribution of this paper. Fifteen "risk areas" were used to organize 96 potential problems. The first six areas represent responsibilities of a specialized manager, such as Purchasing Manager, Equipment Manager, Design Phase Manager, etc. The last nine areas represent responsibilities or conditions that must be understood and dealt with by the planning team as a group.

During construction execution, rudimentary project control uses cost and time actuals, when compared to budget and schedule, to infer which project elements may be in trouble. Such "variances" can be misleading if used as risk indicators. Instead, if one assumes that quality and quantity specifications will be met and that risk effects will be absorbed as cost overruns or schedule slippages (or both), this paper demonstrates that the method of earned value analysis (EVA) can be used to identify activities that may be experiencing risk impacts. The management team would then investigate causes, identify actions to minimize further impacts, and enact the actions justified. Thus, aspects of the taxonomy-based approach during project planning, and the EVA-based approach during project execution, are reported here.

Risk Identification during Construction Planning

The Construction Industry Institute (CII) uses a seven-phase Project Life Cycle, and has published extensive research (go to www.construction-institute.org, Knowledge Structure) on Front-End Planning dealing with the first four phases (Feasibility,

Concept, Detailed Scope, and Design) and the so-called "gates" between them. A computerized Project Definition Rating Index (PDRI) has versions developed for industrial projects, building projects, and infrastructure projects. PDRI is a risk management tool to identify and measure risks related to project scope definition during the early stages of project development; the less definition, the higher the risk. This tool has been proven through field research (Construction Industry Institute 2006) to reduce the variability, hence risk, of projects to the owner, who is seen as the party ultimately responsible to see that front-end planning gets done. In contrast, the research reported here focuses on identifying risks in the transition from design to construction (which we call construction planning) and the actual construction phase (which we call construction execution). During execution, the method we recommend for identifying risk areas is based on classical earned value cost and schedule indices, thus providing a rating of the risk based on project data.

To develop a taxonomy of risk areas for construction projects, we scanned chapters in such reference books and Web sites (including the above), looking for lists of pitfalls associated with various project stages, contract types, and construction activities. As we recorded these findings, and augmented them with transportation-specific factors, a taxonomy was developed. We decided to look at risk from the prime contractor's point-of-view, because we believed the prime contractor has the best opportunity and largest incentive to control construction phase risk.

The taxonomy is provided in Table 1. Fifteen "risk area groupings" were used to organize 96 risk areas. The first six grouping represent responsibilities of a specialized manager, such as Purchasing Manager, Equipment Manager, Design Phase Manager, etc. The last nine groupings represent responsibilities or conditions that must be understood and dealt with by more than one manager after the project is underway. The "X" symbols represent where the project impacts could be felt, should the risk manifest itself on a particular project. Certainly not all 96 risks would be a concern on a given project.

In order to validate these findings, a draft version of the taxonomy presented in Table 1 was sent to nine local construction project managers for comment. After allowing time for review of the draft, the following specific questions were asked of each reviewer: 1. Additional risk areas or potential problem areas (symbolized by the X's) you would include in the taxonomy, and why (if you care to explain)? 2. Items listed as risk areas or potential problem areas in the taxonomy you would delete, and why (if you care to explain)? 3. Any other changes or comments you would like to make regarding the taxonomy? Responses received were confined to question one above, as follows: A total of fifty additional potential problems were foreseen by the experienced construction managers. This represented an increase of approximately 20% in the number of X's identified in the mailed taxonomy. The additions have been made in the taxonomy presented in Table 1. The feasibility of creating a taxonomy for a specific type of construction was demonstrated, though nine reviewers from local, small-to-medium sized contractors represented an accessible group of area experts, *not* a statistically valid industry-wide survey.

Table 1: Taxonomy of construction project risk areas from prime contractor's point-of-view

Risk Area Groupings	Potential Problems			
	Quality	Quantity	Timing	Cost
Procurement, Delivery, and Security of Materials				
1. Ordering of materials	X	X	X	X
2. Expediting of materials	X	X	X	X
3. Delivery of Materials	X	X	X	
4. Security of materials after delivery	X	X	X	X
5. Material Cost estimating				X
6. Material price escalation (e.g., due to shortage)				X
Construction Equipment				
1. Availability of equipment within company, or for lease	X		X	X
2. Quantity of equipment on-site		X		
3. Reliability of equipment			X	X
4. Maintainability of equipment			X	X
5. Scheduling conflicts at site for use of equipment			X	X
Design Phase Management				
1. Project content estimates	X	X	X	X
2. Project cost estimates	X		X	X
3. Construction methods selected	X		X	X
4. Materials selected	X		X	X
5. Delivery time estimates for materials & equipment			X	X
6. Preliminary project time estimates			X	X
7. Plans or specifications that contain errors, omissions, ambiguities, or lack of proper degree of coordination	X	X	X	X
8. Technical complexity of the project			X	X
9. Delivery of completed design documentation			X	X
Field Construction Management				
1. Progress measurement (by what method, how often, corrective actions taken?)			X	
2. Controlled allocation of total project float time			X	X
3. Cost/time management (management by exception)			X	X
4. Resource management (materials, labor, equipment, subcontractors)			X	X
5. Project Financial control (cash flow management)				X
6. Project manager qualifications	X		X	X
7. Field superintendent qualifications	X		X	X
8. Project manager changes	X		X	X
9. Field superintendent changes	X		X	X
10. Turnover of owner-provided sites or facilities	X		X	X
Subcontractor Management				
1. Availability of qualified subcontractors	X		X	X
2. Selection process	X		X	X
3. Qualifications of selected subcontractors	X		X	X
4. Responsiveness of subcontractors	X		X	X
5. Schedule performance of subcontractors			X	X
6. Job performance (quality) of subcontractors	X			
7. Subcontract costs				X
8. Change order management	X	X	X	X
9. Coordination of multiple subcontractors	X		X	X
10. Familiarity of subcontractors with each other	X		X	X
11. Past successes/problems of subcontractors working together	X		X	
Change Order Management				
1. Change in scope of work	X	X	X	X
2. Change in contract amount or time, or both			X	X
3. Appropriate use of written "change directives" and "verbal authorization to proceed"	X		X	X
4. Estimation of impact on subcontractors			X	X
5. Coordination of changes across multiple subcontractors	X		X	X

Table 1: Taxonomy of construction project risk areas from prime contractor's point-of-view (continued)

Risk Area Groupings	Potential Problems			
	Quality	Quantity	Timing	Cost
Management of Critical Activities				
1. Critical path known and periodically updated			X	X
2. Low float time non-critical path activities			X	
3. Activities never before tried in construction industry	X		X	X
4. Activities new to contractor or subcontractor	X		X	X
5. Activities dependent on scarce or unreliable resources	X	X	X	X
6. Activities with weather sensitivities	X		X	X
7. Activities put at risk by earlier slippages	X		X	X
8. Adequate checklists to avoid missed steps	X	X	X	X
Acceptance of Completed Construction				
1. Periodic inspections by foremen, superintendents, engineers	X	X	X	X
2. Rework	X		X	X
3. Final inspections			X	X
4. Call-backs			X	X
Schedule Acceleration Mechanisms				
1. Design-Bid-Construct approach			X	X
2. Fast tracking or phased construction	X		X	X
3. Activity acceleration via additional resources	X		X	X
Weather				
1. Adequate forecasting based on history			X	X
2. Unplanned weather events	X		X	X
Labor Conditions				
1. Availability of labor (skills and numbers needed)	X		X	X
2. Strike	X		X	X
Site Conditions				
1. Soil conditions	X		X	X
2. Subsoil	X		X	X
3. Unforeseen subsurface conditions			X	X
4. Site topography			X	X
Environmental regulations				
1. Studies			X	
2. Permits			X	
3. Inspections/violations			X	X
Safety and Accidents				
1. Construction safety plan and training	X		X	X
2. OSHA requirements	X		X	X
3. State requirements	X		X	X
4. Safety program during construction	X		X	X
5. Safety restraints on sequencing of construction	X	X	X	X
6. Accident reaction plans	X		X	
7. Emergency evacuation plans	X		X	
8. Material Safety Data Sheets	X			
9. Safety equipment storage and readiness	X	X		
10. Drug testing policy and program	X			X
Utilities and Services				
1. Electrical power			X	X
2. Water			X	X
3. Ventilation	X		X	X
4. Compressed Air	X			X
5. Telephone/Fax	X		X	X
6. Computer				X
7. Site Security	X	X	X	X
8. Site food, beverage, vending	X			X
9. Site sanitary services	X			X

Table 1: Taxonomy of construction project risk areas from prime contractor's point-of-view (continued)

Risk Area Groupings	Potential Problems			
	Quality	Quantity	Timing	Cost
10. Soil and concrete testing	X		X	X
11. Trash removal	X		X	X
12. Tire repair			X	X
13. Photography				X
14. Signs and fencing				X

Risk Identification during the Construction Execution

The CII and some construction management textbooks (e.g., Sears, Sears, and Clough 2008) denote by Construction Execution both the procurement that starts as design concludes, and the actual physical construction. The research reported next focused on cost/schedule risk management during Execution. *Procurement* is the ordering, expediting, and delivering of equipment and materials, especially those with long lead-times for delivery. *Construction* is physically erecting the project and putting the materials and equipment into place, which involves providing:

- manpower, with proper skill mix
- construction equipment
- materials
- supplies
- supervision
- management.

Planning may be thought of as the first step in construction schedule control. Job requirements are defined, which lead through planning to:

- what needs to be done
- how it will be done
- for how long
- in what order.

To shorten some activities, schedule adjustments are made to meet the customer's requested completion date. Then manpower and construction equipment requirements are assessed to see what imbalances or conflicts exist, and need adjustment.

When project activities have been scheduled, and labor and equipment requirements have been set, cost estimating begins and progresses through the engineer's estimate and the contactor's estimate, which constitute the construction budget.It is this schedule and budget baseline against which project risk must be detected, and acted upon. Although it is possible to carry out a "pre-contractual project risk assessment," listing potential problems based on the project specifics, they are not nearly as useful as project risk identification produced every schedule/cost reporting period *after* the project begins. The latter method is the basis of the risk identification and ranking method suggested in this paper (and used on the ISS project).

Classical schedule and cost control methods require that deviations (variances) from planned schedules and costs be reported to management. Almost any project management software already has the capability to provide such reports. We are going to suggest interpreted those variances using the more sophisticated earned-value analysis (EVA) concepts of construction project control.

Classical Project Schedule Control

Construction scheduling (and rescheduling) must be done by people who are thoroughly familiar with the type of fieldwork involved (Sears, Sears, and Clough 2008). Bar charts for schedules, also known as Gantt charts, are the most frequently used schedule tools in construction because they are simple and easy to understand. Almost all planning begins with a Gantt chart, and during the project these provide excellent summary-level graphics on schedule progress and milestone achievement. A recognized weakness is their lack of capability to analyze impacts on the entire project, if such exists, of schedule slippage in activities.

The critical path method (CPM) has augmented the Gantt chart as the tool of choice for project schedule analysis. The two are often used together, and in most project software either "view" is available. The critical path is, of course, the longest path through the project schedule network, from current activity status to project completion. The critical path is estimated prior to the project, and may change location (i.e., different activities are included) several times during the project. Many contractors add a contingency of 5-10% onto the overall projected (CPM) time required for the entire job (Sears, Sears, and Clough 2008).

Critical activities are those activities on the current critical path. Critical activities in construction projects usually constitute 20% or less of the total (Sears, Sears, and Clough 2008). Total float is the amount by which the start of an activity can be delayed and not affect project duration. Critical activities have a total float of zero. Although the delay of an activity from its earliest start, by a duration equal to less than its total float, will not subsequently impact the overall project duration, it consumes total float from each path of which it is a member. Free float is the time by which the completion of an activity can be deferred without delaying the earliest start of the following activities.

Classical Project Cost Control

The elements of "Project Cost" in construction projects fit in the following categories:

- Material
- Labor
  - Direct (wages)
  - Indirect labor (payroll taxes, insurance, etc.)
- Equipment
- Subcontractor Bids
- Overhead
  - Project Overhead
  - Home Office Overhead.

The "project (or bid) price" is made up of the project cost plus a "Markup (Margin)" of 5-20% of the project cost. Markup is intended to cover profits, additional overhead, management contingency, and more subjective elements related to knowledge of competitor's likely bids and how badly the firm wants the business.

Project cost control consists of:

- Monitoring current costs
- Combining current and past costs into cumulative activity and project costs
- Analysis of the data, leading to the potential for action.

These actions will only be effective if the control system identifies potential problems with respect to their sources (Kerzner 2006). Simplistic budget control systems

compute differences between budget and actual expenditures, usually on a weekly or monthly basis. But often, these crude variance measures mislead managers into thinking all is well (when it is not) or a budget overrun is projected (when there is no real problem in conduct of the work).

Earned Value Analysis

Modern texts (Kerzner 2006) recognize that control is for decision-making, and that three useful reports are required by management in order to make effective and timely decisions:

1. The project plan, schedule, and budget
2. A detailed comparison of the physical work accomplished to date, with actual cost expenditure, and the planned work to be accomplished by this date.
3. A projection of resources to be expended through program completion.

We are particularly interested in item two above, and providing the busy program manager with such comparisons on a red-yellow-green scale so that he or she can "manage by exception" the red activities. To further explain, we need *three definitions*:

Budgeted cost of work performed (BCWP) = for any activity or collection of activities, sum of the cost budgets assigned to each of the activities accomplished as of this date; for activities not yet finished, it is the activity budget multiplied by the percent complete; BCWP is also known as "earned value" of project to date

Budget cost of work scheduled (BCWS) = for activities that were scheduled to finish by now (regardless of their status), BCWS is the original activity budget; for activities that are in progress now, use budgeted amount X percent completion expected now

Actual cost of work performed (ACWP) = for completed activities, this is the actual cost incurred; for activities that are in progress now, this is the cost to date

Dreger (1992) states that without BCWP, effective cost reporting and analysis is impossible. He delineates three levels of sophistication in cost control methods:

Level 1: Compare actual costs (ACWP) with budgeted costs (BCWS); compute BCWS-ACWP and attempt to identify problem areas. Note: work performed and work scheduled do not typically agree.

Level 2: Compare actual costs with cost estimates to complete activity; Analyze variances between these estimated costs at completion and budgeted costs at completion. Of course, these comparisons are "after the fact," useless for risk management.

Level 3: Kerzner-style comparison of ACWP and BCWS with BCWP, to compute meaningful measures of variance and performance, as explained below.

A variance is any deviation of schedule, technical performance, or cost from plan (Kerzner 2006). We are only concerned with schedule and cost variances in this paper; we assume that efforts will be expended until all the technical requirements (quantity and quality) are met. The budgeting and scheduling system variances must be compared together because:

- The cost variance compares deviations only from the budget and does not provide a measure of comparison between work scheduled and work accomplished.
- The schedule variance provides a comparison between planned and scheduled performance, but does not include costs.

Simplistic cost control uses: Total Variance = BCWS - ACWP at a given time. Need:

Cost Variance CV = BCWP – ACWP, and a negative value is a "cost-overrun"; and Schedule Variance SV = BCWP – BCWS, or earned value – planned value, and a negative variance indicates a "behind-schedule" condition.
Positive variances are good; the larger the better. Also needed for risk analysis are:
Cost Performance Index CPI = BCWP / ACWP
Schedule Performance Index SPI = BCWP / BCWS
Index values > 1.0 indicate a positive performance to plan; the larger the better.
The above earned value calculations may be carried out at any level of the work breakdown structure (WBS). Five questions to be addressed by project managers in response to EVA are (Kerzner 2006):

- What is the problem causing the negative variance or performance index < 1.0?
- What is the impact on time, cost, and performance?
- What is the impact on other efforts, if any?
- What corrective action is planned or underway?
- What are the expected results of the corrective action?

Risk areas can be identified by whether their index values are in a certain range, for example (0, 0.95), [0.95, 1.05], or (1.05, ∞); these might be called red, yellow, or green conditions, respectively, and risk management would focus on those work elements with a red rating in CPI, SPI, or both.

Conclusions

In conclusion, systematic risk identification during construction planning requires a taxonomy of risk areas/potential problems for the specific type of construction involved. During construction execution, earned value analysis is the best method to identify emerging risks from readily available project data bases. This sorting out and ranking of risks can be very helpful to project managers who are having trouble balancing "look-ahead management" with the handling of today's problems. In both construction project planning and execution, project participants must discuss risks, quantify severity, determine causes, and decide if risk management actions are necessary and what they should entail.

References

Construction Industry Institute (2006). *Front End Planning: Break the Rules, Pay the Price,* CII Research Summary 213-1, University of Texas-Austin, Austin, Texas.

Dregner, J. Brian (1992). *Project Management: Effective Scheduling*, Van Nostrand Reinhold, New York.

Kerzner, Harold (2006). *Project Management*, Fourth Edition, Van Nostrand Reinhold, New York.

Maytorena, Eunice, Graham M. Winch, Jim Freeman, and Tom Kiely (2007). "The Influence of Experience and Information Search Styles on Project Risk Identification Performance," *IEEE Trans. on Eng. Mgmt.,* Vol. 54, No. 2, 315-326.

Moynihan, Gary P., Gurdish S. Kalra, and Robert G. Batson (2000). "Development of a risk identification expert system for the International Space Station project." *International Journal of Risk Assessment and Management*, Vol. 1, No. 1, 90-104.

Sears, S. Keoki, Glenn A. Sears, and Richard H. Clough (2008). *Construction Project Management*, Fifth Edition, Wiley, New York.

SUPPORTING MARKET ENTRY DECISIONS FOR GLOBAL EXPANSION USING REAL OPTION + SCENARIO PLANNING ANALYSIS

Du Yon Kim,[1] Byungil Kim,[2] and Seung Heon Han[3]

ABSTRACT: The world has witnessed the dramatic expansion of international construction markets during the last decades, particularly around the developing economies and energy resource-rich countries. However, despite the booming markets, the risks of emerging regions have also increased under the rapidly changing environments confronting global contractors. Most of all, success in overseas business mainly depends on selecting a right market to enter. Accordingly, the right market selection requires global firms to carefully carry out the scientific market entry decision by evaluating country risks, market prospects, firm's capability, level of competition, and among others. This study aims at developing a market entry model by the use of real option analysis (ROA) and scenario planning, which places emphasize on firm's strategic flexibility against uncertainties encompassing the overseas construction markets. Based on the suggested approach, global contractors are expected to make a better decision rather than a widely used static NPV approach in pursuing, postponing, or abandoning a prospective market to their capacity with a consideration of uncertainties as well as its flexible option value.

INTRODUCTION

Overview of International Construction Market

The world has witnessed the dramatic expansion of international construction markets during the last decades, particularly around the developing economies and energy resource-rich countries. According to Global Insight (2007), international construction markets grew by 4.5% annually to reach $5 trillion in 2007. Out of this huge market, limited market portion worth $320 billion is open to foreign construction firms, which implies that international construction markets are likely to expand even further as globalization trends accelerate. However, despite the booming markets, the risks of emerging regions have also increased under the rapidly changing environments confronting global contractors. Most of all, success in overseas business mainly depends on selecting a right market to enter. According to

[1] Ph.D. Candidate, Department of Civil and Environmental Engineering, Yonsei University, Seoul, Korea; e-mail: cagedbird@yonsei.ac.kr
[2] Master Student, Department of Civil & Environmental Engineering, Yonsei University, Seoul, Korea; e-mail: ikim@yonsei.ac.kr
[3] Associate Professor, Department of Civil & Environmental Engineering, Yonsei University, Seoul, Korea; e-mail: shh6018@yonsei.ac.kr

Mahalingam and Levitt (2005), a number of owners in global construction markets, particularly in developing countries, require project financing, high level of technology, and foreign firms' advanced experience, knowledge and management skill to modernize their construction industries. Accordingly, the right market selection requires global firms to carefully carry out scientific market entry decision by evaluating country risks, market prospects, firm's private risks on their capability, level of competition, and among others.

Foreign Market Entry

A number of research papers highlight factors on the foreign market entry. In general, key factors to market entry decision faced by construction firms include go or no-go decision, location to go, timing to enter, entry modes to mitigate risks, investment purpose and amount for overseas business, etc (Kim 2008). As 'purpose' and 'investment amount' are primarily dependent on the capability of a specific corporation, he argued that go or no-go decision, location, timing and entry modes are key variables to a market entry decision. Levy and Yoon (1995) also emphasized company's strategic intention, market opportunity, payback risk and synergy effects as four elements influencing a corporate decision to expand into global market. Dow (2000) suggested a methodology to measure psychological distance between home and host country and illustrated how psychological distance would influence a selection of foreign country.

Market entry mode also has been another focal point of many researches to date. Agarwal and Ramaswami (1992), with a support of logistic regression model, defined ownership advantages of a firm, location advantage of a market, and internationalization advantages of integrating transactions as major elements affecting selection of international market entry mode. Yigang and Tse (2000) divided market entry mode on the basis of equity level and explained factors affecting each mode. In the overseas construction sector as well, there exists a steady stream of researches on go-no go decision (Dikmen and Birgonul 2004; Gunhan and Arditi 2005; Han and Diekmann 2001) and entry mode (Chen 2008; Ling et al. 2005). The aforementioned researches have all been significant in that they highlight and explain key influencing factors in relation to each market entry decision. However, market entry decision bears firm's crucial investment choice calling for more accurate estimation of financial values from long-term perspective (Lint and Pennings 1999). In spite of the importance when deciding on a potential market to pursue, many contractors rely on traditionally discounted cash flow (DCF) and net present value (NPV) method in assessing the feasibility of investment plans rather than a dynamic evaluation of various options as well as specific market risks conditions. This traditional approach is lacking in offering the firm's dynamic and flexible decision-making under the variable and uncertain market conditions. In this respect, this study aims at developing a market entry model by the use of real option analysis (ROA) and scenario planning, which addresses firm's strategic flexibility against the uncertainties encompassing the overseas construction markets.

MARKET ENTRY MODEL

Framework for Real Option Analysis

Recently, ROA is drawing attention for its advantages in addressing 'market uncertainties' and ensuring 'flexibility in corporate decision-making process'. ROA

applies valuation theories of financial options to real assets and provides a method to reflect conditional decisions on valuation in response to changes of project phases or variability in internal/external circumstances. Because of its flexibility in decision-making, ROA extends applications in a variety of sectors including research and development investment, new product release, investment in infrastructure or natural resources, valuation of corporation or Initial Public Offering, just name a few. Construction industry also utilizes ROA in assessing financial feasibility of privately invested projects (Garvin and Cheah 2004; Zhao et al. 2004), developing bidding strategies (Yiu and Tam 2006), and evaluating infrastructures maintenance (Cui et al. 2004; de Neufville et al. 2006). As for market entry decision, ROA can be effective, as it enables private corporations to freely exercise options and address uncertainties, depending on variable conditions of a host country.

Simply put, valuation utilizing ROA is expressed as: *True NPV = Static NPV + Managerial flexibility*. *Static NPV* is estimated by traditional method, that is, without consideration of flexibility or option value, while *Managerial flexibility* is the value of inherent options estimated in consideration of underlying volatility of asset value. *True NPV* is the sum of such figures and equal to the financial value of market entry strategy that the authors intend to assess. There are several established-approaches to estimate option values including partial differential equations (PDE), simulations or lattices. Appropriate method can be selected given the circumstances of problem domain and availability of input data. For example, Black-Scholes model is the best-known structure utilizing PDE. However, the model is so complex for common users to understand intuitively and so are simulation techniques (Garvin and Cheah 2004; Kodukula and Papudesu 2006; Mun 2006). In contrast, lattices are applicable to all types of options. Among lattices, binomial lattice is designed to model *Managerial flexibility* displayed in tree structure, which enables common users to easily comprehend the intuitive structure of value estimation. As construction firm's overseas market entry is akin to holding an option that can be deferred, abandoned, expanded, or reduced in advance depending on volatility of market condition, it is straightforward to say that intuitive understanding of option valuation is more advantageous in developing useful market entry decisions. Therefore, the authors consider binomial model more appropriate for overseas market entry decisions. The following equations are used in option valuation method based on binomial model that is proposed by Kodukula and Papudesu (2006).

$$u = \exp(\sigma\sqrt{\delta_t}) \tag{1}$$

$$d = \exp(-\sigma\sqrt{\delta_t}) = \frac{1}{u} \tag{2}$$

$$p = \frac{\exp(r\delta_t) - d}{u - d} \tag{3}$$

where, σ = volatility, δ_t = time step, r = risk free rate

Equations (1) and (2) indicate functions of underlying asset volatility with up and down factors respectively. Equation (3) means risk-neutral probabilities derived from functions of u, d and risk-free rate. On the basis of above binomial model, the market entry model herein relies on the following boundary conditions and key assumptions: first, construction firms hold a deferral option and basically, it does not incur direct cost in relation to such option while considers only opportunity costs; second, market to enter is already highly competitive and intensity of competition does not change

upon either a contractor's new market entry or a delay of market entry; third, learning curve of a contractor following the accumulated market entries is not considered directly or indirectly on its stock price. Under the above assumptions in principle, two elements of true NPV (i.e, static NPV and flexibility) can be estimated.

Step 1: Estimating Static NPV

First of all, static NPV of underlying asset is estimated by a traditional method. Simply put, inflow such as incoming revenues (or new contracts) and outflow such as cost of execution and operating costs are netted out to estimate NPV. In manufacturing sector, production costs are less volatile than revenues of sales quantity. However, construction market is more likely to fluctuate on cost sides. Notably, as international construction market is exposed to severe risks than domestic market (Han et al. 2007), cost variability in relation to a given overseas project needs to be considered when estimating outflow value. Our preceding study (Kim et al. 2008) examined cost performance of 126 overseas projects constructed over the last decade. Accordingly, this research attempted to break down the results of cost performances in association with regional distributions to reflect its impact on cost variations compared to as-planned cost. Table 1 shows a sort of contingencies that can be added in outflow estimation to the extent that as-planned costs are escalated in proportion to each regional variation rate.

Table 1. Distribution of Cost Variations by Region (Kim et al. 2008)

Region	North-East Asia	South-East Asia	Middle East	Africa	Latin America
Cost variation	100.250%	102.182%	102.942%	105.200%	106.071%

For example, if a project of interest is planned in a Southeast Asian country, assuming that revenue value (incoming contract amount) is 100 and average rate of planned cost of execution is 90%, probable value of outflow cost is equal to 100 × 90% × 102.182% = 91.96, which forms the total outflow when added with operating expenses. Operating expenses herein can be variable, subject to types of entry modes. For example, long-term entry mode involving an establishment of local branch incurs more initial costs and operating expenses than a temporary entry mode based on a single project in general (Chen 2008). This research does not intend a specific entry mode but considers a variety of entry modes as a part of market entry strategy. Therefore, given the characteristics of ROA, the model proposed herein is beneficial in that it can estimate the option value of a candidate entry mode on the condition that inflow revenues and outflow costs are reasonably projected as analysis inputs.

Step 2: Estimating Volatility

Kodukula and Papudesu (2006) defined volatility in option model as "the volatility of the rates of return, which is measured as the standard deviation of the natural logarithm of cash flow returns." They also argued that it is customary to estimate volatility by utilizing historical data and utilize it in predicting market outlook. As the volatility in binomial model indicates uncertainty, it is central to valuation of option analysis. Therefore, when considering entry into a new market, construction firms need to consider uncertainties as much as possible on volatility forecasts for ensuring reasonable estimation of option value. In short, volatility indicates an aggregation of diverse factors influencing overseas market entry. In the real option research area, the measurement of volatility is generally classified into two risk groups as market risk and private risk. Ofori (2003) stated that factors on a contractor's capability side such

as reputation, experience, technological competitiveness, firm's size, and other aspects from a nation's perspective such as political/economic stability, accessibility of a host country, relationships between a host and home country, and previous performance of other foreign firms in a host country would significantly influence overseas market entry decision. Zhao and Shen (2008) also highlighted influencing factors belonging to two different groups, contractor's capability and host country's conditions, as key parameters in analyzing the status of Chinese construction firms.

Nonetheless, it is difficult to measure volatility by considering all the risk factors; thus, many researches generally adopted the way that conceptualizes volatility as representative two factors of market conditions and private firm's risks. Considering the aforementioned propositions in the preceding studies, the authors propose a way to estimate volatility by the deposition of both GDP fluctuation of a host country and stock price variability of a candidate construction firm. The authors presumed that these two aspects are considered relevant criteria in lieu of a host country's parameter and a contractor's capability, respectively. Baek et al. (2005) explained that GDP fluctuation could be an overall risk indicator of a host country. Warner et al. (1988) also indicated that contractor's capability and potentials had a close bearing on its stock price. In this regard, Hitt and Ireland (1985) and Kilka and Weber (2000) used stock price as an indicator of contractor's capability. All together, the authors accordingly provide a simple way to estimate volatility applicable for overseas construction market from two broad perspectives of contractor's capability and host country's potential.

In another aspect, Wang et al. (2004) claimed that risks in overseas construction market are required to be applied differentially, subject to development level of a host country. In a similar way, Gupta and Sravat (1998), Jaselskis and Talukhaba (1998), and Raftery et al. (1998) all focused on influencing factors in developing economies specifically. This approach intends to adjust the balance between the two prospects differentially, depending on the bidding capability of a firm and development level of a host country in terms of how widely the amount of contractual revenues will fluctuate following the entrance of a host country. Equation (4) shows how to estimate this volatility of a revenue projection in a given host county.

$$VIi_{jx} = \alpha_n \times Volatility\ of\ GDP_{ij} + \beta_n \times Volatility\ of\ stock\ price_{xj} \quad (4)$$

where, V_{ijx} = Volatility Index of corporation x in country i at year j

α_n = Country risk coefficient of development level n

β_n = Corporate's capability coefficient of development level n

As shown in Equation (4), it is assumed that coefficients for combined volatility indices of GDP and stock price are variable depending on development level of a given country. Using the rations between country risk and contractor's capability, volatility indices of GDP and construction firm's stock price are aggregated to ultimately produce total market volatility in a combined way. This paper adopts formulas proposed by Kodukula and Papudesu (2006) to use historical close-to-close volatility method preferred in volatility forecasts. For example, Equation (5) shows how to estimate volatility of GDP.

$$r_j = \ln\left(\frac{GDP_{j+1}}{GDP_j}\right), \quad \bar{r} = \frac{r_1 + r_2 + \cdots + r_{m-1}}{m-1} \quad (5)$$

$$GDP\ Volatility = \sigma = \sqrt{\sum_{j=1}^{m-1} (r_j - \bar{r})^2}$$

where, GDP_j = GDP at year j
m = number of historical years used in the volatility estimation

To determine each weight pair (α, β) in Equation (4), this paper analyzed correlations between development level of a host country versus country risk and contractor's capability risk. To that end, cases of risk levels associated with actual project outcomes across the world were utilized, which was collected from our previous studies (Han et al. 2007). The data show risk control levels of 64 identified risk variables per a project in relation to 126 global construction projects. Risk control level herein was measured by Likert 7-point interval scale from '-3: Very Poor' to '3: Very Good'. Table 2 shows the results of confirmatory factor analysis, displaying two group factors forming the 14 country risk variables and 23 contractor's capability risks, respectively.

Table 2. Confirmatory Factor Analysis Results

Factor	Risk Variable	Factor Loading
Country risk 14 elements	[Q6-1] Legal and regulatory framework of host country governing construction industry	0.415
	[Q6-2] Integrity, collusion, grey economy	0.429
	[Q6-3] Policy change, gov't intervention, other external pressure	0.599
	[Q6-4] Political unrest, social disturbance, rapid economic change	0.732
	[Q6-5] Regulation of remittance to home country	0.514
	[Q6-6] Owner's capability of funding project and honoring obligation	0.599
	[Q6-7] Owner's understanding of project and project implementation capability	0.500
	[Q6-26] Force majeure	0.803
	[Q6-27] Weather and climate	0.713
	[Q6-28] Geographical conditions relating to logistics of materials	0.530
	[Q6-29] Site ground conditions and work environment	0.541
	[Q6-30] Complaints from residents or civil groups	0.626
	[Q6-31] Construction infrastructure	0.744
	[Q6-49] Delay in local permit/authorization process	0.528
Contractor's capacity 23 elements	[Q6-10] Availability of tendering process information	0.420
	[Q6-12] FX fluctuation risk	0.419
	[Q6-13] Financing cost	0.462
	[Q6-16] Contingency cost	0.393
	[Q6-20] Unfavorable contract terms and conditions	0.686
	[Q6-25] Lack of experience in applicable process and technological elements	0.509
	[Q6-33] Construction contractor's design	0.552
	[Q6-34] Site office manager's management capability	0.707
	[Q6-35] Site office manager's discretion/treatment of site workers	0.572
	[Q6-36] Site workers' technological expertise and management capability	0.722
	[Q6-37] Collaborative network between head office and construction site	0.681
	[Q6-38] Inter-organizational communication in each project phase	0.604
	[Q6-47] Dedicated organization for resolving claim, civic complaint	0.419
	[Q6-48] Document control	0.560
	[Q6-50] Advance mobilization of manpower and resources	0.685
	[Q6-55] Construction contractor's design capability	0.696
	[Q6-56] Construction expertise and quality control	0.713
	[Q6-57] Errors found in testing, commissioning	0.505
	[Q6-58] Safety and environmental issue control	0.659
	[Q6-59] Contractor's project planning and management capability	0.797
	[Q6-60] Cost estimation/control techniques	0.693
	[Q6-61] Construction financing	0.331
	[Q6-62] Resource allocation and schedule control	0.707

The host countries where 126 projects were performed in total were classified into three groups (i.e., underdeveloped, developing and developed countries) in accordance with IMF (International Monetary Fund) classification standard. As a result, 34 projects were grouped in underdeveloped countries, 79 in developing and 13 in developed countries. Following it is to estimate average control level per each group factor identified in confirmatory factor analysis to see how it would vary, subject to different development level of a host country. Fig. 1 shows mean values of each factor's control level in relation to three development levels of foreign countries. Mean of control level over country risk factor increases in proportion to development levels while that of contractor's capability factor peaks at underdeveloped countries, drops to the bottom in developing countries and rises again in developed countries. Intuitively, it can be noted that contractors' controllability over country risk factor is

apt to increase as the development level of a country keeps down. Also, non-linearity of contractor's capacity risk can be indicative of differences of technical or managerial difficulties in performing overseas projects in a successful way, which signals the most difficulty in developing countries rather than those of developed or under-developed countries. ANOVA analysis was conducted to confirm if the mean differences were statistically significant. The differences in means of country risk and contractor's capability factors were all found to be significant at 95% confidence level. Therefore, as previously assumed, it is deemed to be reasonable to apply different volatility coefficients associated with two risk factors, subject to development levels of a host country. Volatility coefficients of two risk factors were calculated by transforming mean score of each factor as 100 points and calculating the relative weights between mean score of each factor in relation to three development levels (see Table 3).

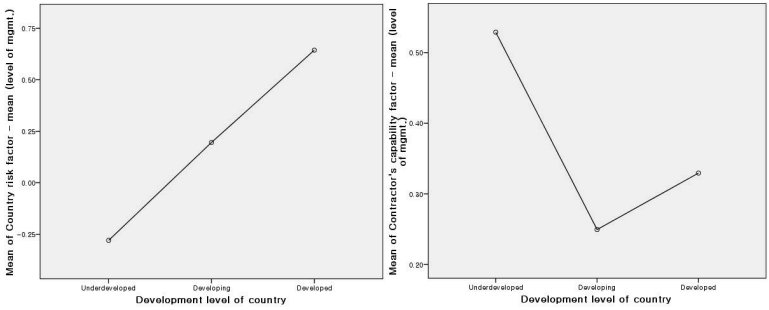


Figure 1. Mean of Risk Factor by Development Level of Host Country

Table 3. Volatility Coefficient by Development Level of Host Country

Development Level	Country Risk		Contractor's Capability	
	Mean Control Level (-3 ~ 3)	Volatility Coef. (α) (0 ~ 1)	Mean Control Level (-3 ~ 3)	Volatility Coef. (β) (0 ~ 1)
Underdeveloped	-0.2797	0.4353	0.5289	0.5647
Developing	0.1955	0.4958	0.2495	0.5042
Developed	0.1167	0.5225	0.3295	0.4775

On the basis of volatility estimation method and ROA framework stated earlier, the next section further describes scenario analysis to illustrate potential application of market entry model.

SCENARIO ANALYSIS

Case of Entry into a Developing Country

Scenario analysis was conducted, assuming a new market entry by a probable contractor, to evaluate applicability of market entry decision framework suggested herein. Toward this end, it was assumed that a Korean contractor listed as one of the ENR Top 225 global contractors is positively recognizing potential entry into the Vietnamese construction market with the following details.

> "…AA Construction is one of the best-known construction contractors of Korea listed in the Korea Stock Exchange (KSE) and awarded construction contracts worth about 50 million USD per annum. The company has a variety of experiences in international construction markets, mostly in the Middle East and the Southeast Asia. This firm is now considering potential entry into civil construction area in Vietnam, without any prior experience in this country…."

To apply ROA to a situation assumed, static NPV is estimated first in accordance with the procedure described previously. Potential incoming revenues (contracts) that can be achievable after deciding on a new market entry is estimated from an inflow perspective. Since AA company does not embark on construction investment in Vietnam yet, cumulative historical contracts of BB firm for the last 10 years, which is quite comparable to AA in revenue volume and already active in civil construction sector of Vietnam, is alternatively used for potential incoming revenue value for the next 10 years following the market entry. Given the cumulative revenue amounts of BB Company, GDP growth rates of the construction sector of Viet Nam, and level of market competitions, this paper projects the potential incoming new contracts of AA firm during the next 10 years as USD 163,421,000. This revenue forecasting can be obtained by integrated approach which uses exponential smoothing method and Delphi method. This is because demand or revenue forecasting shows better accuracy when statistical method and experts' subjective method are jointly used (Armstrong and Collopy 1998). Now, from outflow perspective, the authors estimate projected cost of execution and operating costs during the same time span. Considering average ratio of cost performance for AA firm and cost variation ratio by region (see Table 1), cost of execution is estimated at USD 150,315,000 (=163,421×0.9×1.022). As for annual operating expenses, initial entry costs and annual marketing expenses are estimated to be within 1% of cost of execution when considering a local branch establishment (=163,421×0.9×1.022×0.01×10). Lastly, as AA firm intends to plan long-term operating activities, equipment purchase price is estimated to be 5% of planned cost. Against the backdrop, *Static NPV* = 163,421-(163,421×0.9×1.022 + 163,421×0.9×1.022×0.01×10 + 163,421×0.9×0.05) = -$9,279,000.

As a result, traditional NPV method ends up with an estimation of -$9,279,000, which definitely indicates a negative sign against market entry and calls for the company to delay or give up on entry into Vietnamese market. Differently from traditional method, ROA applies volatility to the static NPV to produce a true NPV. To estimate volatility, the Vietnamese market and the contractor's capability are assessed accordingly. Vietnam poses not only a high growth potential but also a significant market volatility arising out of its national parameters, which requires prudent approach in assessing the market entry decision. Table 4 illustrates volatility indices based on annual GDP data over the last decade in Asian region, of which Vietnam actually shows higher GDP volatility than any other neighbor.

Table 4. GDP Volatility Indices by Asian Countries

Country	Philippines	Sri Lanka	Indonesia	Hong Kong	Kyrgyzstan
Annual Volatility	10.0%	5.1%	20.3%	7.4%	21.0%
Country	Bangladeshi	Vietnam	Taiwan	Thailand	Singapore
Annual Volatility	4.6%	46.0%	8.4%	11.4%	9.1%

Next, volatility of stock price in relation to AA firm's capability and potential is estimated. Table 5 shows the results of volatility calculated by virtue of stock prices of Korean contractors at each month's end during the entire analysis period (refer to Equation 5). AA firm posts a lower volatility figure than those found in other comparable firms.

Table 5. Volatility Index of Stock Price by Similar Contractors

Contractor	H corp.	D corp.	AA	S corp.	DS corp.	Index
Annual Volatility	41.8%	49.1%	37.3%	44.6%	53.4%	38.0%

In reference to data in Table 4, 5 and the IMF classification standard, volatility index applicable to developing countries (see Table 3) is applied to Equation (1), projecting the volatility of Vietnam's construction market as [(37.3%×0.504) + (46.0%×0.496)] = 41.6%. Based on such figure, input parameters and projected parameters are determined to shape a basic binomial model, as shown in Table 6.

Table 6. Input Parameters and Projected Parameters

Input Parameters		Projected Parameters	
Present value of the underlying (1,000 USD)	163,421	Up: u=exp(σ√T)	1.51589
Exercise price (1,000 USD)	22,385	Down: d=1/u	0.65968
Life of the option (in years)	10 years	Risk-neutral prob. p=(1+r-d)/(u-d)	0.45587
Annual risk-free rate	10%		
Standard deviation of return (volatility)	41.6%	Down state risk-neutral prob. 1-p	0.54413
Number of steps	1 year		

Using the parameters in Table 6, binomial model can be propagated to cover possible scenarios over the next 10 years. For example, node (0, 2) is 163,421×1.51589^2 = 375,540 while node (1, 2) is 163,421×1.51589×0.65968 = 163,569. Assuming that market entry is abandoned if estimated incoming revenue is less than boundary sum of exercise price (22,385) that is composed of initial entry cost (163,421×0.9×0.05) and operating expenses (150,315×0.01×10), each binominal cell along the timelines are produced as shown in Table 7.

Table 7. True NPV With Involving Flexibility (unit: thousand USD)

	0	1	2	3	4	5	6	7	8	9	10
0	163,645	247,799	375,540	569,256	862,927	1,308,098	1,982,928	3,005,892	4,556,589	6,907,270	10,470,632
1		108,237	163,569	247,757	375,527	569,256	862,927	1,308,098	1,982,928	3,005,892	4,556,589
2			71,939	108,110	163,487	247,728	375,527	569,256	862,927	1,308,098	1,982,928
3				48,452	71,736	107,955	163,421	247,728	375,527	569,256	862,927
4					33,776	48,158	71,456	107,806	163,421	247,728	375,527
5						25,502	33,405	47,682	71,117	107,806	163,421
6							22,385	25,167	32,687	46,915	71,117
7								22,385	22,385	24,354	30,949
8									22,385	22,385	22,385
9										22,385	22,385
10											22,385

The above extension is calculated backward from the farthest right in principle. For example, as for node (7, 8), projected value utilizing risk-neutral probability and risk-free rate [21,164 = (24,354×0.45587+22,385×0.54413)/1.1] and boundary exercise price (22,385) are compared to fill the node. In a similar way, node (6, 7) is filled with 25,167, because discounted value is greater than boundary price. As such, node (0, 0) is finally loaded with inflow value including option value. As shown in Table 7, valuation including volatility generates option value worth USD 224,000(=163,645,000-163,421,000). Assuming that AA contractor will no longer expend operating expenses upon pullout from the market and be able to sell used equipment by 60% of initial purchase price, then,

True NPV = -9,279 (static NPV)+224 (option value)+163,421×0.9×1.022× 0.01×5 (un-disbursed operating costs)+163,421×0.9×0.05×0.6 (sale price of used equipment) = USD 2,873,000

This indicates a positive conclusion toward market entry in terms of financial

valuation. As demonstrated, ROA can influence market entry decision significantly by discovering real values hidden in corporate strategy and volatility on financial valuation.

CONCLUSIONS

This research proposes an analytics framework based on ROA + Scenario planning for deciding on a new construction market entry. The proposed approach helps to support more realistic decisions by assessing values in strategies available for companies and reflecting market volatility that are critical on firm's decision-making process. The model attempts to reflect volatility of a given host country by utilizing GDP volatility indicative of a host country market climate and stock price index reflecting contractor's capability to maintain overseas business. Furthermore, volatility coefficients that incorporate unique country risk and contractor's capability risk associated with three development levels of a host country is suggested. The results of ROA-based scenario analysis showed that the market entry decision model proposed herein can be applied to practical corporate decision-making scenarios under changing market condition. In addition, the proposed model can support a comprehensive decision-making framework, as it support a variety of dimensions to corporate decisions including go/no-go decision, timing to go, and entry modes to mitigate market risks. In summary, for construction contractors prospecting a new entry into overseas construction, long-term perspective with an aid of flexibility valuation and scenario development deemed to ensure more reasonable market entry decision. However, future procedural study is required, as representativeness of volatility variables and estimation results are not fully verified in statistical terms. Furthermore, more realistic options need to be tested by evaluating diverse scenarios based on broadened historical cases and verifying applicability of each entry mode in relation to the amount of initial entry cost and operating expenses, projected size of incoming revenues and predicted performance of cost expenditure, etc.

REFERENCES

Agarwal, S., and Ramaswami, S. N. (1992). "Choice of Foreign Market Entry Mode: Impact of Ownership, Location and Internalization Factors." *Journal of International Business Studies*, 23(1), 1-27.

Amstring, J. S., and Collopy, F. (1998). "Integration of statistical methods and judgment for time series forecasting. " *Forecasting with Judgment*, John Wiley & Sons Ltd., 269-293.

Baek, I.-M., Bandopadhyaya, A., and Du, C. (2005). "Determinants of market-assessed sovereign risk: Economic fundamentals or market risk appetite?" *Journal of International Money and Finance*, 24(4), 533-548.

Chen, C. (2008). "Entry mode selection for international construction markets: the influence of host country related factors." *Construction Management and Economics*, 26(3), 303 - 314.

Cui, Q., Bayraktar, M. E., Hastak, M., and Minkarah, I. (2004). "Use of Warranties on Highway Projects: A Real Option Perspective." *Journal of Management in Engineering*, 20(3), 118-125.

de Neufville, R., Scholtes, S., and Wang, T. (2006). "Real Options by Spreadsheet: Parking Garage Case Example." *Journal of Infras. Systems*, 12(2), 107-111.

RESILIENCE ENGINEERING: A NEW APPROACH FOR SAFETY MANAGMENT

D. Schafer,[1], T.S. Abdelhamid[2], P. Mitropoulos[3], and T. Mrozowski.[4]

.

Abstract

This exploratory paper proposes a resilient engineering approach to construction safety that departs from traditional views. Accidents are commonly viewed as a linear combination of causes and risks are viewed as arising from unreliable system components such as operators and technology. Traditional risk assessment views model system safety mainly in terms of linear structures that are by nature reactive and based on hindsight. Additionally, current safety models tend to ignore the demands imposed upon projects such as production pressures and tempo changes in work flow.

To remedy the shortfalls of construction safety mentioned above resilience engineering is presented as a new and proactive outlook on construction safety management. In this paper the genesis of the resilience engineering concept is examined and resilience engineering is posed as an exemplar for construction safety. An existing model that supports resilience engineering principles, the Functional Resonance Accident Model (FRAM), is examined in a construction scenario.

Introduction

Resilience engineering offers a new perspective on system safety. A formal definition of resilience engineering is the "…intrinsic ability of a system or an organization to adjust its functioning prior to and/or following changes and disturbances, so that it can sustain operations even after a major mishap or in the

[1] PhD Candidate, 401H Human Ecology, Construction Management Program, Michigan State University, East Lansing, MI 48824-1323. E: schaf123@msu.edu.

[2] Associate Professor, 214 Human Ecology, Construction Management Program, Michigan State University, East Lansing, MI 48824-1323. E: tariq@msu.edu

[3] Assistant Professor, Del E. Webb School of Construction, P.O. Box 870204, Tempe, AZ 85287. 480/965-3378. Arizona State University. E: takism@asu.edu.

[4] Professor, 102B Human Ecology, Construction Management Program, Michigan State University, East Lansing, MI 48824-1323. E: mrozowsk@egr.msu.edu

presence of continuous stress" (Hollnagel, 2006). The primary goal of the resilience engineering perspective is to first avoid losing control of the system by imagining the accident/incident before it happens and taking the necessary steps to prevent its occurrence. Another goal of resilience engineering is to adapt to situations in real time to avoid or mitigate the effects of an accident (Morel et al, 2008). Finally, resilience engineering provides direction to organizations after a mishap so that it may effectively deal with issues associated with the accident and return to a normal operating state or restructure if necessary. In each instance the *sources* of resilience that workers and organizations possess are identified. Once known these can be used to counteract the internal and external challenges to safety (Woods, 2006).

Although the term resilience is well known in various academic domains the term 'resilience engineering' is relatively new as applied to safety, beginning to appear in the literature around the end of the last century (Woods, 2007). However, the elements that characterize resilience engineering have been brewing for many decades. Resilience engineering borrows from many different areas of organizational and safety research such as High Reliability Organizations, Normal Accident Theory, and other similar approaches. Researchers in the field are mainly involved in the areas of healthcare, nuclear power, aviation, and aerospace, and among others characterized by complex, high-risk and high-visibility industries. Resilience engineering draws inspiration from work by industrial psychologists, sociologists, anthropologists, and other safety theorists such as James Reason, Jens Rasmussen, Scott Sagan, Donald Norman, and Charles Perrow. It utilizes and respects the effective methods, models and techniques developed over the years by various industries and academic disciplines with the caveat that they "…must be looked at anew and therefore possibly used in a way that may differ from what has traditionally been the case." (Hollnagel, 2008).

Background

Resilience engineering is rooted in the discipline of Cognitive Systems Engineering (CSE). CSE is a systems approach which was formulated in the early 1980's to study complex system failures such as the Three Mile Island nuclear power generating facility release of radiation and as a way to overcome the limitations of previous safety models (Hollnagel and Woods, 2005).

A cognitive system is defined as one that "…can modify its behavior on the basis of experience so as to achieve specific anti-entropic ends…they [cognitive systems] are able to maintain order in the face of disruptive influences…specifically…to control what it does" (Hollnagel and Woods, 2005). CSE focuses on analyzing Joint Cognitive Systems (JCS). JCS's are a human-machine coagency where humans and machines are described as "equal partners," humans are not described as if they are machines nor are machines given human attributes, the analysis is on what the JCS does, not what it is, and how performance is controlled (Hollnagel and Woods, 2005). Machines are expressed as artifacts in CSE. An artifact is something devised for a specific purpose, for instance a screwdriver is an artifact, so is a corporation. On a construction project one can envision many JCS's as well as many JCS's nested within others. The largest may be the JCS of the stakeholders and the organization. With regard to resilience the emphasis is in how the JCS copes with surprise

(unexpected events) and error (Woods and Hollnagel, 2006). Finally, the CSE outlook considers all work as cognitive; everything we do requires our brain (Hollnagel and Woods, 2005). This is especially true in the construction industry.

A resilient system is able to maintain control when faced with disruptions and perturbations in the form of unexpected events. A system is said to be in control if it is able to mitigate or eliminate unwanted internal or external variability with respect to the demands placed on the system, especially pressing time concerns such as schedule acceleration or increased tempo of projects (Hollnagel and Woods, 2006).

Foundations of Resilience Engineering

The notion of resilience engineering has evolved in other domains (e.g. aviation, nuclear industries) as a way to overcome the limitations of existing accident analysis and risk assessment models that are used to manage safety. As such, it is presented here as an exemplar to the construction research community. It is a proposal to cease from relying primarily on hindsight to explain the cause of accidents to exploring the sources of resilience that prevent and mitigate accidents. The process of identifying such sources presents the opportunity to recognize where gaps (i.e. where sources are lacking) in the safety process. Many accident causation models are sequential, such as Heinrich's popular Domino Model and Reason's Swiss Cheese Model (Hollnagel, 2004). The physical structure of devices such as fault-trees and event trees (i.e. the structural view) promote the idea that accident causation is linear. Additionally, regulatory standards are often just bolstered incrementally to cover the latest crack in the regulation as exposed by the latest accident. Safety is often managed by error tabulation and probabilities, such as in setting goals to reduce falls by 33%.

In contrast, resilience engineering is more focused on unearthing the positive quality of resilience rather than on managing by error counts such as the number of fatalities and injuries. Resilience engineering cites research that explains that "Untoward events more often are due to an unfortunate combination of a number of conditions, than to the failure of a single function or component" (Woods and Hollnagel, 2006). This outlook promotes the functional view, as opposed to structural views, that looks to the interdependencies among system components. In this outlook control is considered both on the activity level and on the system level, as described in the Functional Resonance Accident Model outlined below. A more subtle point of the functional versus structural view is that many accidents rarely re-occur in the same fashion but are a confluence of seemingly unrelated events, each necessary but only jointly sufficient to create an accident. In this respect resilience engineering looks more to functions of the JCS rather than to structural means (e.g. fault trees) to sort out accident causes and to propose solutions. This view is in line with the notion that work is complex and that accidents and performance variability concerns cannot be confined to a single component but emerge from a confluence of demand induced pressures (Hollnagel, 2004).

From this perspective, developing foresight, or trying to imagine what might go wrong and developing strategies to defeat failure, is a more valuable skill than relying *exclusively* on hindsight when extrapolating accident investigations to accident assessment models. To avoid failure we must anticipate key aspects of the future to imagine what might go wrong. This notion, as conceived by Westrum, is embodied

in the idea of requisite imagination. This prescient activity "…is a means for the designer to explore what can affect design outcomes in future contexts" (Adamski and Westrum, 2003). The use of this method by designers and front line workers can foretell routes to disaster, as well as to success. In light of the above discussion, safety management must then be reactive *and* proactive (Hollnagel, 2008), reactive to respond to those threats that have materialized or are imminent and proactive to bolster gaps in the organization's safety.

Resilience engineering recognizes that despite even outstanding planning efforts, performance conditions are always underspecified (Hollnagel, 2008; Rasmussen, 1983). The front-line worker, in both a JCS and non-JCS situation, must always make adjustments in the course of operations given the context of changing environmental conditions and the intensity of demands. In other words, there will always be performance variability on the part of the JCS due to the need to respond to demands imposed on the system. Resilience engineering aims to dampen the variability that may contribute to adverse events and to amplify the variability that leads to positive outcomes (Hollnagel, 2008).

Hollnagel's (2004) Efficiency-Thoroughness Trade-Off (ETTO) Principle captures an aspect of this notion. In attempts to optimize performance goals people work to be as thorough as they can be (i.e. follow the rules) given the prevailing conditions. However, there is also pressure to be efficient. People and organizations that are not efficient are, respectively, unemployed and unprofitable (or bankrupt). Also, those who are not sufficiently thorough possibly endanger safety and may also cease to exist economically. One reason thoroughness is sometimes shunted is that in the quest to optimize work processes people skip seemingly unnecessary steps in work tasks. In construction this is manifest in the phrase "We have always done it this way" when discussing field operations with, for example, a subcontractor, when in fact, field conditions may necessitate that operations be revised from what has always been done. The shortcut, (e.g. always doing it this way) is the norm in work rather than the exception given that work environments are relatively stable places and that accidents are rare events (Hollnagel, 2004). People may take certain aspects of their work for granted and skip seemingly inefficient steps. This can sometimes lead to an accident. An example might be to neglect to "tie-off" a ladder to save time. Excuses can range from "We never have ladders slip" to "I was only going on the roof for a minute." The event of an accident and its associated costs can wipe out efficiency gains from shortcuts.

Closely allied with the ETTO Principle is the outlook that failure is the temporary inability to effectively cope with complexity under demanding conditions. A situation that resilience engineering addresses closely allied to complexity is the all too common production and efficiency tensions inherent in construction. Research has shown that workers implicitly choose production over safety concerns when a trade-off is available and therefore act in a riskier manner than they normally would (Howell et al 2003, Woods, 2004). An example in construction would involve knowing when to relax production pressures by, for example, reducing overtime hours, adding additional crews, subcontracting extra work in critical periods, or simply knowing when to slow down production so that safety is not endangered. The

Stress-Strain analogy, explained in the next section, may serve as a useful guide to help managers know when to relax production pressures.

To summarize, Hollnagel (2008) defines the essential attributes of a resilient system as the ability to cope with the dimensions of the actual, the critical, the potential, and the factual of system operations. Examples of how a construction firm might demonstrate resilience with respect to each of these are presented below.

The *actual* refers to the regular threats, or those that occur enough for the individual or organization to develop a standard response that matches the current demand with adaptive capacity (Westrum, 2006; Hollnagel, 2008; Woods, 2006). Here the resilient construction firm would have site specific safety plans in place that address common hazards found on construction sites that meet safety regulations. As site conditions are always underspecified in such plans the resilient firms would be able to apply the plan over a wide range of hazard scenarios, perhaps even practicing for the occurrence of multiple 'regular events' at the same time. For instance, how well could a company deal with the occurrence of a fire and a major fall from height at the same time?

The *critical* coping mechanism refers to the importance of monitoring and assessing the system so that surprises do not catch stakeholders off guard in the near term. The Stress-Strain Analogy, explained below, is one means for assessing the state-space of system safety. A construction company may perform an honest assessment and realize that they are operating dangerously close to a safety breakdown and relax production goals or garner other resources to alleviate the problem. Surprises are abundant in the construction industry, the trick is to not let them catch you off guard.

Irregular events, or the understood but challenging one-off event(s) that are unexpected but not impossible, are the impetus for dealing with the *potential* to anticipate disruptions, pressures, and their consequences. For instance, suppose a unique (i.e. not easily replaced) crane is hoisting and installing sections in a segmental bridge over a heavily-trafficked thoroughfare. The resilient firm would plan for the possibility of the crane collapse – how would that collapse occur? how would it affect safety and operations? How could the firm regain control of the project if this happens? Planning for scenarios such as this requires the skill of requisite imagination and strengthens the firms' resistance to such events as they realize the best insurance policy is avoidance. Unexampled events could also be considered in the discussion of the potential.

Individual and organizational learning from experience is the cornerstone for dealing with the *factual*. Learning should be a continuous activity and involve all levels of the firm, from the CEO to field labor. Because fatalities and injuries are relatively rare events the opportunity to learn from them is limited. The resilient construction firm will take opportunities to learn from near-misses which occur more frequently than fatalities (Groenewig, 1998). This outlook assumes that an atmosphere of true collaboration exists and that associates are able to voice legitimate concerns without retribution from others.

Stress-Strain Analogy for Resilience Engineering

Woods and Wreathall (2008) borrow the concept of stress-strain plots from material science to characterize and assess the resilience of a system. Figure 1 illustrates a typical stress-strain plot. Varying demands placed on a project (e.g. production and labor demands as described above) stand-in for stress (normally on the y-axis) on the plot. Strain is analogized to describe how the system adapts (or stretches), using available capacity (e.g. working overtime, renting additional excavation equipment) to the stress applied. Strain is plotted on the x-axis. The defining characteristic (i.e. parameters and regions) of the typical stress-strain plot, also known as the state space, distinguishes the organization (or unit of analysis) as resilient in terms of adaptability. The state space also acts as a harbinger for management so that they can calibrate the organizations true status with perceived status. Typically, managers overestimate the state of safety, in other words firms believe that they are acting in a safer manner than reality indicates.

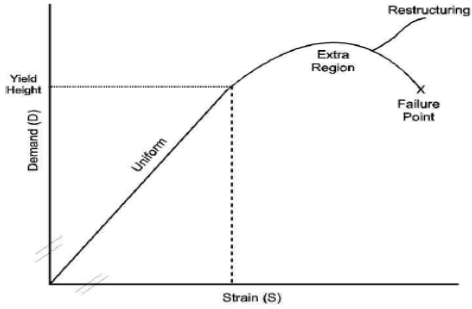


Figure 1: Stress-strain state-space (from Woods and Wreathall, 2008)

The uniform portion of the curve (the elastic region) corresponds to times and situations where the organization handles demands easily, stretching to accommodate them. Here the risks are anticipated by building in capacity to avert extraordinary failure or disruption. In other words, the company has adequately foreseen disruptions that may impact failures. Plans, procedures, and flexibility in operations are the bellwether of the uniform region. In general, the demands are well-known and accounted for, making stretching easy in this region. The yield height (the inflection point of the curve where elasticity ends and plasticity begins) of the uniform response curve captures the first-order adaptive capacity of the firm. The linear region is also called the *on-plan* performance area.

The yield height can be adjusted by adding capacity in the uniform region or by changing the range of demands the curve can accommodate. One example could be additional training such as high-rise rescue training, drills, and simulation on a multi-story building. Thinking in terms of adaptation and capacity can help the construction manger foresee risks and adapt plans accordingly.

Beyond the uniform region lies what Woods and Wreathall call the extra region (x-region for short). In material science this is known as the plastic region. Here the demands encountered become more difficult to accommodate and the firm's reaction to them is non-linear. Demands are imposed upon the firms that go beyond what was

anticipated in the on-plan performance area. In this region safety and production efficiencies may be compromised as 'gaps' appear in the organizations that exceed the first-adaptive capacity. Resources, or second-order adaptive capacity, must be garnered to avoid reaching the failure point. Commonly, experienced groups or individuals at the workface can recognize when they are operating in the plastic region and take actions to cope with increasing demands, in other words they begin to fill in the 'gaps' caused by lack of capacity and foresight. These actions are indicators that the firm is in the x-region. This is reflected in the upswing portion of the x-region that corresponds to extra capacity added to meet demands. This action is fraught with potential problems. Other bottlenecks and constraints may appear and the tempo of the project increases. For instance, adding additional crews will incur more supervision. If additional superintendents or other supervisors are not added as the tempo increases in the x-region then safety might suffer as other areas on-site are neglected.

If the demands imposed in the x-region begin to exceed second-order adaptive capacity then the curve begins to acquire a negative slope and heads toward the failure point. To avoid failure, the firm may decide to *re-structure.* The re-structuring occurs at a point in the x-region, prior to failure but at a location where there is time to rally the requisite resources to rescue the project. This could entail comprehensively re-planning the project. Resilient firms will anticipate the re-structuring phase and adjust capacity accordingly. Firms that are not resilient may erode safety margins and endanger personnel. This highlights the importance of calibration, or knowing where a firm is situated with respect to the state space system. Mis-calibrated firms don't realize that they are in the x-region or perhaps heading toward failure.

The Functional Resonance Model (FRAM)

In 1976 Halpin and Woodhead posited that construction operations can be grouped by structure, material, or by function. It seems axiomatic to state that safety is best approached from a functional perspective. To that end the FRAM model developed by cognitive scientist Eric Hollnagel, a leading protagonist of resilience engineering, is being examined by the researchers for its suitability to aid the improvement of construction safety.

The FRAM is a qualitative and systematic approach to accident modeling that describes how the interdependencies of multiple functions and conditions combine and resonate. Systems that resonate "out of control" as defined by tightly-coupled system parameters may lead to an adverse event (Hollnagel, 2004). FRAM principles include: that failure is averted by parties anticipating risks and hazardous situations and taking the appropriate action in time to avoid or mitigate their effects; adjusting and adapting work performance to meet actual work conditions is necessary to avoid accidents; that variability from multiple sources may cause the system to act in emergent and non-linear ways; and that accidents are a dynamic phenomena not attributable to simple causal links (Hollnagel et al, 2008).

Resonance is a physical phenomenon that explains the tendency of a system to oscillate at maximum amplitude at certain frequencies. An example is the simple child's swing. Small movements by the child (or an externally applied force) at the

right moment can produce large amplifications in the swing, conversely movements at the wrong time can dampen the swing. To be in control a system must operate within its natural frequency, otherwise the system may fail (e.g. The Tacoma Narrows Bridge, "Galloping Gertie," collapse in 1940).

Formally defined, functional resonance is "…the unanticipated non-linear combination and amplification of normal - and normally useful - performance variability" (Hollnagel, 2004). The FRAM inspects the functional resonance among systems and sub-systems for resonance that occurs in unwelcome ways (i.e., is damaging to the system). It should be noted that some variance is welcome and useful so that the system operators can spot weaknesses in the adaptive capacity (Furniss et al, 2007). Potential problems can be identified by illuminating the dependencies among and between different subsystems and anticipating those that may dynamically resonate in an unanticipated manner.

The steps involved in developing a FRAM representation of a system consists of: a)identifying and characterizing essential system functions; b) characterizing the context potential for variability using a context specific checklist; c) defining functional resonance based on identified dependencies among functions; and d) identifying barriers for variability (or damping factors) and specifying required performance monitoring (Hollnagel, 2004).

Graphically, the FRAM is represented by modules/nodes that represent functions/activities. Connected modules form a network of dependencies. The 6 ports serve as connection points to other functions/activities to form dependencies. The module and connectors are described in Figure 2.

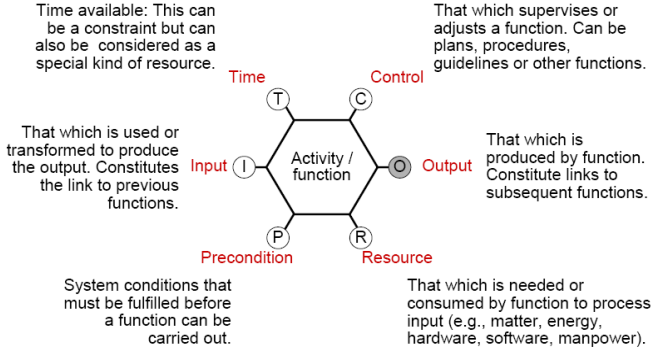


Figure 2: FRAM hexagonal node representation and connector descriptions (Hollnagel, 2004)

A tunneling operation example borrowed from Halpin and Woodhead (1976) is used to demonstrate the FRAM. A tunneling operation can be described by the 3 sub-activities (or functions) of lowering/positioning the pipe from a lay down area or truck flatbed, installing the jacking collar and jacks, and forward jacking the pipe.
Due to space limitations here the entire network cannot be shown and a single representative checklist is illustrated in Table 1. In a complete FRAM model multiple

nodes as depicted in Figure 2 would be represented and their ports interconnected as defined by the investigator/modeler. In the tunneling example the 3 sub-activities could be represented and the corresponding ports connected. For example, the output node of 'lower/position pipe' could be connected to the input node of 'installing the jacking collar and jacks' function.

Function	Lower/Position pipe
Input	New section of pipe
Output	Pipe off-loaded from truck & lowered into shaft
Preconditions	Site clear & level, stable outrigger surface and pads, certified crane operator, hand signal training, favorable weather conditions
Resources	Crane, pipe harness(s) & slings, trained crew
Time	Sufficient to load & lower pipe
Control	Lift plan in place, site specific safety plan, identification of known hazards (overhead power lines, etc.), daily crane checklist, rigging examined for fitness of use,...

Table 1: Checklist for Tunneling example (adapted from Hollnagel template, 2004)

Conclusion

This paper explored the notion that resilience engineering, as devised and applied in other domains, can serve as an exemplar to improve construction safety. The genealogy of resilience engineering was traced to its cognitive systems engineering roots and the concept was explained in general terms and by analogy to the stress-strain diagram. Finally, the FRAM was explained as a model that supports the resilience engineering g concept.

Further research is needed before resilience engineering might be used as a construction model. To date it is mainly a qualitative approach. Quantitative indicators of resilience are needed as well as a solid framework of how it could be used in the construction industry. The FRAM may help to visualize the interdependencies and associated hazards between functional activities on a broader scale than is now possible. Research directions by the authors include developing a framework of construction safety inspired by resilience engineering. To test the framework an agent based model simulation (ABMS), where the agents are given resilient engineering qualities and compared to agents having traditional qualities, will be pursued.

References

Adamanski. A. and Westrum, R. (2003). "Requisite Imagination: The Fine Art of Imagining What Might Go Wrong" in. *Handbook of cognitive task design. Human factors and ergonomics*. Hollnagel, E., N.J., Mahwah, eds., Lawrence Erlbaum Publishers, 193-220.

Datta, P. (2007). **"**A complex system, agent based model for studying and improving the resilience of production and distribution networks." PhD dissertation, Cranfield University, School of Management.

Dekkar, S. (2006). *The Field Guide to Understanding Human Error*. Ashgate, Aldershot, UK.

Groeneweg, J. (1998). *Controlling the Controllable*. DSWO Press, The Netherlands.
Hollnagel, E. (2004). *Barriers and Accident Prevention*. Ashgate, Aldershot, UK.
Hollnagel, E., and Woods D.D. (2005). *Joint Cognitive Systems: Foundations of Cognitive Systems Engineering*. Boca Raton, FL: Taylor & Francis.
Hollnagel, E. (2006) "Resilience – The Challenge of the Unstable" in Hollnagel, E., Woods, D. D., & N. Leveson, eds., *Resilience engineering: concepts and precepts*. Aldershot, England, Ashgate, 9-17.
Hollnagel, E. (2008). "Resilience Engineering in A Nutshell." *Resilience Engineering Perspectives. Volume 1, Remaining Sensitive to the Possibility of Failure*, Hollnagel, E., Nemeth, C. P., & S. Dekker, eds., Ashgate studies in Resilience Engineering. Aldershot, Ashgate, xi-xiv.
Howell, G. A., Ballard, G., Abdelhamid, T. S., and Mitropoulos, P. (2003). "Rethinking safety: Learning to work near the edge." *Proceedings of the 2003 ASCE Construction Research Congress*, 19-21 March 2003, Honolulu, Hawaii.
Morel G, Amalberti R, & Chauvin C. (2008). "Articulating the differences between safety and resilience: the decision-making process of professional sea-fishing skippers." *Human Factors,* 50(1), 1-16.
Reason, J. (1997). Managing the Risks of Organizational Accidents. Ashgate, Burlington.
Sheridan, T. (2008). Risk, "Human Error, and System Resilience: Fundamental Ideas." *Human Factors -New York Then Santa Monica.* 50(3), 418-426.
Woods,D. and Wreathall, J.(2008). "Stress-Strain Plots as a Model of an Organization's Resilience." *Resilience engineering perspectives. Volume 1, Remaining sensitive to the possibility of failure*, Hollnagel, E., Nemeth, C. P., & S. Dekker, eds., Ashgate studies in Resilience Engineering. Aldershot, Ashgate, 143-158.
Woods, D. D., & Hollnagel, E. (2006). Joint cognitive systems: patterns in cognitive systems engineering. Boca Raton, CRC/Taylor & Francis.
Woods, D. (2006). "Essential Characteristics of Resilience. " *Resilience engineering: Concepts and Precepts*, Hollnagel, E., Woods, D., & N. Leveson, eds., Aldershot, England, Ashgate, 21-34.
Woods, D. D. (2007). Proactive safety management: Engineering resilience makes the difference between a disruption and a disaster. *Industrial Engineer –Norcross,.* 39, 44-48.

IDENTIFYING AND COMMUNICATING PROJECT STAKEHOLDER RISKS

Dr Peter J Edwards[1], Professor Paul A Bowen[2], Professor Cliff Hardcastle[3], and Dr Peter J Stewart[4].

[1]School of Property, Construction and Project Management, RMIT University, GPO Box 2476V, Melbourne 3000, Australia. peter.edwards@rmit.edu.au Tel: +61 3 9925 2230; Fax: +61 3 9925 1939 (corresponding author).
[2]Department of Construction Economics and Management, University of Cape Town, Rondebosch, South Africa. paul.bowen@uct.ac.za
[3]University of Teesside, Middlesborough, UK. cliff.hardcastle@btopenworld.com
[4]Department of Education and Early Childhood Development, State Government of Victoria, Melbourne 3000. Australia. stewart.peter.jp@edumail.vic.gov.au

Abstract:
A systematic approach to risk management is needed if stakeholders are to effectively manage the risks they face on projects. Risk identification is a critical part of risk management. Using observations from project experience and class workshops, the effectiveness of several risk identification techniques is explored in the context of construction projects. Emphasis is given to the risk communication processes involved, from an intra-stakeholder perspective. While some techniques are effective for particular project stages and situations, a work breakdown structure (WBS) approach is found to be a good 'fall back' method for identifying project risks at the schematic and subsequent design stages. The more detailed the WBS, the more comprehensive the risk identification can be. Multiple risk identification workshops are recommended during the pre-construction phase of a project. Precise risk statements are essential for effective risk communication, and project risk schedules should be developed as active documents.

Introduction

Risk management is a systematic way of dealing with risk. There is general agreement in the literature about the process of risk management, albeit with some differences in the labelling and detail of the steps involved (e.g. Flanagan and Norman 1993; Chicken 1994; Grey 1995; Chapman and Ward 1997; AS/NZS 4360 2004; HB436 2004; Cooper *et al.* 2004; Edwards and Bowen 2005). Broadly, systematic risk management should:

- Establish the context
- Identify risks
- Analyse risks
- Respond to risks
- Monitor and control risks
- Capture risk knowledge

The consistency and level of adoption of these processes, the application of appropriate techniques in undertaking them, and the knowledge expertise gained in doing so, hallmarks the risk management maturity of an organisation.

Most projects are not unilateral undertakings – different stakeholders are involved. Projects undertaken in the public sector may often involve the engagement of multiple stakeholders and project failure – rather than project success – will commonly be reported in the media. Clearly risk management becomes more critical for public projects as complexity, community impact and scale increase. Even "in-house" or "entrepreneurial" private sector projects usually have external organisations engaged in the project process at some point. Each stakeholder is likely to be participating in different aspects of the project and may be seeking to fulfil different objectives. Potential conflict between the different objectives of different stakeholders means that they cannot share the same risk management system, since they will each be trying to deal with different risks – possibly in different micro-contexts – on the same project.

Risk has negative and positive connotations: it may pose a threat (to the achievement of objectives) or provide an opportunity (to exceed them or to fulfil them more efficiently). Threat risks tend to command more attention than opportunity risks (both in the literature and in practice) since their realisation inevitably leads to some perception of project failure. The neutral definition of risk: *'the chance of something happening that will have an impact upon objectives'* (AS/NZS4360 2004: p4) is adopted for this paper, but from a threat perspective.

Construction project threat risks are rarely managed by individuals acting alone, but a team responsible for identifying a stakeholder's risks will not necessarily be the same as one involved in analysing the risks, nor the one that will treat, monitor and control them. The managerial function assigns different responsibilities to different people/groups (within the stakeholder organisation and beyond). Risk information may have to be transmitted *intra*-organisationally and/or *inter*-organisationally. Communication therefore becomes an important aspect of risk management (and hence of risk identification). HB 436 (2004) notes that risk management is a key business process; not just a technical task but an activity undertaken in a social context where communication and consultation are an integral part of risk management and should be considered explicitly. A guidance document of the Victorian State Government (DTF, 2007: p4) advocates a common risk management methodology that *'...supports the sharing of risk management information at agency, inter-agency and whole-of-government levels…'.*

The purpose of this paper is therefore to suggest a conceptual understanding of the project risk context, and to explore techniques for identifying threat risks faced by

particular stakeholders on particular construction projects. These are presented from an underlying aim of achieving effective risk communication in the process.

The paper is based upon experiential observation rather than empirical research involving controlled tests or surveys. The authors have drawn upon their own experience in the construction industry, and upon the reflective efforts (in class workshops and assignments) of many postgraduate students in project management programs at universities in Australia, South Africa, Scotland and Singapore.

The context for project risk management

Unless the context is properly established, there is little chance of identifying project risks thoroughly. Given the theme of this conference, the obvious macro-context for risk management is the unique construction project. However, this context has to be elaborated more carefully.

Project risks arise from the decision-making associated with the pursuit of project objectives (Parkin 1996). The nature of construction projects means that decisions are made at a very early stage that might affect the delivery/procurement of a project, its operational phase, or even its eventual disposal – or any combination of these (Edwards and Bowen 2005). Project management students with a background in construction projects, given their preoccupation with the delivery/procurement phase, sometimes find this concept difficult to follow through in terms of the risk management context. The conceptual gap can be bridged by considering short term events projects, such as a Formula 1 grand prix motor race on a temporary street circuit, where construction risks may be encountered by a stakeholder (over a period of no more than a few weeks) in the delivery, operational and disposal (street/amenity restoration) phases of the project.

Decision making is associated with every element of a project, including the tasks (what is to be done); technologies (how it is to be done); and resources (materials, labour, finance etc. required to do it). The decisions are made within a co-ordinating element of organisation (planning, ordering, staffing, supervising, etc.) which itself involves extensive decision- making.

Furthermore, projects do not take place in a vacuum. They arise, and are undertaken within an environment which embraces aspects which may be perceived as physical, social, or economic. These are not mutually exclusive, and form the *drivers* of project risk (Russell and Nelms 2007). All risks are shaped in some way by them. Physical environmental risk drivers might include factors such as location, topography, geology, hydrology, seasonal weather variation, technical feasibility, etc. Social risk drivers could include cultural factors (Edwards *et al.* 2005a), issues such as indigenous land ownership and mineral exploitation rights, as well as statutory instruments and codes. Employment creation policies, loan finance availability, loan interest rate variability, rental market climate, materials and labour supply, and prevailing levels of construction demand constitute some of the economic risk drivers for a project. This concept of project context is depicted in Figure 1.

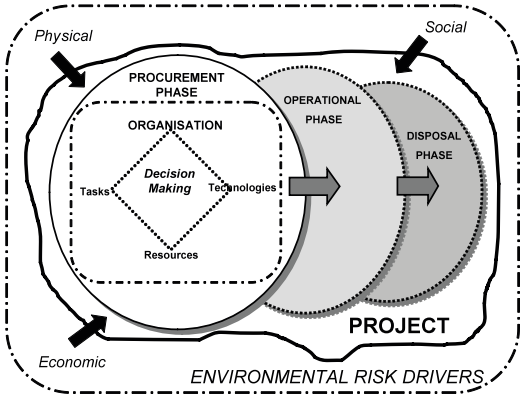


Fig. 1. The project context for risk identification (project phases, elements and environmental risk drivers).

Establishing the context for identifying project risks for a particular stakeholder entails:

- Identifying the target project.
- Clarifying the stakeholder's contribution and project objectives.
- Selecting the relevant project phases(s): delivery/procurement; operation; disposal.
- Identifying the dominant organisational aspect of the stakeholder where project decisions are made.
- Selecting, and then assessing the available information, the stakeholder's task, technology, resource and organizational elements of the project.
- Assessing the presence and strength of relevant environmental risk drivers.

Project risk management workshops often proceed in the belief that the project context is familiar to all participants. This is rarely completely true. Most participants will have some knowledge of some aspects of the context, but few will enjoy a complete and comprehensive grasp. Communication processes at the start of a risk identification workshop should therefore focus on achieving an acceptable and common level of understanding about the project context. Knowing the context allows risk identification to proceed.

Risk Identification

"Unknown" projects are inherently more risky than "known" projects (Smith 1999) and unless some attempt is made to explain the unknowns – and expose their assumptions – their associated risks will not be identified. If risks are not identified, they remain risks but cannot be managed proactively and thus may eventually

become crises requiring re-active treatment (and possibly disaster recovery). Nor should risk identification be seen as a "once only" stage of risk management, since the progress of a project from concept through plan to reality may give rise to new risks that must then also be identified, analysed and treated. The same progression should generate more information that will decrease the level of uncertainty in some aspects of the project (see Figure 2): thus some risks may have to be revisited and their characteristics (likelihood and impact) re-assessed in the light of new knowledge. Project risk management should therefore be applied as an iterative cycle of activities (Edwards and Bowen 2005) to match the dynamic nature of the risks.

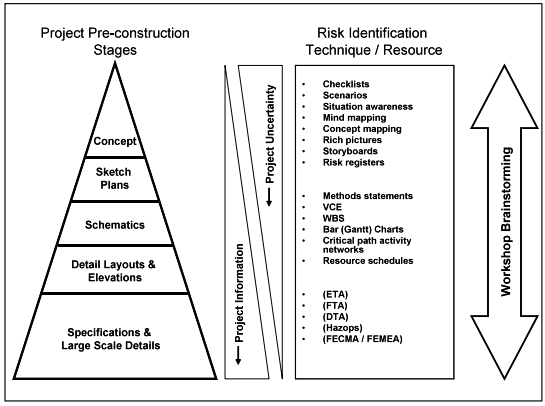


Fig.2. Project pre-construction stages and risk identification techniques.

The focus in this paper is on the pre-construction stages of a project since this part of the procurement phase provides the best period for effective risk identification. It is also the stage where many decisions are made that will affect the subsequent operational and even the eventual disposal phases of the project.

Figure 2 indicates typical pre-construction design stages for a project, and risk identification techniques/resources appropriate to each stage. Brainstorming is an essential ingredient across all stages and all techniques, preferably used on a group basis within a facilitated risk identification workshop. The workshop group participants should be capable of providing expert judgement in all relevant areas of the project, and should represent the decision-making hierarchy of the stakeholder organisation. While a workshop itself may be conducted informally (but with clearly recognisable structure and experienced facilitation/leadership), the workshop outcomes should be recorded formally – preferably by using a lap-top computer and/or electronic whiteboard. Suitably edited summaries of these outcomes, including a complete list of risks identified for the stakeholder organisation on that project, should be communicated back to participants after the workshop, for comment and confirmation or correction. It is important for the stakeholder to "own" its risks in this way.

At the conceptual stage of project design, little may be decided about the project other than its scope and nature in terms of procurement and functional objectives.

Checklists are advocated (Chong and Brown 2000) but their effectiveness in risk identification at this point is constrained by their reliance on the availability of information from similar historical projects. Limitations also arise because such lists frequently comprise only one- or two-word descriptions of risks that do not necessarily convey the same meaning to all workshop participants; e.g. for one participant "cost over-run" is a risk event but for another it is a consequence of some other prior risk event. Similarly "safety" may be construed as alluding to threat risk events but is more likely to be a project procurement objective for a construction company. A further problem at this stage is that, while a checklist may help to identify many risks, there is unlikely to be sufficient information available in the conceptual design stage to reliably assess the comparative severity of those risks, and the subsequent risk management process may stall.

Risk registers may also be used at the conceptual stage of a project. These differ from checklists in that they should comprise a fuller exposition of the organisation's formal repository of risk knowledge. Risks recorded in the register will include descriptions of source events, frequency of occurrence, magnitude and timing of potential consequences, treatment options, control procedures and indications of risk management costs. In this sense, a risk register is distinguished from a project *risk schedule* in that the latter is an explicit record of the risks that an organisation proposes to manage for a specific project. It is the product of the risk management workshops for a specific project. A risk register, on the other hand, is a compendium of risk knowledge gained from the organisation's experience across all projects and from other external sources. Although risk registers are technically better than checklists for identifying risks at the conceptual stage of design, they share some of the disadvantages of checklists, and a strategic approach may be more desirable at this early point. Techniques such as *situation awareness and mind/concept mapping* can be effective (McLucas 2003), but prior training and an experienced facilitator in the risk identification workshop are essential if brainstorming structured in this way is to be successful. Rich pictures and storyboarding can also be used but suffer from similar constraints (postgraduate project management students have reported them to be useful in some specific situations but generally "woolly" and imprecise, especially if workshop participants begin to stray from the project context). A more appropriate approach might be to use *scenario testing* (or *scenario analysis*, see HB436 2004) particularly since the design concept stage often marks a strategic decision point when major "go/no-go" decisions about a project are made. The scenario approach asks workshop participants to brainstorm the risk implications if "situation X" was to arise during a particular phase of the project. Multiple scenarios can test a variety of potential "X" situations. Micro-scenarios might relate to intra-organisational events (e.g. key personnel are suddenly lost). Macro-scenarios can be escalated to higher levels of concern (e.g. a sudden increase in oil prices occurs beyond a global benchmark; political unrest arises in a project location or nearby country; anticipated government support fails to materialise; or another "9/11" or "tsunami" disaster happens). Scenario testing can reveal (often dramatically) the vulnerability of a project to crisis-type events. While threat risk scenarios are most commonly used,

opportunity risk scenarios are also possible if workshop time permits. Any scenario proposal for a risk identification workshop requires careful consideration beforehand, and should not be based on sudden whim, but the workshop focus needs to stay on the implications for the project and not on the event itself.

The pre-construction sketch plan and schematic design stages develop physical form and texture for a project, and allow decisions to be made regarding the main technical design solutions, together with some notion of issues of buildability. During these stages, the usefulness of the more strategic risk identification techniques (including scenario testing) falls away quite rapidly as more definitive project information quickly builds up and the cost / benefit ratio of the strategic techniques diminishes. Checklists and risk registers, on the other hand, are far more relevant during these stages since closer, more reliable comparisons can be made with historical project contexts. *Methods statements* (relating to the construction process) may also be useful to guide risk identification at this point, and can be interrogated in terms of particular types of risk.

The preparation of small-scale detailed layouts and elevations, and the subsequent provision of specifications and large-scale details, mark the stages when decisions about the construction process itself can be considered with sufficient confidence for project planning devices such as *work breakdown structures* (WBS), *bar charts*, *activity networks* and *resource schedules* to be prepared and utilised. Quite early in these stages, it may be possible to create a computerised dynamic rendering of the project and its construction process, using *VCE* (Virtual Constructed Environment) IT applications (Lucas *et al.* 2008). A VCE may offer an effective resource for project risk identification, since it is a powerful visual medium capable of spurring focussed brainstorming.

Questions addressed by a threat risk identification workshop during these stages would focus upon what could threaten a successful outcome for a particular task; the application of a particular technology; the acquisition of a particular resource; or the effective management of a particular process? Since all the techniques noted above are based upon decomposing a project into its constituent parts or activities, they all provide useful foci for answering these questions. The WBS has an additional advantage, since it also allows identified risks to be mapped, using a two-dimensional matrix of work items against risk categories and/or risk shaping factors (Edwards *et al.* 2005a; 2005b). Bar charts and activity networks are less useful for mapping identified risks as they are already two-dimensional graphic representations of project activities against time, and the introduction of a third (risk category) dimension may be too confusing for the workshop. Students and workshop participants generally express enthusiasm for decompositional approaches to risk identification, as most are familiar with techniques of project planning and scheduling. However, they also report that this approach is time-consuming unless the diagrams are pre-prepared for the workshop, and point out that the attainable levels of project decomposition are still limited by the extent of project information available. Nevertheless, WBS and similar techniques are generally regarded as providing a good “fall back” approach under most circumstances, capable of creating a sound platform for risk identification.

More structured, dedicated techniques for risk identification found in the literature include: HAZOPS (Hazard and Operability Studies) and FECMA (Failure Effects and Criticality Mode Analysis) or FEMEA (Failure Events Modes and Effects Analysis) – originating in the chemical engineering and automotive manufacturing industries respectively (AS/NZS 3931, 1998, and the website URLs). While these techniques can be used for risk identification in the detail and specification stages of project design, in practice their effectiveness for construction projects is found to be quite limited. Given their origins they are more suitable for application to the design of the operational requirements of facilities rather than to the procurement (construction) phase. Postgraduate project management students have reported that adapting design interrogation questions formulated for the typical operational flow processes of production engineering systems, to suit the more diverse and complex systemic features of construction projects, is just too difficult and time-consuming.

Sutton (1992) explains event tree analysis (ETA) and fault tree analysis (FTA) as risk identification tools, together with decision tree analysis (DTA), but the real benefit of these techniques is found more in the analytical processes of risk management (HB436 2004). These diagrammatic techniques are capable of exposing risk drivers (mainly for threat risks but also for opportunities) through identifying areas of relative uncertainty in a project. ETA inductively traces the potential consequences of an identified risk event (so the event must be known before ETA can be applied). FTA deductively analyses causes of an "event" which is actually a consequence of those causes. DTA explores the implications of alternative options/outcomes in a sequence of related decisions. The main disadvantages with all the diagrammatic "tree" approaches are that few workshop participants will be completely familiar with them (particularly in terms of their theoretical logic) and that the essential diagrams cannot be prepared beforehand.

Using a workshop approach to risk identification in the pre-construction stage of a project gives rise to the question as to how many such workshops should be held? The answer will be guided by the scope and scale of the project itself. For construction projects perceived as relatively small, uncomplicated and familiar in terms of stakeholder experience, a single workshop held during the period when detailed layouts and elevations are available should be sufficient to identify risks using a checklist, risk register or WBS approach. Larger, more complex and less familiar projects might warrant a short workshop, using scenario testing, at the conceptual design stage; followed by a longer workshop when layout details and elevations are known. Major projects, in terms of scale, scope, complexity and value would easily justify at least three risk identification workshops during the pre-construction stage.

Whatever the number and size of the risk identification workshops, their outcome should be a project risk schedule (ideally designed as an active "live" document rather than a passive record) incorporating precise statements of the risks faced by the stakeholder organisation. The statements should each describe the type of risk, the risk event and its likelihood, and the consequences for the project, plus an indication of the exposure period where appropriate. For a construction project, a typical contractor's risk statement might be:

"There is a chance 'p' that shortages in the supply of cement will occur over the next 12 months, causing delay and additional cost during the concrete casting phase of the project (Economic Risk)."

While lacking quantitative detail at this stage of risk management, this level of risk statement precision provides a clear framework for subsequent analysis and assessment of risk severity. It may also provide clues about subsequent treatment options for the risk. A spreadsheet provides a good basis for a project risk schedule, facilitating subsequent risk analysis and recording of treatment decisions, together with monitoring and control procedures. The use of IT intra-nets will enable risk communication across the stakeholder organisation to be undertaken effectively in a controlled manner.

Conclusions

Construction projects are complex systems, often undertaken in difficult and uncertain circumstances involving many stakeholders. They are inherently risky endeavours. A systematic approach to dealing with project risks (especially threat risks) is a prudent approach to project management for a stakeholder. Proactive management of risks requires that they be identified as early as possible in the pre-construction phase. Decision-makers in a project stakeholder organisation need to have a comprehensive understanding of the project context and objectives in order to successfully identify risks. Facilitated group-based workshops allow this understanding to be achieved and risk identification to be carried out. The number of risk identification workshops needed during the pre-construction phase will be informed by the nature of the project and its scope and scale. While several techniques are available to identity project risks, not all are suitable for construction projects and not all can be applied throughout the pre-construction phase. Brainstorming, using a work breakdown structure as a guide, is a practicable approach when a reliable WBS becomes available. The workshop outcomes should comprise precise statements of each identified risk. Achieving these outcomes requires effective communication, both within the risk identification workshops and across the decision-making hierarchy of the stakeholder organisation.

References

AS/NZS 3931 (1998) *Risk analysis of technological systems - application guide*. Standards Australia. Homebush, NSW.

AS/NZS 4360 (2004) *Risk Management*. Standards Australia. Homebush, NSW.

Chicken, J. (1994) *Managing risks and decisions in major projects*. Chapman and Hall. UK.

Chapman, C B and Ward, S C. (1997) *Project risk management: processes, techniques and insights*. John Wiley and Sons. UK.

Chong, Y Y and Brown, E M. (2000) *Managing project risk*. Pearson Education Ltd. (Prentice Hall). London.

Cooper, D F., Grey, S J, Raymond, G A and Walker, P R. (2004) *Project risk management guidelines: managing risk in large projects and complex procurements*. John Wiley and Sons. UK.

DTF (2007) *Risk Management Framework.* Department of Treasury and Finance. Victorian State Government, Melbourne, Australia.

Edwards, P J and Bowen, P A. (2005) *Risk management in project organisations*. UNSW Press. Sydney / Elsevier Science International. London.

Edwards, P J and Bowen, P A. (2007) Construction risk management as a universal systematic application. *Proceedings:* CME25 Conference (Construction Management and Economics Journal) "Past, Present and Future". 16 - 18 July. University of Reading. UK.

Edwards, P J, Bowen, P A and Stewart, P J. (2005a) Cultural risks in construction procurement. *Proceedings:* CIB W92/TG23 Symposium: Construction procurement – the impact of cultural differences and systems on construction performance. International Council for Information and Research in Building and Construction (CIB). 8 – 10 February. University of Las Vegas, Nevada, USA.

Edwards, P J, Hardcastle, C and Bowen, P A. (2005b) Mapping risk and complexity for construction projects. *Proceedings:* Becon2005 – 1st International Conference on Built Environment Complexity. 11 - 14 September. Centre for Complexity Research. University of Liverpool. UK.

Flanagan, R and Norman, G (1993) *Risk management and construction*. Blackwell Science Publications. London.

Grey, S J. (1995) *Practical risk assessment for project management*. John Wiley and Sons. UK.

HB436 (2004). *Risk Management Guidelines - Companion to AS/NZS 4360*. Standards Australia. Homebush, NSW.

Lucas, J., Thabet, W. and Bowman, D. (2008) Using Virtual Prototyping techniques for implementations of a Virtual Constructed Environment. *Proceedings:* CIB W78 25th International Conference on IT. (Ed. Leonardo Reischmoller. International Council for Information and Research in Building and Construction (CIB). 15 – 17 July. Universidad de Talca, Santiago, Chile.

McLucas, A C. (2003). *Decision making: risk management, systems thinking and situation awareness*. Argos Press. Canberra.

Parkin, J. (1996) *Management decisions for engineers*. Thomas Telford. London.

Russell, A.D. and Nelms, C.E. (2007) The application of information technology to support the elicitation of expert judgement in project risk management. *Proceedings:* CME25 Conference(Construction Management and Economics) "Past, Present and Future". 16-18 July. University of Reading. UK.

Smith, N J. (1999) *Managing risk in construction projects*. Blackwell Science Publications. London.

Sutton, I S. (1992) *Process reliability and risk management*. Van Nostrand Reinhold. New York.

Websites

www.uscg.mil/hq/g-m/risk/e-guidelines/hazop.htm (accessed June 2008)

www.rsc.org (accessed July 2008)

A RISK-BASED APPROACH TO CONTINGENCY ESTIMATION IN HIGHWAY PROJECT DEVELOPMENT

Keith R. Molenaar[1], Craig R. Wilson[2]

ABSTRACT

Highway design and construction projects require engineers and construction managers to coordinate a multitude of human, organizational, technical, and natural resources. These projects can be extremely complex and fraught with uncertainty. The engineering and construction complexities are often overshadowed by economic, societal, and political challenges. The outcome of these challenges has too often been significant cost escalation. This paper discusses a three-tier approach for risk analysis and contingency estimation that has been developed through two National Cooperative Highway Research Projects (NCHRP) and applied in one research project for the Minnesota Department of Transportation (Mn/DOT). The three tiers have been defined as: Type I - risk identification and contingency percentage; Type II - qualitative risk analysis and identified contingency items; and Type III - quantitative risk analysis and active contingency management. This paper explains this approach and discusses its application in the highway project development process.

BACKGROUND

Project cost escalation is a major problem for state highway agencies (SHAs). The problem of project cost exceeding SHA estimated cost is a major performance issue and erodes the travelling public's confidence in public engineers' ability to deliver and maintain our US highway network. The ramifications and effects that result from differences between early project cost estimates and the bid price or the final project cost are significant. This fact is illustrated by the media coverage and political response to bids for the Woodrow Wilson Bridge in Washington, D.C. and the San Francisco-Oakland Bay Bridge East Span, and to the cost increases on the Central Artery/Tunnel project in Boston (National 2003). These problems are pervasive in the transportation industry. A study of 258 infrastructure projects spanning a time

[1] K. Stanton Lewis Associate Professor, Dept. of Civil, Envir. & Arch. Engineering, Campus Box 428, Univ. of Colorado, Boulder, CO 80309-0428, Phone (303) 735-4276, keith.molenaar@colorado.edu

[2] Graduate Research Assistant, Dept. of Civil, Envir. & Arch. Engineering, Campus Box 428, Univ. of Colorado, Boulder, CO 80309-0428, Phone (303) 735-0815, craig.wilson@colorado.edu

period of more than 70 years found that project costs are underestimated in approximately 90 percent of the projects, and actual costs average 28 percent higher than estimated based on this sample (Flyvbjerg, et. al 2002). Although highway projects fared better than rail and fixed-linked projects, the sample still displays an increase in project costs of more than 20%. Clearly, additional guidance would assist in better estimating procedures for SHAs.

The National Cooperative Highway Research Program (NCHRP) is investing in two major research efforts to address cost escalation. The first study, NCHRP Project 8-49, Procedures for Cost Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction, is complete and has resulted in the publication of a guidebook for cost estimating, NCHRP Report 574 (Anderson et al. 2007). NCHRP Report 574 identifies 18 cost escalation factors and addresses these factors through a systematic approach to cost estimating and management consisting of eight global strategies, 30 implementation methods and 90 tools applications.

In completing NCHRP Project 8-49 members of the research team and the NCHRP research panel identified the need for more detailed tools in the areas of risk analysis and risk management, particularly in the long-range transportation planning, priority programming, and preconstruction stages of the project development process. Upon completion of Project 8-49, NCHRP began a second project to specifically address cost escalation through risk analysis and risk management applications. NCHRP Project 8-60, Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs, is addressing the cost escalation issue through the following project goals:

- Developing consistent definitions for "cost escalation," "risk," and "uncertainty";
- Developing guidance for consistent application of contingency to risk management and cost estimation;
- Developing systematic and uniformed approach for documenting and tracking risk;
- Identifying appropriate timing of risk management procedures given various levels of project complexity during the different project development phases;
- Addressing policy, political, and communications issues;
- Determining appropriate organizational structures and required organizational commitment to achieve a risk management culture; and
- Developing performance measurements and accountability tools that can exist within transportation agency organizational structures.

NCHRP Project 8-60 will provide a guidebook of risk analysis tools and management practices to aid in controlling project costs. The guidebook will address risk identification, assessment, analysis, mitigation, allocation, and tracking and control in a manner that is systematically integrated into the organizational structure and culture of our nation's SHAs (NCHRP 2008).

As part of the NCHRP 8-60 project, the research team conducted a survey of current risk management practices. The results of this survey were used to steer the development of the guidebook. This survey revealed that only six percent of state highway agencies had published project risk management policies or procedures.

Additionally, only 19 percent had a published definition of contingency. Given the large amount of uncertainty in transportation projects, these results are alarming.

Uncertainty and risk play a major role in cost escalation throughout project development. State highway agencies need guidelines that comprehensively describe risk-related analysis tools and management practices for estimating and controlling transportation project cost. Inadequate estimating invariably leads to misallocation of scarce resources. If estimates are consistently high, compared to bid costs and ultimately final costs, fewer projects will be authorized than could have been performed with the resources available, resulting in a loss of benefits. If estimates are consistently low, more projects can be authorized than can be fully funded, resulting in project slowdowns, scope changes, and performance shortfalls, and generally higher costs and lower benefits. If estimates are neither consistently high nor low, but still inaccurate, the estimated benefit/cost ratios will not be correct and the most beneficial projects may not be authorized, while less beneficial projects are authorized. All of these conditions result in misallocation of funds and a loss in benefits to the public.

Substantial value results from providing risk assessment, cost estimating, cost management, and cost containment techniques at the earliest stages in the project development process. Cost engineering research has illustrated that the ability to influence and manage cost is greatest at the earliest stages in a project ("Pre-Project Planning: Beginning…", 1994). A project management oversight function definitely has the ability to help manage the process - especially in the area of cost containment - but it is imperative to examine the problems and solutions for cost-risk analysis and management practices at the earliest stages of the project. To neglect the earliest stages of the project development process would diminish the practical application of this research. Risk assessment, cost estimating, cost management, and cost containment techniques must be implemented at the earliest stages of the process - even if the transparency of uncertainty in the engineering and political process is difficult to define and manage.

This paper discusses a three-tier approach for risk analysis and contingency estimation. The approach relies on a formal categorization of highway project complexity to guide the appropriate level of risk analysis and contingency estimation.

METHODOLOGY

The three-tier approach for risk analysis and contingency estimation stemmed from a synthesis of interviews and case studies with more than 30 state from both the NCHRP 8-49 and 8-60 research projects. The NCHRP 8-49 project was conducted in two phases. The first phase focused on a state-of-practice review of cost estimation practice and cost estimation management processes. The current state of estimation practice was characterized by an extensive review of the literature supported by interviews of transportation agencies. Major factors causing project cost escalation were identified during this first phase of the research. Twenty-three state highway agencies provided input on the practices they use during different project development phases. A critical review of these practices formed the basis for identifying viable and successful approaches to cost estimation practice and cost

estimation management. Based on this literature and interview work, eight strategies were identified to address the root causes of project cost escalation. These eight strategies were then linked to over 30 implementation methods. From the discussion with state highway agencies, over 90 tool applications were identified to support the 30 methods. These strategies, methods, and tools align with planning, programming, and preconstruction. This strategic approach, including the methods and tools, was reviewed and approved by the NCHRP 8-49 oversight panel as validation.

Based on the state-of-practice data from the state highway agencies, the second phase of the research developed the guidebook. The guidebook, with a focus on addressing cost escalation through the use of strategies, methods, and tools, was prepared in draft form. It was then critically reviewed by 10 state highway agencies. These state highway agencies provided a critique of the guidebook's content, structure, layout, and user friendliness. The NCHRP 8-49 panel reviewed and commented on the final version of this guidebook.

Upon completion of the NCHRP Project 8-49 and concurrently with the NCHRP 8-60 project, the Minnesota Department of Transportation (Mn/DOT) commissioned the research team to apply the 8-49 research process to their state estimating practices. The Mn/DOT Cost Estimation Process Improvement and Organizational Integration project was treated as a separate validation and calibration effort. The project began by carefully and thoroughly examining Mn/DOT's cost estimating and cost management practices and policies. Mn/DOT is similar to many SHAs across the nation, with programs and projects that seem to constantly increase in cost from that predicted in early estimates and which present a significant delivery challenge to all parties involved. The relationship of the three projects can be seen in Figure 1.

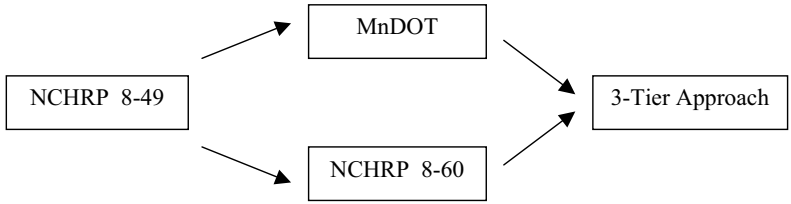


Figure 1: Development of the Three-Tier Approach

Minnesota DOT has decided to take an offensive posture and to proactively address its cost estimating and cost estimate management challenges. Accordingly, the project is designed to address the many challenges and difficulties associated with estimating both program and project cost, and to aid Mn/DOT in managing those costs during all phases of project development. The project's stated purpose is to improve Mn/DOT's cost estimating and cost estimate management practices and integrate the improvements into the organization. Success is defined as accuracy, consistency, and accountability in cost estimation and cost management efforts during the planning, scoping, design, and PS&E (Plans, Specifications, and Estimates) phases of project development.

The Mn/DOT estimate improvement effort is being conducted in four phases, all of which are based on the NCHRP Project 8-49 research. In broadest terms, the effort can be summarized as a process of: I) assessment: II) definition; III) development; and IV) implementation. Phase I focused on identifying, examining, and assessing the current Mn/DOT cost estimating practices and strategies. Phase II focused on defining and communicating the desired cost estimating and cost estimate management processes, methods, and procedures that are aligned with the Mn/DOT culture. Phase III focused on developing the documentation of the selected methods, tools, and procedures for estimating manuals for the new process. Phase IV, the final phase, is focusing on implementing change through communication and training.

Through the NCHRP 8-49 and 8-60 research projects, the research team examined the risk analysis and contingency estimating tools found in interviews and case studies with more than 25 SHAs. The research team subsequently synthesized these tools into the three-tier approach. The approach was then demonstrated and tested with Mn/DOT in a series of validation workshops project applications.

THREE-TIER APPROACH

The three-tier approach stems directly from project complexity. A determination of the project complexity in three categories: 1) minor (non-complex) projects; 2) moderately complex projects; and 3) major (most complex) projects, leads to the selection of the risk analysis and contingency estimating approach (see Figure 2).

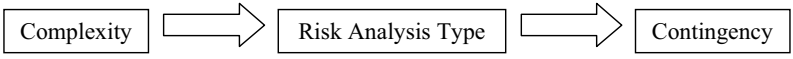


Figure 2: Three-Tier Approach Process

In this approach, transportation project complexity is based on an analysis of seven categories of project complexity: Roadway, Traffic Control, Structures, Right-of-Way, Utilities, Environmental, and Stakeholders. An example of the differences between the complexity levels follows. Only the "Roadway" category is shown. For a complete definition of project complexity, see NCHRP Report 574 (Anderson et al. 2007).

Major (Most Complex) Projects

- New highways; major relocations
- New interchanges
- Capacity adding/major widening
- Major reconstruction
- Congestion Management Studies are required

Moderately Complex Projects

- Rehabilitation, restoration, resurfacing, and reconstruction projects which do not add capacity
- Minor roadway relocations
- Certain complex (non-trail enhancements) projects
- Slides, subsidence

Minor (Non-Complex) Projects

- Maintenance betterment projects
- Overlay projects, simple widening without right-of-way (or very minimum right-of-way take) little or no utility coordination
- Non-complex enhancement projects without new bridges (e.g. bike trails)

Based on an evaluation of where the project falls in the seven different categories for the different levels of complexity, a different "Type" of risk analysis is defined for the project. The three tiers of risk analysis and contingency setting follow.

Type I - Risk Identification and Percentage Contingency

The Type I risk analysis is the simplest form of risk analysis and applies only to minor projects. A Type I risk analysis involves the development of a list of risks and the use of a percentage of project cost to estimate the contingency. The estimator should use their judgment within percentage contingency range of acceptable standards set by the SHA.

Type II - Qualitative Risk Analysis and Indentified Contingency Items

The Type II risk analysis correlates to moderately complex projects and involves more rigorous risk identification tools and specific contingency items that complement the percentage-based contingency in the Type I analysis. A probability-impact (P x I) matrix analysis is suggested to qualitatively rank the risks. Expected values are then calculated for the highest ranked risks and added to the Type 1 contingency-based percentage.

Type III - Quantitative Risk Analysis and Contingency Management

A Type III risk analysis applies to major projects. It is typically facilitated by individuals trained in quantitative risk management practices. The process generally begins with a risk analysis workshop involving key team members to identify project risks. A stochastic estimate of cost and schedule is then generated and used to estimate an appropriate contingency. The risks and associated contingency are then updated throughout the project development process. Maintenance of a risk register or risk information system to monitor the risks is essential.

The level of risk analysis will determine the selection of appropriate risk-related tools for risk identification, risk analysis and estimation of contingency. All projects, regardless of project size and project complexity, require some form of risk analysis and risk management planning. The risk process analysis remains the same (e.g.,

identification, assessment/analysis, risk planning, risk monitoring, etc.), but the tools and level of effort vary with the risk analysis level.

The three-tier approach stems from a synthesis and formalization of risk identification, risk analysis and contingency estimating tools found in the literature and in practice. Table 1 summarizes the most frequently applied tools and their relationship to the three-tier approach. The paragraphs that follow provide a short description of the tools and references for more information.

Table 1: Risk Analysis and Contingency Estimation Tools

Tool Name	Analysis Level		
	I	II	III
Risk Identification			
Assumption Analysis	●	●	●
Red Flag Item Lists	●	●	●
Checklists	●	●	●
Expert Interviews		●	●
Crawford Slip Methods		●	●
Risk Identification Workshops			●
Risk Assessment and Contingency			
Contingency Percentage	●	●	●
Risk Register	●	●	●
P x I Matrix		●	●
Contingency Identified		●	●
Three-Point and Range Estimates		●	●

Assumption Analysis

An assumption analysis involves examining cost, schedule and design assumptions, documenting these assumptions, and analyzing them as potential risks. Each assumption should be examined for validity, accuracy, consistency, completeness, and context. If uncertainties in these assumptions are identified, then risks should be developed surrounding these uncertainties (FHWA 2006; WSDOT 2006).

Red Flag Item Lists

A red flag item list is created at the earliest stages of project development and maintained as a checklist during project development. It is perhaps the simplest form of risk identification and risk management. The list helps estimators to better understand the required contingency and helps managers to more effectively control scope growth throughout the project development process. Not all projects will require a comprehensive and quantitative risk management process. A red flag item list can be used in a streamlined qualitative risk management process (Anderson et al. 2007; Curran 1998; and Grey 1995).

Checklists
Risk checklists are a tool for risk identification that can be used at the earliest stages of risk identification to learn from past projects and past team member experience. The list helps estimators to better understand the required contingency and helps managers to more effectively control scope growth throughout the project development process. The use of a risk checklist is the final step of risk identification to ensure that common project risks are not overlooked (Anderson et al. 2007; Molenaar, Diekmann and Ashley 2006).

Expert Interviews
Expert interviews provide risk analysts and estimators with additional input from expert sources. Experts may have insights into risks where the project team lacks experience. Interviews are simply the solicitation of expert opinions. The questions are generally open-ended and discuss areas of individual expertise. Documentation of the discussion is important, as the discussion may reveal a number of different risks, and the expert may provide information beyond the identification of the risk, such as probability and impact (FHWA 2006; Molenaar 2005).

Crawford Slip Method
The Crawford Slip method provides a way for a project team to quickly generate a large number of potential risks. The Crawford Slip method is a rapid, independent brainstorming session. Introductions are given and the process is explained. For ten minutes, each participant is instructed to write down one risk each minute. After every minute, each risk is set aside. This forces each participant to write down one, and only one, risk during each minute. At the end of the ten minutes, the facilitator collects all of the risks. The facilitator later collates and organizes the risks, eliminating duplicates (FHWA 2006).

Risk Identification Workshops
Risk workshops are formal meetings in which the participants are asked to make qualitative and/or quantitative assessments of project risks. Qualitative analysis allows for influence of the project performance estimate (e.g., contingency) and the rating of each risk (e.g., to guide subsequent risk management). Quantitative analysis quantifies uncertainty in project performance (e.g., total escalated cost) and also quantifies the significance of each risk (e.g., for subsequent risk management cost-benefit analysis) (Molenaar 2005).

Contingency Percentage
When a percentage contingency is added to the base estimate during project development based on judgment, the rationale behind the percentage must be clearly documented. As the project proceeds with development, the estimated contingency percentage declines because the level of uncertainly associated with the project also declines. If extraordinary conditions exist that call for higher contingencies than what have historically been used, the rationale and basis must also be documented in the estimate (Anderson et al. 2007).

Risk Register
A risk register is a tool to document and monitor project risks throughout project development. The risk register should be maintained as part of a project estimate or project management file that also includes information related to the cost estimate. It is a "living" document throughout project development that describes details of risks such as their probability of occurrence, impact(s) on project or agency objectives, team responses, individual(s) assigned to monitor the evolution and the resolution of each risk, and the current status of the risks (Caltrans 2006; and Molenaar, Diekmann and Ashley 2006).

PxI Matrix
A probability-impact (PxI) matrix is used for qualitative assessment and ranking of risks on a project. It is formed by combining each risk's probability of occurrence (frequency) with its impact (severity) on project objectives to determine the level of priority to be assigned to that risk on the project, whether high, medium or low. These assessments can be used as a first step in a quantitative analysis (Caltrans 2006; and Molenaar, Diekmann and Ashley 2006).

Contingency Identified
The most predominant SHA method for assigning contingency has been to either follow standard percentage(s) for the varying stages of project development or to rely solely on project estimators' experience. The enumeration and assessment of a project's risks offers a more effective method for determining project contingency than does the standard SHA practice of broad-based percent add-on contingency amounts. This process begins with the percentage contingency method and then adds any additional contingency for the highest ranked items by calculating the expected value of these risks (Anderson et al. 2007).

Three-Point and Range Estimates
Expressing a cost estimate in terms of an estimate range transparently communicates the uncertainty associated with an estimate. The generation of a range can be as simple as applying an historic plus-minus factor to estimated cost (i.e -10% to +20%). Alternatively, an estimate range may be generated through sophisticated probabilistic models or simply as a three-point estimate ranging from an optimistic amount to a pessimistic amount and a most likely amount in between (Anderson et al. 2007).

CONCLUSION AND FUTURE RESEARCH

This paper discussed a three-tier approach for risk analysis and contingency estimation that has been developed through two extensive NCHRP research projects and applied in one Mn/DOT research project. The three-tier approach has been developed through a synthesis of risk analysis methods and tools as found throughout the US highway estimating community. It is proposed that more consistent application of risk management and better estimates for contingency will assist SHAs in combating the current cost escalation problem.

Future research will involve a more extensive validation of the overall process and a calibration of the tools used to estimate contingency. The validation and calibration will be a long process. Initial highway planning estimates are conducted 10-15 years prior to construction. Even once a project scope is defined, SHAs can take more than five years to complete design and begin construction. The research team is currently developing performance measures with Mn/DOT to validate and calibrate the tools, but results of these measures will not be known for at least three to four years. In the short-term, the research team will validate the process through more qualitative means with users of the tree-tier approach and contingency estimating tools.

REFERENCES

Anderson, S., Molenaar, K.R., and Schexnayder, C. (2007). Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming, and Preconstruction, *NCHRP 574, ISBN# 978-0-309-09875-5, National Cooperative Highway Research Program, Transportation Research Board of the National Academies*, Washington, DC.

Caltrans (2006). Project Risk Management Handbook. *Report of the California Department of Transportation (Caltrans), Office of Project Management Process Improvement*. Sacramento, CA.

Curran, Michael W. (1998). Professional Practice Guide 2: Risk. Association for the Advancement of Cost Engineering International, Morgantown, WV.

Committee for Review of the Project Management Practices Employed on the Boston Central Artery/Tunnel ("Big Dig") Project (2003). *Completing the "Big Dig": Managing the Final Stages of Boston's Central Artery/Tunnel Project,* National Academies Press.

Federal Highway Administration (2004). Major Project Program Cost Estimating Guidance, *Federal Highway Administration*, Washington, D.C.

FHWA (2006). *Risk Management Instructor Guide* USDOT Federal Highway Administration, Washington D.C.

Grey, S. (1995). Practical Risk Assessment for Project Managers. John Wiley and Sons, Chichester, England.

Molenaar, K. R. (2005). "Programmatic Cost Risk Analysis for Highway Mega-Projects," Journal of Construction Engineering and Management, Vol. 131, No. 3.

Molenaar, K.R., Diekmann, J.E, and Ashley, D.B. (2006). Guide to Risk Assessment and Allocation for Highway Construction Management, *Report # FHWA-PL-06-032, Federal Highway Administration, U.S. Department of Transportation*, American Association of Stare Highway Transportation Officials, and the National Cooperative Highway Research Program, Washington, DC.

NCHRP (2008). NCHRP 08-60 Project Description, <http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=936> , Viewed August 1, 2008.

"Pre-Project Planning: Beginning a Project the Right Way" (1994). Construction Industry Institute, Research Summary 39-1, The University of Texas at Austin.

WSDOT (2006). Basis of Estimate, Washington State Dept. of Transportation, Olympia, WA.

Author Index

Page number refers to first page of paper.

Abdelhamid, Tariq S., 705, 766
Abdel-Wahhab, Osama, 1068
AbouRizk, S. M., 1223, 1270, 1290
Abraham, Dulcy M., 1154
Ahmed, Syed M., 1439
Akinci, Burcu, 416, 1164
Al Qady, Mohammed, 1479
Al-Bataineh, M., 1223
Al-Derham, Hassan, 1145
Al-Hussein, Mohamed, 386, 406
Allread, Ben S., 31
Alvanchi, A., 1290
Ammar, Mohammad, 350
An, Sang-Mok, 816
Angelides, Demos C., 81
Ariaratnam, Samuel T., 618, 1233
Aslani, Pooyan, 467
Awwad, Rita E., 249
Azambuja, Marcelo M., 259
Aziz, Ahmed M. Abdel, 896

Bae, Jin-Woo, 1009
Bai, Yong, 11, 131
Baik, Kyeong Geun, 151
Ballard, Glenn, 360, 866, 1029, 1038
Bates, A. J., 1368
Batson, Robert G., 746
Behzadan, Amir H., 1214
Beliveau, Yvan, 568
Bode, Thaddaeus, 516
Bogus, Susan M., 876
Bohn, Jeffrey S., 21
Botteicher, Richard (Bo), 1233
Bouferguene, Ahmed, 406
Boukamp, Frank, 457
Bowen, Paul A., 279, 776
Brilakis, Ioannis, 81, 1204
Brummett, Jenna, 161

Carey, Brad D., 269
Castro-Lacouture, Daniel, 211, 608, 1079
Cattell, K. S., 279
Chae, M., 497
Chan, Albert P. C., 955
Chang, Chen-Yu, 288
Chang, Chul-Ki, 1308
Charalambides, Jason, 628
Chasey, Allan D., 665
Chen, Qian, 588
Cheung, Sai On, 298
Chiang, Y. H., 955
Chiara, Nicola, 1174
Chiarelli, Lawrence, 467
Cho, M., 497
Cho, Yong K., 516
Chong, Wai K. (Oswald), 526, 537
Cline, R. Casey, 1409
Cloud, Joshua, 598
Conger, Robert F., 726
Cooper, Casey, 1318
Cordova, Francisco, 81
Costa, George S., 1105

da C. L. Alves, Thaís, 1105
Dai, Jiukun, 1087
Dainty, Andrew R. J., 309
Darnell, Brent, 1358
Davis, Kirsten A., 1409
de la Garza, Jesús M., 916
de P. Barros Neto, José, 1105
Devkar, Ganesh A., 201
Dossick, Carrie S., 396, 1469
Dyer, Bryan D., 121

Edwards, Peter J., 776
El Asmar, Mounir, 1308

El-adaway, Islam H., 675
El-Anwar, Omar, 1135
Elazouni, Ashraf, 1068
Elghamrawy, Tarek E., 457, 936
Ellis, Ralph D., 1096
Elnashai, Amr, 1135
El-Rayes, Khaled, 806, 846, 1135, 1145
Elwakil, Emad, 350
Enache-Pommer, Elena, 636
Everett, John G., 705
Eweda, Ahmed, 350

Fard, Mani Golparvar, 51
Fares, H., 1125
Farooqui, Rizwan U., 1439
Fayek, Aminah Robinson, 219
Feng, Peter P., 866
Fernando, S., 1223
Finnsson, Siggi, 1233
Fiori, Christine M., 1388, 1398
Fischer, Martin, 926,608
Ford, George, 380
Froese, Thomas, 71, 979
Fullerton, Clare E., 31

Gaikwat, Yogesh, 1378
Garrett, James H., Jr., 416, 1194
Garvin, Michael J., 191, 1469
Gastrock, Brian, 1260
Ghosh, Arnab, 1233
Gibson, G. Edward, 685, 1348
Glick, Scott, 655
Golparvar-Fard, Mani, 41
Goodrum, Paul M., 111, 121
Grant, Denise, 1338
Griffis, F. H. (Bud), 467
Gross, Martha E., 191
Guggemos, Angela Acree, 655
Gunhan, Suat, 320
Guo, W., 1194

Haddad, Gilbert, 171
Hague, S., 1223
Hallowell, Matthew R., 1489, 1499
Han, SangUk, 51
Han, Seung Heon, 756
Han, Zonghai, 71
Hanna, Awad S., 171, 1308
Hardcastle, Cliff, 776
Hasan, Shafiul, 386
Hassan, Marwa, 568, 836
Hermann, R., 1270
Hermann, U. H., 386
Hermreck, Christopher, 526
Hewage, Kasun N., 487, 989
Hicks, Carolyn, 101
Ho, Peggy, 926
Homayouni, Hoda, 396
Horman, Michael, 558, 636
Huan, Luke, 11, 131
Hwang, Seokyon, 1300

Ioannou, Photios G., 1250, 249
Isaac, Shabtai, 1

Jain, Atul Kumar, 665
Javernick-Will, Amy, 338
Jay, C. I., 279
Jenicek, Elisabeth, 426
Jergeas, George F., 989
Johnson, Lisa M., 588
Johnston, David W., 1328
Jooste, Stephan F., 1184
Jun, Dho Heon, 806
Jung, Youngsoo, 816

Kalidindi, Satyanarayana N., 201
Kamat, Vineet R., 1214
Kandil, Amr, 239, 1479
Kang, Sang Hyeok, 151
Karshenas, Saeed, 1419
Kashiwagi, Dean T., 370
Kashiwagi, Jacob S., 370
Kim, Byungil, 756
Kim, Du Yon, 756
Kim, Ho-Sung, 457
Kim, Hyunjoo, 426

Kim, J., 497
Kim, Jin-Lee, 1096
Kim, Kyunghwan, 916
Kim, Seonghoon, 11, 131
Kim, Yong-Rak, 516
Kim, Yong-Woo, 1009
Klotz, Leidy, 1338
Kong, Robert Tiong Lee, 716
Korkmaz, Sinem, 558
Korman, Thomas M., 999
Ku, Kihong, 969, 1378

Lai, Wally S. W., 298
Lawrence, M., 506
Lee, Bok Nam, 816
Lee, G., 497
Lee, Namhun, 826
Lee, S., 1290
Lee, Sang-Hoon, 1318
Lee, Young Hwan, 816
Leicht, Robert M., 437, 1358
Leite, Fernanda, 416
Levitt, Raymond E., 338, 1184
Lewis, Angela, 1358
Liao, Pin-Chao, 1087
Likhitruangsilp, Veerasak, 1250
Lin, Yu-Cheng, 477, 906
Lu, Na, 946
Lucko, Gunnar, 1115, 1449
Luna, Eduardo, 370

Mahalingam, Ashwin, 201
Mahfouz, Tarek, 239
Mahmoud, Muhammad, 350
Malhotra, Neha, 370
Mannering, Fred L., 1154
Marsh, Krista, 219
Martinez, Adam A., 886
Mashhour, Ibarhim, 350
McCabe, Brenda, 101
McCoy, Andrew P., 91
Medaglia, Andrés L., 608, 1079
Menassa, Carol, 646, 726
Menches, Cindy L., 796
Messner, John I., 437, 1358
Michael, John K., 269
Migliaccio, Giovanni C., 229, 886
Mirsky, Rebecca, 330
Mitchell, Zane W., Jr., 1115, 1368
Mitropoulos, Panagiotis 'Takis', 695, 766
Mohamed, Dalia, 736
Mohamed, Y., 1270
Molenaar, Keith R., 786
Mrozowski, T., 766
Muga, Helen, 548
Mukherjee, Amlan, 548, 1459
Mulva, Stephen P., 1087

Nahmens, Isabelina, 1058
Namboodiri, Manoj, 695
Nasr, Ziad Bou, 796
Neff, Gina, 396
Nepal, M. P., 506
Ng, S. Thomas, 955
Nguyen, Thuy, 141
Nobe, MaryEllen C., 161, 1429

Oberle, Rita, 211
O'Brien, William J., 141, 259, 1087
Oh, Young-Seok, 816
Olearczyk, Jacek, 406
Onder, Nilufer, 1459
Orabi, Wallied, 1145

Park, J., 497
Parra-Montesinos, Gustavo, 1204
Parrish, Kristen, 360
Partouche, Rebecca, 1019
Patterson, John, 380
Pearce, Annie R., 1398
Peddi, Abhinav, 11, 131
Peña-Mora, Feniosky, 41, 51, 646, 726
Peralta, María L., 1154
Phillips, H. Clay, 876
Pocock, J. B., 1368
Pottinger, R., 506

Prakash, Santosh, 655

Qian, Qiyu, 716

Ramos, Michelle, 1243, 1260
Rendall, Joseph, 537
Riecke Smith, Valerie R., 211
Riley, David R., 558, 1358
Roh, Seungjun, 51
Rojas, Eddy M., 826, 856, 1449, 1459
Ronie Navon, 1
Ross, Timothy J., 876
Russell, Jeffrey S., 1308
Ruwanpura, Janaka Y., 61, 487, 989
Rybkowski, Zofia K., 1038

Sacks, Rafael, 1019
Safouhi, Hassan, 386
Said, Hisham, 846
Sauer, Michael, 578
Savarese, Silvio, 41
Schafer, D., 766
Schaufelberger, John, 598
Schmidt, Kathy, 141
Sefair, Jorge A., 608, 1079
Senouci, Ahmed, 1145
Seo, Jong Won, 151
Shrestha, Pramen P., 229
Siddiqi, Khalid, 578
Sideris, Dimitris, 81
Sihabuddin, Shaik, 618
Sillars, David N., 1499
Silva, Lahiru P., 487
Sims, Bradford, 380
Singh, Amarjit, 181
Soetanto, Robby, 309
Soibelman, L., 1194
Son, JeongWook, 856
Song, Lingguang, 1318
Song, Xinyi, 726
Songer, Anthony D., 330, 1388
Srour, Florida, 736
Staheli, Kimberlie, 1243
Staub-French, S., 506
Stewart, Peter J., 776
Stumpf, Annette, 426
Sullivan, Kenneth T., 269, 370

Taam, Thomas, 181
Tabra, Wael, 736
Taghaddos, H., 1270
Tang, Pingbo, 1164
Taylor, J. E., 1280, 1469
Teizer, Jochen, 21, 31, 447
Teizer, Winfried, 447
Telyas, Avi, 406
Thomas, Stephen R., 1087
Tighe, Susan, 101
Tommelein, Iris D., 360, 866, 1048
Tuholski, Stan J., 1048

Unsal, H. I., 1280

Venugopal, Manu, 447

Webster, A., 506
Weerasinghe, I. P. Tharindu, 61
Whittington, Donald A., 685, 1348
Wilson, Craig R., 786
Wong, James M. W., 955
Wong, Peter S. P., 298
Woo, Sungkwon, 816

Xi, Lili, 705

Yang, Jin-Soo, 816
Ye, Jianguo David, 979

Zandbergen, Paul, 886
Zayed, Tarek, 350, 736, 1125
Zhai, Dong, 111
Zhang, J., 506, 936
Zhu, Zhenhua, 1204

Subject Index

Page number refers to first page of paper.

Alaska, 1260
Algorithms, 11
Asphalts, 526
Assembling, 406
Assessments, 141, 1154, 1358
Assets, 548
Automation, 61, 406, 628, 816, 826, 1135

Bids, 249
Building design, 426, 467, 506, 537, 558, 568, 628, 665
Buildings, high-rise, 1009, 1019, 1154
Buildings, residential, 181, 578, 655, 1009
Business management, 330, 350

California, 866
Cameras, 21
Canada, 101
Carbon, 618
Case reports, 71, 457, 816, 866, 969, 1243, 1260, 1469
Classification, 876
Coating, 836
Communication, 396, 487, 776, 856
Comparative studies, 1439
Computer software, 497, 1105
Concrete, 1204
Concrete columns, 1214
Concrete pavements, 695
Configuration, 979
Construction costs, 588, 886, 1038, 1419
Construction equipment, 31, 1318
Construction industry, 121
Construction materials, 608, 1079
Construction sites, 31, 91, 406, 497, 846
Contractors, 330, 598
Contracts, 171, 219, 269, 288, 1250
Costs, 121
Cranes, 386, 1300
Critical path method, 916

Damage, 1204, 1214
Data analysis, 705, 979
Data collection, 61
Data processing, 416
Databases, 380, 1115
Decision making, 360, 548
Delay time, 380
Delivery, 211, 229, 279, 969
Design/build, 229
Developing countries, 1154
Dispute resolution, 239, 726
Drilling, 1233, 1243

Economic factors, 249, 655, 955, 1115, 1184
Electrical systems, 171, 416, 796, 999
Emergency services, 1135
Energy, 426, 537, 558, 598, 646, 1174
Energy efficiency, 628
Engineering education, 1328, 1358, 1368, 1378, 1388, 1409, 1419, 1429, 1439
Environmental issues, 211, 558, 598, 608, 636, 655, 665, 1009, 1058
Estimation, 886
Expert systems, 219

Failures, 1125
Financial management, 675

Forecasting, 955
Foreign projects, 756
Fuzzy sets, 219, 1125

Geographic information systems, 151, 886

Health care facilities, 636, 866
Highway and road construction, 101, 191, 526, 786, 896
Highway and road management, 229
Hong Kong, 298
Housing, 588, 1105, 1135
Human factors, 11
Hybrid methods, 1290

Identification, 41, 416
Imaging techniques, 51, 81, 979, 1194, 1204, 1214, 1419
Implementation, 1
India, 201
Information management, 71, 81, 396, 457, 467, 506, 1164, 1479
Information technology (IT), 111, 989
Infrastructure, 716, 1154, 1164, 1174, 1184, 1214, 1308
Innovation, 71, 91, 1029, 1164
Insurance, 675, 726
Integrated systems, 969, 1270, 1280
Interfaces, 477
International factors, 320, 338, 756
Internet, 1378
Internships, 1398
Inventories, 1029
Investments, 111

Knowledge-based systems, 338, 906, 936, 1479

Labor, 161
Lean construction, 360, 1058, 1115
Life cycles, 836
Litigation, 239, 726
Local governments, 279

Location, 886
Logistics, 239, 1300

Maintenance, 191
Mapping, 279, 906, 936
Measurement, 131
Measuring instruments, 141
Mechanical systems, 999
Minority groups, 161
Monitoring, 21, 41, 51, 1068
Monte Carlo method, 1308
Multimedia, 1419
Multiple objective analysis, 806
Municipal engineering, 201

Natural disasters, 1135, 1145
Nebraska, 526
Neural networks, 1068
North America, 989
North Carolina, 380
Numerical models, 1233

Occupational health, 1489
Optimization, 846, 1105, 1135
Optimization models, 608
Organizations, 350, 370
Owners, 219, 776, 989, 1038

Partnerships, 201, 269, 716
Pavements, 516
Personnel management, 61, 705, 955
Pipes, 1233
Plumbing, 416, 999
Predictions, 705, 736, 896, 1233
Pricing, 726
Procurement, 229, 259, 288, 646, 1009
Productivity, 11, 111, 121, 131, 151, 171, 695, 946, 1019, 1029, 1087, 1096
Public health, 1184

Quality control, 516, 1328

Rainfall, 380
Reconstruction, 1145
Recycling, 526, 1429
Regression analysis, 896, 1115
Regression models, 239
Regulations, 211
Rehabilitation, 1048, 1194
Renewable resources, 646, 1174
Renovation, 685, 926
Research, 1038, 1348, 1449, 1459, 1469, 1499
Residential location, 181
Resource allocation, 816, 1145
Risk management, 675, 716, 746, 776, 786, 1125, 174, 1250, 1308
Rivers, 1243

Safety, 31, 386, 695, 766, 1489
Scheduling, 806, 816, 826, 856, 876, 916, 926, 1105, 1270, 1318
Seismic effects, 1048
Sensors, 516
Simulation, 1223, 1270, 1280, 1290, 1318, 1459
Solar energy, 568
South Africa, 279
Stochastic processes, 1
Storms, 675
Structural design, 1048
Students, 141, 1398, 1409, 1429, 1439
Subcontractors, 1280
Surveys, 141, 161, 1164
Sustainable development, 330, 537, 548, 578, 588, 598, 636, 665, 1338, 1368

Temporary structures, 1300
Three-dimensional models, 497
Time factors, 736, 896, 916
Tolls, 191
Transportation networks, 1145
Trenchless technology, 1260
Tunneling, 1223, 1250

U.S. Army Corps of Engineers, 370
Uncertainty principles, 309
Undergraduate study, 1328, 1368
Underground construction, 618, 1214
United Kingdom, 969
United States, 946
Urban areas, 201
Utilities, 618

Validation, 81, 926

Washington, 1243
Water distribution systems, 1125
Water pipelines, 1194, 1204
Workspace, 101, 437

This page intentionally left blank

Volume 2

Building a Sustainable Future

Proceedings of the 2009 Construction Research Congress



Edited by
Samuel T. Ariaratnam, Ph.D., P.E.
Eddy M. Rojas, Ph.D.

ASCE

CI
Construction Institute

BUILDING A SUSTAINABLE FUTURE

VOLUME TWO

PROCEEDINGS OF THE 2009 CONSTRUCTION RESEARCH CONGRESS

April 5–7, 2009
Seattle, Washington

SPONSORED BY
Construction Institute (CI)
of the American Society of Civil Engineers

University of Washington

EDITED BY
Samuel T. Ariaratnam, Ph.D., P.E.
Eddy M. Rojas, Ph.D.

Published by the American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data

Construction Research Congress (2009 : Seattle, Wash.)
Building a sustainable future : proceedings of the 2009 Construction Research Congress, April 5-7, 2009, Seattle, Washington / sponsored by Construction Institute of the American Society of Civil Engineers [and] University of Washington ; edited by Samuel T. Ariaratnam, Eddy M. Rojas.
v. cm.
Includes bibliographical references and index.
ISBN 978-0-7844-1020-2
1. Building--Technological innovations--Congresses. 2. Construction industry--Congresses. 3. Sustainable architecture--Congresses. I. Ariaratnam, S. T. II. Rojas, Eddy M. III. Construction Institute. IV. University of Washington. V. Title.

TH5.C67 2009
624--dc22 2009005848

American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4400

www.pubs.asce.org

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefore. This information should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing this information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

ASCE and American Society of Civil Engineers—Registered in U.S. Patent and Trademark Office.

Photocopies and reprints.
You can obtain instant permission to photocopy ASCE publications by using ASCE's online permission service (http://pubs.asce.org/permissions/requests/). Requests for 100 copies or more should be submitted to the Reprints Department, Publications Division, ASCE, (address above); email: permissions@asce.org. A reprint order form can be found at http://pubs.asce.org/support/reprints/.

Copyright © 2009 by the American Society of Civil Engineers. All Rights Reserved.
ISBN 978-0-7844-1020-2
Manufactured in the United States of America.

Preface

We would like to welcome you to the 2009 Construction Research Congress (CRC) sponsored by the Construction Institute (CI) of the American Society of Civil Engineers (ASCE) and hosted by the University of Washington. The theme of "Building a Sustainable Future" is one that reflects a priority for construction professionals. It is only fitting that the Congress is held in picturesque Seattle, a city known worldwide for environmental preservation and sustainable development.

The two-volume Proceedings contain 152 peer reviewed papers covering 16 general state-of-knowledge research topic areas in construction engineering and management. There were 285 abstracts initially submitted that were reduced to 167 accepted draft papers following a peer review. From this, a final 152 papers were accepted for publication and presentation based on the same double peer review process used in abstract selection.

We are delighted to see that this event is truly global with representation from 16 foreign countries including Canada, Colombia, Thailand, Israel, United Kingdom, Saudi Arabia, India, Singapore, Hong Kong, China, Korea, Japan, Brazil, Australia, Turkey, and South Africa.

Our sponsors merit special mention. We would like to recognize our Platinum Sponsors – Mortensen Construction, Kiewit Corporation, and Turner Construction and our Gold Sponsor – GLY Construction. Their participation is greatly appreciated and enabled us to enhance many of the Congress activities.

In closing, we both hope that you enjoy these Proceedings and have a memorable experience of both the Congress and Seattle. It will be an excellent opportunity to catch up with old friends and colleagues and make new ones!



Samuel T. Ariaratnam, Ph.D., P.E.
Arizona State University
2009 CRC Technical Program Chair



Eddy M. Rojas, Ph.D.
University of Washington
2009 CRC Conference Chair

Acknowledgments

The 2009 Construction Research Congress Technical Program Committee should be acknowledged for their dedication and contributions to the conference program.

Conference Program Committee members are listed below:

Eddy Rojas, University of Washington (Conference Chair)

Samuel Ariaratnam, Arizona State University (Technical Program Chair)

Ahmel-Abdel Aziz, University of Washington

Yong Bai, University of Kansas

Carrie Dossick, University of Washington

Christine Fiori, Virginia Tech University

Jimmie Hinze, University of Florida

Vineet Kamat, University of Michigan

YongWoo Kim, University of Washington

Gunnar Lucko, Catholic University

John Messner, Penn State University

Giovanni Migliaccio, University of New Mexico

Panagiotis Mitropoulos, Arizona State University

Keith Molenaar, University of Colorado

Amlan Mukherjee, Michigan Tech University

William O'Brien, University of Texas

Aminah Robinson, University of Alberta

Janaka Ruwanpura, University of Calgary

John Schaufelberger, University of Washington

Lucio Soibelman, Carnegie Mellon University

Kenneth Sullivan, Arizona State University

Xiangyu Wang, University of Sydney

Contents

Volume One

Automated/Real-Time Systems for Project Control

An Automated Tool for Identifying the Implications of Changes in Construction Projects 1
Ronie Navon and Shabtai Isaac

Development of Human Pose Analyzing Algorithms for the Determination of Construction Productivity in Real-Time 11
Abhinav Peddi, Luke Huan, Yong Bai, and Seonghoon Kim

Benefits and Barriers of Monitoring Construction Activities Using Hi-Resolution Automated Cameras 21
Jeffrey S. Bohn and Jochen Teizer

Pro-Active-Real-Time Personnel Warning System 31
Clare E. Fullerton, Ben S. Allread, and Jochen Teizer

Interactive Visual Construction Progress Monitoring with D^4 AR—4D Augmented Reality—Models 41
Mani Golparvar-Fard, Silvio Savarese, and Feniosky Peña-Mora

Visualization Application for Interior Progress Monitoring in 3D Environment 51
Seungjun Roh, Feniosky Peña-Mora, Mani Golparvar Fard, and SangUk Han

Automated Data Acquisition System to Assess Construction Worker Performance 61
I.P. Tharindu Weerasinghe and Janaka Y. Ruwanpura

Project Information Management in Mega Oil Sands Projects 71
Zonghai Han and Thomas Froese

Validation of Vision Tracking at Egnatia Odos Motorway 81
Francisco Cordova, Dimitris Sideris, Ioannis Brilakis, and Demos C. Angelides

Operations, Productivity, and Workforce Issues

Towards Establishing an Innovativeness Index for Construction Sites 91
Andrew P. McCoy

Evaluation of Work Zone Capacity Models 101
Carolyn Hicks, Brenda McCabe, and Susan Tighe

The Relationship between Information Technology and Construction Productivity: A View from Country-Level Data 111
Dong Zhai and Paul M. Goodrum

Construction Industry Productivity: Omitted Quality Characteristics in Construction Price Indices 121
Bryan D. Dyer and Paul M. Goodrum

Measuring Construction Productivity Using the WRITE System....131
Seonghoon Kim, Yong Bai, Luke Huan, and Abhinav Peddi

Construction Student Technology Skill Assessment: A Survey Instrument 141
Thuy Nguyen, William O'Brien, and Kathy Schmidt

3D-GIS Based Earthwork Planning System for Productivity Improvement....151
Sang Hyeok Kang, Jong Won Seo, and Kyeong Geun Baik

Surveying Methods for Bilingual Construction Workers....161
Jenna Brummett and MaryEllen C. Nobe

Overtime and Productivity in Electrical Construction....171
Awad S. Hanna and Gilbert Haddad

Procurement and Contracting

Unabsorbed Overhead: Eichleay and Other Methods 181
Amarjit Singh and Thomas Taam

Approaches for Structuring Concession Lengths and Toll Rates for Transportation Infrastructure PPPs 191
Martha E. Gross and Michael J. Garvin

Analyzing the Institutional Framework for Urban Public Private Partnerships in Indian States....201
Ganesh A. Devkar, Ashwin Mahalingam, and Satyanarayana N. Kalidindi

Effects of the Regulatory Environment on Construction Project Delivery Method Selection 211
Valerie R. Riecke Smith, Daniel Castro-Lacouture, and Rita Oberle

Development of a Fuzzy Expert System for Surety Underwriting 219
Krista Marsh and Aminah Robinson Fayek

Analysis of Design-Build Procurement Activities Durations for Highway Projects 229
Giovanni C. Migliaccio and Pramen P. Shrestha

Factors Affecting Litigation Outcomes of Differing Site Conditions (DSC) Disputes: A Logistic Regression Model (LRM) 239
Tarek Mahfouz and Amr Kandil

Study of Less Than Average Bid Method....249
Rita E. Awwad and Photios G. Ioannou

Investigation of Supply Chain Management Practices in Industrial Projects: State of Practice vs. State of Knowledge....259
Marcelo M. Azambuja and William J. O'Brien

A New Approach to Contracting Design Professionals....269
John K. Michael, Brad D. Carey, and Kenneth T. Sullivan

Mapping the Value Thread in Local Government Service Delivery in South Africa....279
C. I. Jay, P. A. Bowen, and K. S. Cattell

How Far a Contract Can Be Stretched? The First Building Block for Procurement Engineering....288
Chen-Yu Chang

Organizational Leadership and Management

Exploring the Learning Styles of the Construction Practitioners in Hong Kong 298
Peter S. P. Wong, Sai On Cheung, and Wally S. W. Lai

Integrating Uncertainty Management in Strategic Planning Practice.....309
Robby Soetanto and Andrew R. J. Dainty

The Last Decade Analysis and the Near Future Trends in International Construction 320
Suat Gunhan

Beyond Sustainability: The Contractor's Role in Regenerative System Design 330
Rebecca Mirsky and Anthony D. Songer

Acquiring Local Knowledge for International Projects 338
Amy Javernick-Will and Raymond Levitt

Investigation and Modeling of Critical Success Factors in Construction Organizations.....350
Emad Elwakil, Mohammad Ammar, Tarek Zayed, Muhammad Mahmoud, Ahmed Eweda, and Ibarhim Mashhour

Use of A3 Reports to Focus Design and Construction Conversations.....360
Kristen Parrish, Iris D. Tommelein, and Glenn Ballard

Creating Organizational Change: Minimizing Client Generated Construction Inefficiencies at the US Army Medical Command 370
Jacob S. Kashiwagi, Neha Malhotra, Eduardo Luna, Dean T. Kashiwagi, and Kenneth T. Sullivan

Technologies to Improve Project Planning, Design, and Construction

How to Determine Construction Project Rain Delay Times Using Local Rainfall Databases in Asheville, NC 380
George Ford, John Patterson, and Bradford Sims

Integrated Module for Mobile Crane Dynamic Instability Analysis and Supporting System Design 386
Shafiul Hasan, Mohamed Al-Hussein, U. H. Hermann, and Hassan Safouhi

The Realities of Building Information Modeling for Collaboration in the AEC Industry 396
Carrie S. Dossick, Gina Neff, and Hoda Homayouni

Virtual Construction Automation for Modular Assembly Operations 406
Jacek Olearczyk, Mohamed Al-Hussein, Ahmed Bouferguene, and Avi Telyas

Identification of Data Items Needed for Automatic Clash Detection in MEP Design Coordination 416
Fernanda Leite, Burcu Akinci, and James Garrett, Jr.

Early Design Energy Analysis Using BIMs (Building Information Models) 426
Annette Stumpf, Hyunjoo Kim, and Elisabeth Jenicek

Improving Site Utilization Planning through the Use of Interactive Workspaces 437
Robert M. Leicht and John I. Messner

Nanotechnology: Benefits, Barriers, and Impact on Construction 447
Manu Venugopal, Jochen Teizer, and Winfried Teizer

Ontology-Based, Semi-Automatic Framework for Storing and Retrieving On-Site Construction Problem Information—An RFID-Based Case Study 457
Tarek Elghamrawy, Frank Boukamp, and Ho-Sung Kim

Building Information Model: The Role and Need of the Constructors 467
Pooyan Aslani, F. H. (Bud) Griffis, and Lawrence Chiarelli

Developing Construction Network-Based Interface Management System.....477
Yu-Cheng Lin

Virtual Supervision in Construction Projects.....487
Lahiru P. Silva, Janaka Y. Ruwanpura, and Kasun N. Hewage

3D Work Environment Modeling for the Intelligent Excavation System (IES) 497
M. Chae, G. Lee, J. Park, J. Kim, and M. Cho

Querying IFC-Based Building Information Models to Support Construction Management Functions 506
M. P. Nepal, J. Zhang, A. Webster, S. Staub-French, R. Pottinger, and M. Lawrence

Advanced Quality Control Methods for Road Paving Construction by Utilizing Sensory Devices 516
Yong K. Cho, Thaddaeus Bode, and Yong-Rak Kim

Sustainable Construction and Facilities

Embodied Energy of CDW Recycling and Technical Metabolism Due to Regional Differences and Building Designs.....526
Christopher Hermreck and Wai K. (Oswald) Chong

A Proposed Eco-Labeling Method for Building Design.....537
Joseph Rendall and Wai K. (Oswald) Chong

A Decision-Making Framework to Assess Stakeholder Value in Adoption of Sustainable Practices in Construction 548
Amlan Mukherjee and Helen Muga

Key Attributes of a Longitudinal Study of Green Project Delivery 558
Sinem Korkmaz, Michael Horman, and David Riley

Performance Testing of an Integrated Solar Collector System.....568
Marwa Hassan and Yvan Beliveau

Incentives for Green Residential Construction 578
Michael Sauer and Khalid Siddiqi

Adaptable and Visitable Housing: Affordable and Sustainable Changes.....588
Lisa M. Johnson and Qian Chen

LEED Certification: A Constructor's Perspective 598
John Schaufelberger and Joshua Cloud

Optimization Model for the Selection of Materials Using the LEED Green Building Rating System 608
Daniel Castro-Lacouture, Jorge A. Sefair, Laura Flórez, and Andrés L. Medaglia

Quantification of Carbon Footprint on Underground Utility Projects 618
Shaik Sihabuddin and Samuel T. Ariaratnam

Improving Energy Efficiency in Building through Automated Computer Design Process 628
Jason Charalambides

Key Processes in the Building Delivery of Green Hospitals 636
Elena Enache-Pommer and Michael Horman

An Investigation of Real Option Theory to Evaluate Design, Procurement, and Construction of Renewable Energy Facilities 646
Carol Menassa and Feniosky Peña Mora

Economic and Environmental Analysis of Residential Greywater Systems for Toilet Use 655
Scott Glick, Angela Acree Guggemos, and Santosh Prakash

Sustainability for Advanced Technology Facilities 665
Allan D. Chasey and Atul Kumar Jain

Project Risks and Safety

Financial Model for Insuring against Catastrophic Storm Risks 675
Islam H. El-adaway

Development of the STAR Tool for the Management of Shutdown/Turnaround/Outage Projects 685
Donald A. Whittington and G. Edward Gibson, Jr.

Integrating Productivity and Safety Analysis with the Task Demand Methodology: A Case of Concrete Paving 695
Panagiotis "Takis" Mitropoulos and Manoj Namboodiri

The Validity of Data Dependent System Modelling to Predict Relative Physiological Workload during Construction Work 705
Tariq Abdelhamid, Lili Xi, and John G. Everett

Catastrophe Risk Management for Private-Public Partnership (PPP) Infrastructure Projects 716
Qiyu Qian and Robert Tiong Lee Kong

Applying Insurance Pricing Theory for Pricing ADR as an Insurance Product 726
Xinyi Song, Carol Menassa, Feniosky Peña Mora, and Robert F. Conger

A Prediction Model for Construction Project Time Contingency 736
Dalia Mohamed, Florida Srour, Wael Tabra, and Tarek Zayed

Project Risk Identification Methods for Construction Planning and Execution 746
Robert G. Batson

Supporting Market Entry Decisions for Global Expansion Using Real Option + Scenario Planning Analysis 756
Du Yon Kim, Byungil Kim, and Seung Heon Han

Resilience Engineering: A New Approach for Safety Management 766
D. Schafer, T. S. Abdelhamid, P. Mitropoulos, and T. Mrozowski

Identifying and Communicating Project Stakeholder Risks 776
Peter J. Edwards, Paul A. Bowen, Cliff Hardcastle, and Peter J. Stewart

A Risk-Based Approach to Contingency Estimation in Highway Project Development 786
Keith R. Molenaar and Craig R. Wilson

Volume Two

Project Planning and Control

Aligning Pre-Construction Planning and Project Management in the Electrical Construction Industry 796
Ziad Bou Nasr and Cindy L. Menches

Multi-Objective Optimization of Resource Scheduling in Construction Projects 806
Dho Heon Jun and Khaled El-Rayes

Automated CPM Schedule Generation for Early Project Planning: Methodology and Case Study 816
Youngsoo Jung, Young Hwan Lee, Sungkwon Woo, Jin-Soo Yang, Sang-Mok An, Young-Seok Oh, and Bok Nam Lee

Developing Effective Visual Representations to Monitor Project Performance 826
Namhun Lee and Eddy M. Rojas

Life-Cycle Assessment of Titanium Dioxide Coatings 836
Marwa Hassan

Global Optimization of Dynamic Site Layout Planning in Construction Projects 846
Khaled El-Rayes and Hisham Said

Understanding Collaborative Working Processes of Temporary Project Teams in Large-Scale Construction Projects 856
JeongWook Son and Eddy M. Rojas

Modeling the Effect of an Alternative Review Process: Case Study of a State Permitting Agency 866
Peter P. Feng, Iris D. Tommelein, and Glenn Ballard

An Approach to Classifying Uncertainties in Construction Schedules 876
H. Clay Phillips, Susan M. Bogus, and Timothy J. Ross

Assessment of Methods for Adjusting Construction Cost Estimates by Geographical Location 886
Giovanni C. Migliaccio, Paul Zandbergen, and Adam A. Martinez

Time Prediction for Highway Pavement Projects Using Regression Analysis 896
Ahmed M. Abdel Aziz

Development of People-Based Maps Experience Management System for Construction Projects 906
Yu-Cheng Lin

Application of the Resource-Constrained Critical Path Method to Multiple Calendars and Progressed Schedules 916
Jesús M. de la Garza and Kyunghwan Kim

Validating Renovation Phasing Schedules Using 4D Model Based Methods 926
Peggy Ho and Martin Fischer

Mapping Actors and Roles in Construction Knowledge 936
J. Zhang and T. E. El-Diraby

Project/Process Integration and Improvement

The Current Use of Offsite Construction Techniques in the United States Construction Industry 946
Na Lu

Forecasting Construction Manpower Demand: An Econometric Model 956
James M. W. Wong, S. Thomas Ng, Albert P. C. Chan, and Y. H. Chiang

The Core of Eden: A Case Study on Model-Based Collaboration for Integrated Project Delivery 969
Kihong Ku

Visualization Configuration Model for Integrating Presentation of Construction Project Management Data 979
Jianguo David Ye and Thomas Froese

Stakeholder Views on IT in Construction: A North American Perspective 989
Kasun N. Hewage, Janaka Y. Ruwanpura, and George F. Jergeas

Rules and Guidelines for Improving the Mechanical, Electrical, and Plumbing Coordination Process for Buildings 999
Thomas M. Korman

Lean Construction

Assessing the Environmental Impacts of Lean Supply System: A Case Study of Rebar Supply in High-Rise Condominium Construction Projects 1009
Jin-Woo Bae and Yong-Woo Kim

Production Flow in the Construction of Tall Buildings 1019
Rafael Sacks and Rebecca Partouche

How to Lower the River to Reveal the Rocks without Putting a Hole in Your Boat 1029
Glenn Ballard

Overcoming the Hurdle of First Cost: Action Research in Target Costing 1038
Glenn Ballard and Zofia K. Rybkowski

Structural Design Iteration: The Application of DSM to Seismic Retrofit 1048
Stan J. Tuholski and Iris D. Tommelein

From Lean to Green Construction: A Natural Extension 1058
Isabelina Nahmens

Quantitative Methods and Models

Progress Monitoring of Construction Projects Using Neural Networks Pattern Recognition 1068
Ashraf Elazouni and Osama Abdel-Wahhab

Material Selection in Building Construction Using Optimal Scoring Method (OSM) 1079
Jorge A. Sefair, Daniel Castro-Lacouture, and Andres L. Medaglia

Development of Project Level Engineering Productivity Benchmarking Index 1087
Pin-Chao Liao, Stephen R. Thomas, William J. O'Brien, Stephen P. Mulva, and Jiukun Dai

A Framework for Integrating Elitist GA and Project Management Tool 1096
Jin-Lee Kim and Ralph D. Ellis, Jr.

Creating Value in Housing Projects: The Use of Post-Occupancy Analysis to Develop New Projects 1105
Thaís da C. L. Alves, George S. Costa, and José de P. Barros Neto

Preparation of Incongruous Economic Datasets for Regression Analysis 1115
Gunnar Lucko and Zane W. Mitchell, Jr.

Infrastructure Management and Disaster Mitigation

Risk Assessment for Water Mains Using Fuzzy Approach 1125
H. Fares and T. Zayed

An Automated System for Optimizing Temporary Housing Arrangements after Natural Disasters 1135
Omar El-Anwar, Khaled El-Rayes, and Amr Elnashai

Planning Post-Disaster Reconstruction Efforts of Damaged Transportation Networks 1145
Wallied Orabi, Khaled El-Rayes, Ahmed Senouci, and Hassan Al-Derham

Assessment of Impacts of High-Rise Buildings on the Electric and Transportation Infrastructures in Developing Countries 1154
María L. Peralta, Dulcy M. Abraham, and Fred L. Mannering

Extracting Surveying Goals from Point Clouds to Support Construction and Infrastructure Inspection 1164
Pingbo Tang and Burcu Akinci

Infrastructure Risk Management in Renewable Energy Projects Using Risk Flexibility Theory 1174
Nicola Chiara

The Impacts of Infrastructure PPPs on Public Sector Capacity 1184
Stephan F. Jooste and Raymond E. Levitt

Automated Defect Detection in Urban Wastewater Pipes Using Invariant Features Found in Video Images 1194
W. Guo, L. Soibelman, and J. H. Garrett, Jr.

Real-Time Concrete Damage Visual Assessment for First Responders 1204
Zhenhua Zhu, Ioannis Brilakis, and Gustavo Parra-Montesinos

Underground Construction

Interactive Augmented Reality Visualization for Improved Damage Prevention and Maintenance of Underground Infrastructure 1214
Amir H. Behzadan and Vineet R. Kamat

Collaborative Tunneling Simulation Using Synthetic Environments 1223
S. M. AbouRizk, S. Hague, M. Al-Bataineh, and S. Fernando

Development of a Numerical Model for Predicting Pulling Loads on Fusible PVC Pipe 1233
Samuel T. Ariaratnam, Arnab Ghosh, Richard (Bo) Botteicher, and Siggi Finnsson

Horizontal Directional Drilling on the Snoqualmie River: A Case Study.....1243
Kimberlie Staheli and Michelle Ramos

Risk Allocation in Standard Forms of General Conditions for Tunneling Contracts.....1250
Veerasak Likhitruangsilp and Photios G. Ioannou

Trenchless in Anchorage—Case Studies 1260
Michelle Ramos and Brian Gastrock

Construction Simulation

Integrated Simulation-Based Scheduling for Module Assembly Yard 1270
H. Taghaddos, S. AbouRizk, Y. Mohamed, and R. Hermann

Integrating Agent-Based Simulation with Game Theory to Investigate the Hold-Up Problem in Project Networks.....1280
H. I. Unsal and J. E. Taylor

Modeling Architecture for Hybrid System Dynamics and Discrete Event Simulation.....1290
A. Alvanchi, S. Lee, and S. M. AbouRizk

Planning Temporary Hoists for Building Construction.....1300
Seokyon Hwang

Alliance Team Selection for Infrastructure Projects Using Monte Carlo Simulations.....1308
Mounir El Asmar, Awad S. Hanna, Chul-Ki Chang, and Jeffrey S. Russell

Real-Time Simulation for Look-Ahead Scheduling of Heavy Construction Projects 1318
Lingguang Song, Casey Cooper, and Sang-Hoon Lee

Education

Development of a Construction Engineering Laboratory Course and Facility.....1328
David W. Johnston

A Balanced View of Sustainability in Civil Engineering and Construction.....1338
Leidy Klotz and Denise Grant

Engagement of Industry in Best Practices Research 1348
G. Edward Gibson, Jr. and Donald A. Whittington

Assessing Traits for Success in Individual and Team Performance in an Engineering Course 1358
Robert M. Leicht, Angela Lewis, David R. Riley, John I. Messner, and Brent Darnell

One Approach to Incorporating Sustainable Design into Undergraduate Engineering Programs.....1368
J. B. Pocock, Z. Mitchell, and A. J. Bates

Construction Education in Second Life 1378
Kihong Ku and Yogesh Gaikwat

Enhancing Construction Education with Contextual Service Learning.....1388
Christine M. Fiori and Anthony D. Songer

Improving the Internship Experience: Creating a Win-Win for Students, Industry and Faculty **1398**
Christine M. Fiori and Annie R. Pearce

Improving Course Comprehension through Experiential Learning **1409**
Kirsten A. Davis and R. Casey Cline

Visualization and Multimedia Applications in Cost Estimating Education **1419**
Saeed Karshenas

Work Experience Impacts on Construction Management Students' Cognitions Related to Construction Waste Recycling **1429**
MaryEllen C. Nobe

Key Skills for Graduating Construction Management Students—A Comparative Study of Industry and Academic Perspectives **1439**
Rizwan U. Farooqui and Syed M. Ahmed

Research Methods

Research Validation in the Construction Domain **1449**
Gunnar Lucko and Eddy M. Rojas

Research Methods Associated with Situational Simulations in Construction **1459**
Amlan Mukherjee, Nilufer Onder, and Eddy M. Rojas

Constructing Research with Case Studies **1469**
J. E. Taylor, C. S. Dossick, and M. J. Garvin

Techniques for Evaluating Automated Knowledge Acquisition from Contract Documents **1479**
Mohammed Al Qady and Amr Kandil

Techniques to Minimize Bias When Using the Delphi Method to Quantify Construction Safety and Health Risks **1489**
Matthew R. Hallowell

Opinion-Based Research: Lessons Learned from Four Approaches **1499**
David N. Sillars and Matthew R. Hallowell

Indexes

Author Index **I-1**

Subject Index **I-5**

VOLUME TWO

ALIGNING PRE-CONSTRUCTION PLANNING AND PROJECT MANAGEMENT IN THE ELECTRICAL CONSTRUCTION INDUSTRY

Ziad Bou Nasr, M.S.[1] and Cindy L. Menches, Ph.D., P.E.[2], M.ASCE

[1] Graduate Research Assistant, Dept. of Civil, Arch. & Env. Engineering, The University of Texas at Austin, 1 University Station C1752, Austin, TX 78712-0273.
[2] Assistant Professor, Dept. of Civil, Arch. & Env. Engineering, The University of Texas at Austin, 1 University Station C1752, Austin, TX 78712-0273. Phone: (512) 471-6982. E-mail: menches@mail.utexas.edu

Abstract

Efficient management of construction projects continues to be an important topic. A recently completed study evaluated the relationship between pre-construction planning and project performance in the electrical construction industry. The research resulted in a model Electrical Pre-Construction Planning Process that was based on projects that were well-planned and performed well. A follow-on study was recently launched to develop a model Electrical Project Management Process that is aligned with the model Pre-Construction Planning Process. The study is investigating the theory that properly aligned planning and management processes will increase the efficiency of project execution and will result in more successful project outcomes. Five exploratory interviews were conducted with project managers to help the researchers conceptualize the electrical project management process, and this data was used to develop a questionnaire that was sent to 2000 electrical construction companies about their project management practices. The results of the survey were used to revise the electrical project management process, and an initial alignment was performed to identify connections and disconnects between planning and project management. The results of the alignment process revealed that, currently, safety and labor control receive insufficient attention during planning, and, likewise, budget preparation and sequencing receive insufficient attention during project management. Hence, comprehensive interviews are scheduled to investigate the impact of these disconnects on performance and to revise the planning and management processes to provide better alignment and facilitate more successful project performance.

***Keywords*:** planning, pre-construction, project management, performance

Introduction and Previous Research

The continued strength of the construction market has inspired the electrical construction industry to search for ways to improve the efficiency of their project

processes. In 2006, they adopted a standardized pre-construction planning (PCP) process following an extensive research project that identified planning activities that were strongly correlated with successful project outcomes (Menches et al., 2008). The process consists of 73 activities divided into 20 planning categories (Fig. 1) that, if performed sufficiently well and at the appropriate time during the planning process, can contribute to more successful project performance (Menches and Hanna 2006). The research quantified the relationship between pre-construction planning and the likelihood of achieving a successful outcome and found that those projects that performed a comprehensive planning process were more likely to achieve their estimated work hours, profit, budget, and schedule goals.

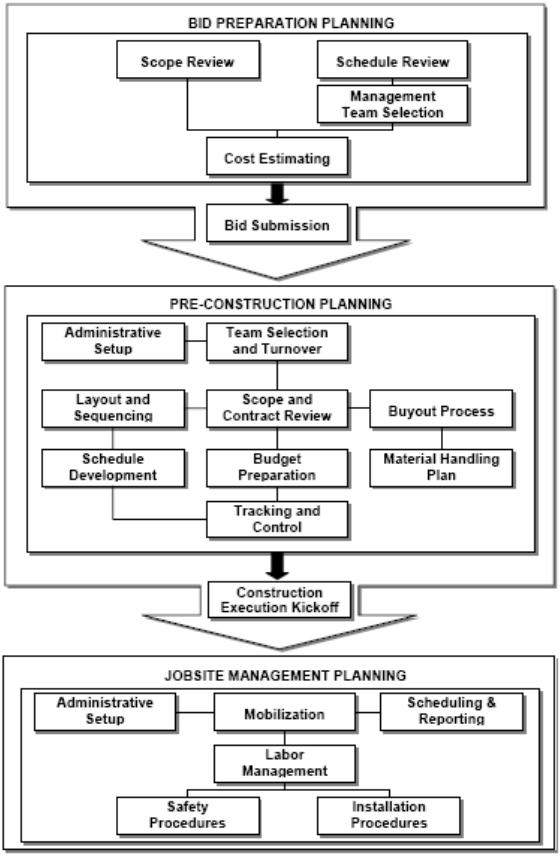


Figure 1. Model Electrical Pre-Construction Planning Process (Menches and Hanna 2006)

During the study, the researcher interviewed nearly 50 project managers, and, through the interview process, it became clear that the quality of *project management* was also an important element to performance. However, the research was designed to study pre-construction planning, and, as a result, very little data was collected on the project management process. Nevertheless, an exploratory data analysis was conducted using the limited project management data, and the results revealed that effective planning *combined with effective project management* contributed to significantly better performance. The conceptual model of the relationship between planning and management is shown in Figure 2 (Menches and Hanna 2006). This model acknowledges that there are many factors that can influence the performance of a project. Problems such as excessive changes, poor productivity, or numerous delays can have a negative impact on the outcome of a project. However, good planning that establishes systems that can be used to properly manage the problems during the execution stage can improve the chances of achieving a successful outcome. In the diagram, the project characteristics are acknowledged as influencing the planning effort, project management, and performance. For example, a specific characteristic, such as complexity of the work, might influence how a project is planned, how it is managed, or how it ultimately performs. If the contractor correctly determines the project is complex, the contractor might decide to expend more time planning and managing the project to minimize the risk of loss or failure. Likewise, if the contractor fails to identify the project as complex, and fails to properly plan for a complex job, making it more difficult to manage problems that arise, the project might perform poorly. Hence, the characteristics will influence how a project is planned, and the planning will influence how a project is managed, which will ultimately impact performance.

Recently, the electrical industry has taken another look at their existing project management process to determine whether the process can be improved by aligning it with the new pre-construction planning process. A research project was initiated that

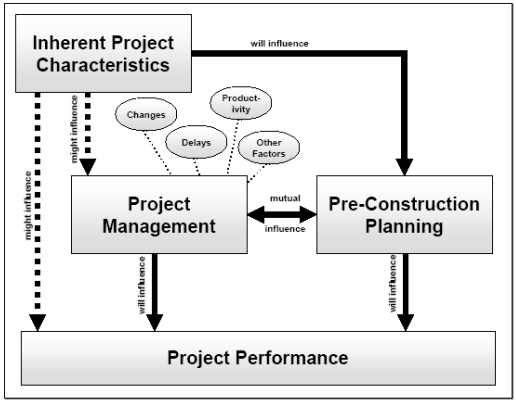


Figure 2. Conceptual model of the relationship between project characteristics, pre-construction planning, management, and performance (Menches and Hanna 2006)

is investigating the relationship between pre-construction planning, project management, and performance. The research will result in a model Electrical Project Management Process that is aligned with the model Electrical Pre-Construction Planning Process, *resulting in a comprehensive project success strategy that pairs planning with project management to achieve significantly better performance*.

Other Related Research

Research on project management has been prolific, spawning numerous textbooks (Kerzner 2006; Mincks and Johnston 2004; Schaufelberger and Holm 2002) and other proprietary manuals that are used daily in the construction industry. However, few attempts have been made to *scientifically align* the various stages of project management (i.e., materials management, cost control, labor management) and there has been no previous research that scientifically aligns the pre-construction planning process with the project management process in the electrical construction industry. Scientific alignment necessarily involves statistically demonstrating that activities in one stage of a project can impact activities in another stage.

The Project Management Institute (PMI) has taken a quasi-scientific approach to project management by publishing a body of knowledge that "includes proven traditional practices that are widely applied, as well as innovative practices that are emerging in the profession" (Project Management Institute 2004). They have identified a set of five process groups that represent "good practice" in the industry, indicating that "there is general agreement that the application of those project management processes has been shown to enhance the chances of success over a wide range of projects" (p. 37). These five process groups as: (1) Initiating Process, (2) Planning Process, (3) Executing Process, (4) Monitoring and Controlling Process, and (5) Closing Process. They have also identified nine project management knowledge areas that include:

Integration Management	Scope Management	Time Management
Cost Management	Quality Management	Human Resources Management
Communication Management	Risk Management	Procurement Management

PMI has develop a diagram that maps the nine project management knowledge areas to the five process groups but has not specifically identified how the nine project management knowledge areas potentially impact each other.

Previously, Sanvido (1988) developed a theoretical model of the conceptualized management functions that support jobsite operations, essentially aligning project management with jobsite management and demonstrating their critical inter-dependence. In his study, Sanvido developed a *conceptual construction process model* and created a simple worksheet to record whether the management functions were performed at the right *level*, such as craftsman level, superintendent level or project manager level. He then assigned each function a score based on when it was performed, with functions performed at a lower level than optimum considered as sub-optimized and functions performed at a higher level than optimum considered as over-controlled. He was able to demonstrate that projects that performed activities at the proper time achieved better cost and schedule performance.

The current research differs from previous work in that it will investigate how the alignment between planning and management activities impacts project performance

Research Goals and Questions

The goals of the research are to (1) develop a model Electrical Project Management Process that is aligned with the model Pre-Construction Planning Process, and (2) investigate and quantify the relationship between pre-construction planning effectiveness, project management effectiveness, and performance. The investigation seeks to answer the following questions:

1. Can the project characteristics, effectiveness of pre-construction planning, and effectiveness of project management more accurately predict the probability of successful performance than just the characteristics and planning alone?
2. Is there a relationship between the effectiveness of planning and the effectiveness of project management or are these functions independent of one another?
3. Can we determine how to adjust pre-construction planning to overcome *anticipated* deficiencies in project management?
4. Can we determine how to adjust project management to overcome *known* deficiencies in pre-construction planning?

Research Methodology and Framework

The research aims to investigate and quantify the relationship between project characteristics, pre-construction planning, project management, and performance. To support the goal, the research methodology includes five key stages (Fig. 3):

Stage One:
1. Review the relevant literature and develop a generic project management process
2. Conduct preliminary interviews with local electrical contractors to learn about their project management process
3. Revise the generic process based on the preliminary interview results

Stage Two:
1. Use the revised process to develop a brief questionnaire about broader electrical project management practices
2. Distribute questionnaire to 2000 randomly-selected members of the National Electrical Contractors Association (NECA)
3. Revise the electrical project management process based on survey results and use the data to construct a questionnaire and interview guide for in-person interviews

Stage Three:
1. Solicit those 28 contractors that participated in the original pre-construction planning study to encourage them to participate again
2. Solicit additional participants from those who responded to the questionnaire and expressed a willingness to continue participating
3. Conduct comprehensive in-person interviews to learn about project management practices employed on one successful and one less-than-successful project; interview tools include a questionnaire and interview guide

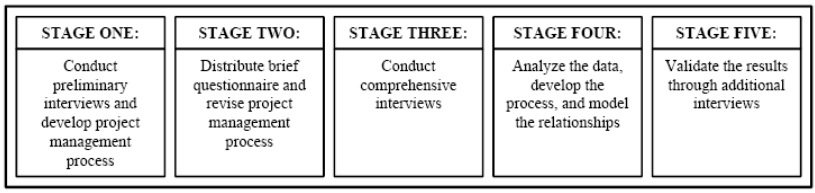


Figure 3. Methodology for the Research

Stage Four:

1. Analyze the data and develop a model of the relationship between pre-construction planning, project management, and performance
   1.1. Construct a model electrical project management process that includes management activities commonly performed on all projects as well as activities that are performed on the most successful projects
   1.2. Develop a scorecard for rating the effectiveness of project management
   1.3. Create composite project management variables that can be used to evaluate the effectiveness of individual activities and the process as a whole; these variables will be developed from a principle components analysis of the data
   1.4. Develop a quantitative model of the relationship between characteristics, pre-construction planning, project management, and performance; this model will use the composite project management variables in a multiple linear regression to evaluate the impact of the performance of management activities on project outcome
2. Conduct simulation exercises to investigate how various combinations of characteristics, pre-construction planning activities/effectiveness, and project management activities/effectiveness can influence the probability of achieving a successful outcome

Stage Five:
Validate the model by collecting new data from additional contractors using similar data collection techniques

Currently, the researchers have completed Stages One and Two. Results from these first two phases is scheduled for separate publication; consequently, this paper presents the preliminary findings resulting from an initial alignment of the existing Electrical Pre-Construction Planning Process with the preliminary Electrical Project Management Process. This information will be used during Stage Three to query companies about the impact of activity alignment on project performance.

Initial Findings

Preliminary Interviews with Electrical Construction Companies. A review of the relevant literature was used to develop a conceptual diagram of a generic project management process (Fig. 4). This diagram formed a significant part of a questionnaire that was used to conduct face-to-face preliminary interviews with five electrical construction companies to learn more about the specific activities that make

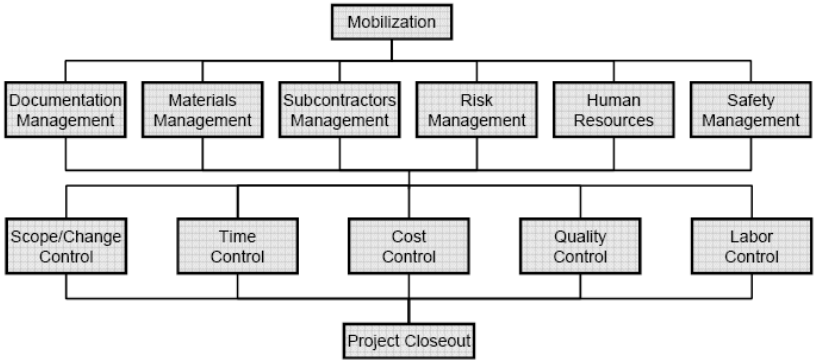


Figure 4. Generic Project Management Process

up their project management practices and how these activities differ from the generic process. During the interview, the participants were first asked to DEVELOP A LIST OF THE MAIN PROCESS GROUPS that make up the company's project management process. Then, the participants were shown a "sample" project management flowchart that included the generic process groups (i.e., materials management, cost control, etc.) and also included several empty boxes. Each participant was asked to review the flow-chart to develop a sense of how closely it represented their company's process and FILL IN MISSING PROCESS GROUPS in the empty boxes. They were also encouraged to CROSS OUT PROCESS GROUPS that represent activities they do not perform and change the location of process groups within the flow chart to better represent their own process. Alternatively, participants were provided with a blank piece of paper if they wanted to draw their company's project management process from scratch. To complete the interview, participants were asked to LIST SPECIFIC ELECTRICAL CONSTRUCTION ACTIVITIES in each process group. Activities that were unique to the electrical construction industry included:

- Detailed labor analysis and reporting
- Equipment cost management
- Creation of a commissioning binder
- Develop prefabrication drawings
- Crew mix management
- Materials security management

Upon completion of the interviews, the researchers revised the generic project management process to represent an initial concept of the electrical project management process. Overall, the process was not significantly different than the generic process, but it was noted that none of the companies had a human resources management process because their workforce was exclusively union, so the Human Resources Process was removed from the flowchart. Several companies indicated they do not typically have subcontractors, and only a few companies appeared to perform a separate risk analysis.

Initial Questionnaires. The results from the preliminary interviews were used to develop an initial questionnaire that was distributed to 2000 randomly-selected members of the National Electrical Contractors Association (NECA) in the U.S. The

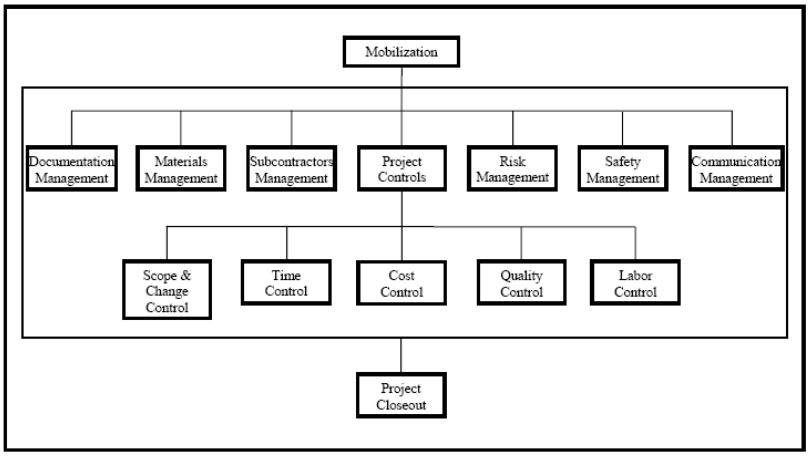


Figure 5. Revised Electrical Project Management Process

primary purpose of the brief questionnaire was to further refine the electrical project management process prior to conducting comprehensive interviews with companies. The detailed results of the initial questionnaire are scheduled for publication separately, but overall, there was general agreement among companies throughout the U.S about the electrical project management process. Figure 5 show the revised process resulting from the questionnaire responses. Communications Management was identified as an important process that was initially overlooked during the preliminary interviews. Likewise, Risk Management, while remaining in the flowchart, was generally not managed as a separate process. Furthermore, all of the control functions (i.e., cost, time, scope control) were typically managed together, and thus were grouped into a separate process called "Project Controls."

Initial Alignment Results. The initial model Electrical Project Management Process was compared to the model Electrical Pre-Construction Planning Process to identify potential areas of proper alignment and significant misalignments that might be a source of problems during the execution of the work. *Proper alignment* is defined as the completion of a set of planning activities during the pre-construction phase that results in a process or set of tools that are used to manage the project during the execution stage. A *misalignment* occurs when a set of planning activities is performed after the project has been executed rather than during the pre-construction stage, creating a delay in the development of a process or set of tools that can be used to manage the activities. Furthermore, "no corresponding process" occurs in two cases: (1) when a set of planning activities is performed during the pre-construction phase but there is no corresponding process to manage the activities after execution, or (2) when a set of activities needs to be managed following execution but no pre-construction planning was performed and, hence, no process or set of tools was developed to manage these activities.

Table 1 identifies the results from the initial alignment of the Electrical pre-Construction Planning Process with the preliminary Electrical Project Management Process. Overall, many of the activities that are performed during the execution phase do, indeed, have a corresponding pre-construction planning process that is intended to set up the systems for successful management of those activities. However, the researchers noted that safety procedures and labor management activities were identified as part of the Jobsite Management Planning Process rather than the Pre-Construction Planning Process, potentially causing a delay in the establishment of management procedures for safety and labor. This is an area that will need further investigation during the comprehensive in-person interviews to determine whether the misalignment creates significant management difficulties. Likewise, the researchers noted that two pre-construction planning activities – Budget Preparation and Layout and Sequencing – do not have corresponding management functions in the preliminary Electrical Project Management Process. During the comprehensive interviews, specific questions will be asked to determine (1) whether corresponding management processes do, indeed, exist and have thus far been overlooked, (2) whether the management of these activities is embedded within other project management processes, or (3) whether these management activity-groups need to be added to the model.

Future Research: Quantifying the Relationship Between Project Characteristics, Pre-Construction Planning, Project Management, and Performance

The research team will develop and administer a questionnaire and conduct face-to-face interviews to learn about the pre-construction planning and project management practices employed on specific successful and less-than-successful electrical construction projects. The questionnaire will focus on project performance, including cost and schedule, while the interview will focus on pre-construction planning and project management activities performed. The interview will be largely open-ended

Table 1. Results from the Initial Alignment of Electrical Pre-Construction Planning and Electrical Project Management Processes

Pre-Construction Planning Process	Project Management Process
Properly Aligned Processes	
Administrative Setup	Document Management
Buyout/Materials Handling	Materials Management
Scope & Contract Review	Risk Management
Tracking & Control	Project Controls
Schedule Development	Project / Time Control
Misaligned Processes	
Safety Procedures	Safety Management
Labor Management	Labor Control
No Corresponding Process	
Budget Preparation	[Billing & Payment Management]
Layout & Sequencing	[Work Flow Control]

Note: Brackets indicate a missing process

so that the researcher can learn about *specific* planning and management activities used by each participant on their project that may have contributed to its performance. Specific topics that will be explored during the interview process include, but are not limited to: labor management; cost, scope, and change control; schedule control; materials management, including methods for planning and managing the risks involved with owner-furnished materials; and, communication and information management. A detailed data analysis involving qualitative and quantitative analysis techniques will be performed to construct the model Electrical Project Management Process and model the relationship between pre-construction planning, project management, and performance.

Conclusion

An on-going research project is investigating the relationship between pre-construction planning, project management, and performance in the electrical construction industry. A preliminary Electrical Project Management Process has been developed and has been aligned with the existing Electrical Pre-Construction Planning Process. This alignment process is critical because it highlights specific connections and disconnects between the two processes, which may create difficulties during the execution phase. Specifically, activities that have not been properly planned may be difficult to manage and may lack the tools necessary for efficient project management. The information gained from performing the alignment process will be used in upcoming comprehensive interviews in which the researchers will investigate the impact of the relationship between planning, project management, and their alignment on the performance of successful and less-than-successful electrical construction project.

References

Kerzner, H. (2006). *Project management: A systems approach to planning, scheduling, and controlling*, John Wiley & Sons, Inc., Hoboken, NJ.

Menches, C.L. and Hanna, A.S. (2006). Conceptual Planning Process for Electrical Construction. *Journal of Construction Engineering and Management*, 132(12), 1284-1293.

Menches, C.L., Hanna, A.S., Nordheim, E.V., and Russell, J.S. (2008). Quantifying the impact of pre-construction planning on project performance in the U.S. electrical construction industry. *Construction Management and Economics*, 26(8), 853-867.

Mincks, W. R., and Johnston, H. (2004). *Construction jobsite management*, Delmar Learning, Clifton Park, NY.

Project Management Institute. (2004). *A guide to the project management body of knowledge*, Project Management Institute, Inc., Newtown Square, PA.

Sanvido, V. (1988). "Conceptual construction process model." *Journal of Construction Engineering and Management*, 114(2), 294-310.

Schaufelberger, J. E., and Holm, L. (2002). *Management of construction projects: A constructor's perspective*, Prentice Hall, Upper Saddle River, NJ.

MULTI-OBJECTIVE OPTIMIZATION OF RESOURCE SCHEDULING IN CONSTRUCTION PROJECTS

Dho Heon Jun[1] and Khaled El-Rayes[2]

[1]Ph.D. Candidate, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801 Telephone: (217) 265-5215, Fax: (217) 265-8039, Email: dhojun@uiuc.edu
[2]Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801 Telephone: (217) 265-0557, Fax: (217) 265-8039, Email: elrayes@uiuc.edu

ABSTRACT

Resource allocation and leveling techniques have been widely used to consider the impact of resource availability and minimize undesirable resource fluctuations. These techniques and existing models deal with two distinct problems in a sequential manner rather than simultaneously. This paper presents the development of a robust multi-objective optimization model for optimizing resource allocation and leveling simultaneously. Two innovative resource leveling metrics, namely Release and Re-Hire (RRH) and Resource Idle Days (RID), are incorporated in the model to directly measure and minimize the negative impact of resource fluctuations on construction productivity and cost. An application example is analyzed to illustrate the use of the model and demonstrate its capabilities in generating optimal tradeoffs between resource utilization efficiency and project duration.

INTRODUCTION

Construction schedules generated by network scheduling techniques often need to be modified in order to avoid unintended high resource demands and reduce significant fluctuations in resource utilization levels over the project duration (Harris 1978). As shown in Figure 1(A), these resource fluctuations are impractical, inefficient and costly to implement on construction sites, as they (1) require additional costs to hire additional resources (Popescu and Charoenngam 1995); (2) require the hiring and releasing of workers on a short-term basis; (3) create difficulties in attracting and keeping top-quality workers if stable employment is not guaranteed (Harris 1978); (4) produce disruption in the learning curve effects (Stevens 1990); and/or (5) require contractors to maintain an unproductive level of workforce on site that keeps some workers idle during low demand periods. Two types of techniques, resource allocation and resource leveling, have been widely used to reduce the aforementioned negative impact on construction productivity and cost. Resource allocation

(sometimes referred to as resource constrained scheduling) is applied to allocate available resources to project activities in an attempt to obtain the shortest project duration. On the other hand, resource leveling is used to minimize resource fluctuations by shifting non-critical activities within their available float times to prevent any delay in the project completion date. As such, these techniques have two different objectives and deal with two distinct sub-problems that can only be applied to a project one after the other rather than simultaneously (Hegazy 1999). In practice, however, construction planners need to analyze these two problems simultaneously to assess the impact of the revised schedule on both the project duration and the efficiency of resource utilization.

A number of research studies have developed models to optimize resource allocation and leveling simultaneously (Chan et al 1996; Chua et al. 1996; Hegazy 1999; Leu and Yang 1999; Senouci and Eldin 2004). These research studies introduced and utilized various metrics in their models to produce optimal schedules that provide improved resource profiles and minimum project durations. Despite the significance and contributions of these research studies, there is no or little research focusing on (1) directly measuring and minimizing undesirable resource fluctuations in order to maximize overall resource utilization efficiency; and (2) generating feasible tradeoffs between resource utilization efficiency and project duration for construction planners to enable the selection of an optimal plan that satisfies the specific requirements of the project being considered.

This paper presents a robust multi-objective optimization model that is capable of simultaneously optimizing resource allocation and leveling. The objectives of the present model are to (1) minimize project duration while resolving all resource conflicts and (2) maximize resource utilization efficiency by minimizing undesirable resource fluctuations that cause non-productive crew idle time, as shown in Figure 1(B). A multi-objective genetic algorithm is implemented in the model to generate a set of optimal trade-offs between those two objectives. Construction planners can evaluate this set of optimal tradeoff solutions and select an optimal construction plan that satisfies the specific requirements of the project being considered. The following sections of the paper present: (1) two newly developed resource utilization metrics that can be used to directly measure and minimize undesirable resource fluctuations; (2) a multi-objective optimization model for resource scheduling in construction projects; and (3) an application example that illustrates the use of the developed model.

RESOURCE UTILIZATION METRICS

Two new resource leveling metrics, namely Release and Re-Hire (RRH) and Resource Idle Days (RID), are developed and used in the present model to measure the overall resource utilization efficiency in construction projects. Only undesirable fluctuation which can be graphically depicted as a valley shape, as shown Figure 1(A), is measured by the two new metrics. The undesirable fluctuation forces a contractor to either (1) temporarily release the additional construction resources and rehire them at a later stage when they are needed; or (2) retain the idle construction resources on site until they are needed later in the project. In order to generate a productive and

cost effective construction schedule, this undesirable fluctuation should be directly measured and minimized.

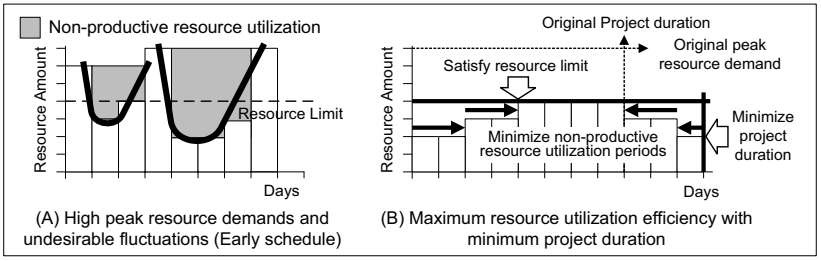


Figure 1. Optimizing resource allocation and leveling by the present model

Release and Re-Hire (RRH)

This metric (RRH) is designed to quantify the total amount of resources that need to be temporarily released during low demand periods and rehired at a later stage during high demand periods. Release and Re-Hire (RRH) can be calculated using Equation (1) that is designed to calculate the total number of resources that need to be released and rehired, as shown in Figure 2(A).

$$RRH = \frac{1}{2} \times \left[r_1 + \sum_{t=1}^{T-1} \left| r_t - r_{t+1} \right| + r_T \right] - Max\{r_1, r_2, ..., r_T\} \quad (1)$$

Where, T = total project duration; r_t = resource demand on day (t); and r_{t+1} = resource demand on day (t+1). It should be noted that this metric is practical and useful in projects that allow the release and rehire of construction workers.

Resource Idle Days (RID)

This metric (RID) is designed to quantify the total number of idle and non-productive resource days caused by undesirable resource fluctuations. Resource Idle Days (RID) can be calculated using Equation (2) that is designed to calculate the shaded area of resource idle time, as shown in Figure 2(B).

$$RID = \sum_{t=1}^{T} \left[Min\left\{ Max\left(r_1, r_2, ..., r_t\right), Max\left(r_t, r_{t+1}, ..., r_T\right) \right\} - r_t \right] \quad (2)$$

Where, T = total project duration; and r_t = resource demand on day (t). This metric is practical and useful in projects that restrict the temporary release and rehire of resources.

The two newly developed metrics can be effectively used to directly measure and minimize only undesirable resource fluctuations that cause negative impacts on construction productivity and cost. Construction planners can select to minimize the Release and Re-Hire (RRH) or Resource Idle Days (RID) metrics depending on the

special conditions and requirements of the construction project. The present model incorporates these two new metrics in the present model to maximize overall resource utilization efficiency for construction projects, as shown in Figure 2(C).

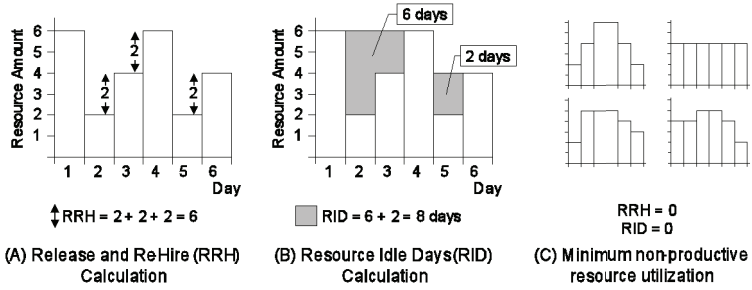


Figure 2. Calculation of the new metrics for resource leveling

MULTI-OBJECTIVE OPTIMIZATION MODEL

The present optimization model is developed and organized in four modules: (1) Initialization module; (2) Multi-objective genetic algorithm module; (3) Activity ranking module; and (4) Resource allocation and leveling module as shown in Figure 3.

Initialization Module

The main objective of this module is to identify the lower and upper bounds for the two main decision variables of Priority-Value (P_n) and Maximum-Shift-Days (M_n), which are used to model the priority of each activity in the project and the maximum number of days that it can be shifted. As shown in Figure 4, each of these two variables is represented using a genetic algorithm chromosome that has a length of N (i.e. the number of activities in the project). This initialization module is performed using the following four main steps:

1.1) Create five sets of project activities as follows:
   a) U: Set of all the project activities (U = {1, 2,… , N}).
   b) A_n: Set of activities that should be completed before starting activity (n).
   c) B_n: Set of activities that require the completion of activity (n) to start.
   d) Z_n: Set of activities that have parallel relationships with activity (n) ($Z_n = U - A_n - B_n$)
   e) C_n: Set of activities that are in Z_n and have a resource conflict with activity (n).

1.2) Calculate the upper bound (UB_n) for the decision variable of Maximum-Shift-Days (M_n) for activity (n) using Equation (3).

$$UB_n = \sum_{n \in Z_n} d_n - \sum_{n \in C_n} d_n \quad (3)$$

Where, d_n = duration of activity (n).

1.3) Set the lower and upper bounds on the decision variables, P_n and M_n ($0 \leq P_n \leq N-1$, $0 \leq M_n \leq UB_n$).

1.4) Repeat steps 1.1 to 1.3 for the remaining activities in the project.

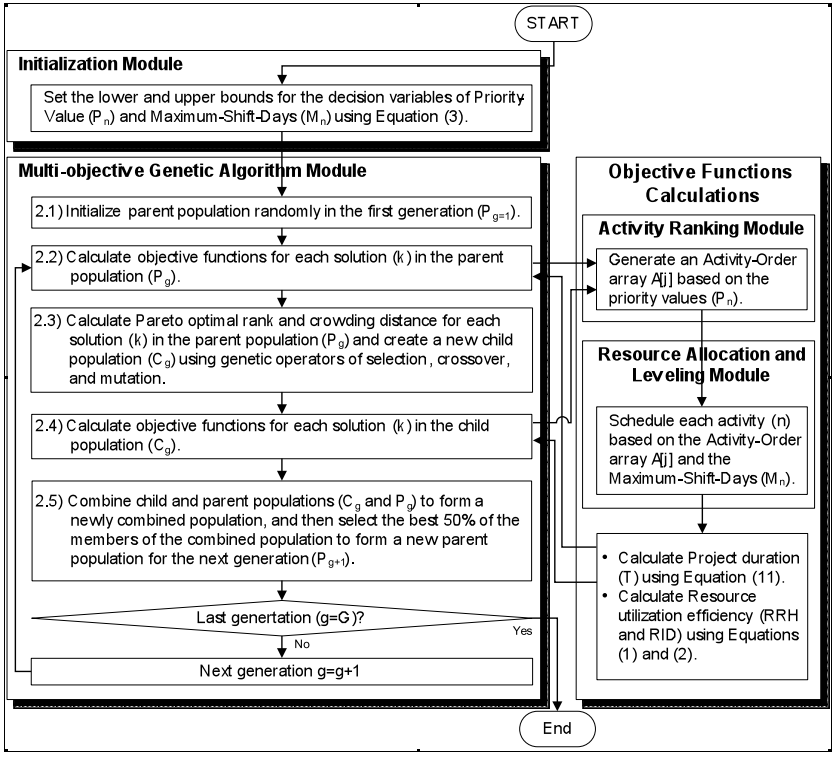


Figure 3. Optimization model

Multi-Objective Genetic Algorithm Module

In order to simultaneously maximize resource utilization efficiency and minimize project duration, a multi-objective genetic algorithm (Deb et al. 2001) is used to implement the present model. Genetic algorithm has been successfully used as a search and optimization tool by many studies including resource leveling and allocation for construction projects (Chan et al 1996; Chua et al. 1996; Hegazy 1999; Leu and Yang 1999; Senouci and Eldin 2004). The module is implemented in the following five main steps:

2.1) Generate an initial set of solutions (k=1 to K) for the initial population ($P_{g=1}$) in the first generation (g=1). Each solution (k) consists of randomly generated

values for the Priority-Value and the Maximum-Shift-Days variables (P_1, P_2,…, P_N, M_1, M_2,…, M_N,). These solutions are designed to produce an initial set of feasible project schedules and resource profiles, as shown in Figure 4.

2.2) Calculate the values of the objective functions (i.e. project duration (T) and resource utilization efficiency (RRH or RID)) for each solution (k) in the parent population (P_g). This step is performed using the Activity ranking module and the Resource allocation and leveling module that return the values of the objective functions for a given set of decision variables values.

2.3) Calculate Pareto optimal rank and crowding distance for each solution (k) in the parent population (P_g) and create a new child population (C_g) using the genetic operators of selection, crossover, and mutation.

2.4) Evaluate the fitness functions for each solution in the newly created child population (C_g) in a process similar to step 2.2.

2.5) Combine child and parent populations (C_g and P_g) to form a newly combined population, and then select the best 50% of the members of the combined population to form a new parent population for the next generation (P_{g+1}). This process acts as a strong form of elitism as it preserves the best solutions of the parents' population over generations (Deb et al. 2001).

The above steps from 2.2 to 2.5 are repeated over a number of predetermined generations (G) in order to generate a Pareto optimal set of non-dominated solutions that simultaneously minimize project duration and maximize resource utilization efficiency.

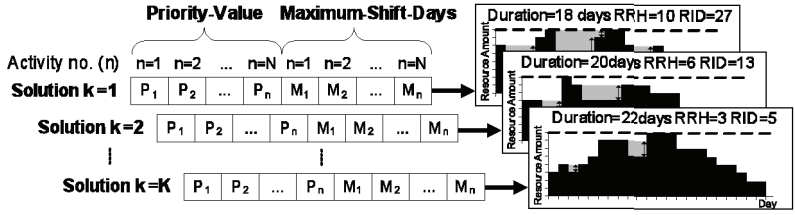


Figure 4. Decision variables and their produced schedules

Activity Ranking Module

The main objective of this module is to generate an activity order based on the randomly generated priority values (P_n). The serial method proposed by Kelley (1963) is employed in this module to produce various activity orders. The module is performed using the following eight main steps:

3.1) Create Scheduled set (S), Unscheduled set (U), Decision set (D), and Activity-Order array (A[j]; j = 0, 1,…, N-1).

3.2) Put all the project activities into set (U).

3.3) Set j = 0 and select the activities that do not have predecessors from the set (U).

3.4) Move the activities selected in the previous step from set (U) to set (D).

3.5) Select activity (n*) that has the highest value of P_n from set (D) (select the

activity that has the smallest activity number (n) in case of a tie) and save it in Activity-Order array (A[j]).

3.6) Move the selected activity (n*) from set (D) to set (S).

3.7) Set j = j+1 and select the activities from set (U) if all their predecessors exist in set (S).

3.8) Repeat steps 3.4 to 3.7 for the remaining activities in set (U).

The generated Activity-Order array (A[j]) is then used in the Resource allocation and leveling module to resolve resource conflicts by defining the scheduling sequence of competing activities, which is described in more detail in the following section.

Resource Allocation and Leveling Module

The main objectives of this module are to (1) schedule each activity (n) based on the generated Activity-Order array (A[j]) and the randomly generated Maximum-Shift-Days (M_n); and (2) calculate project duration (T) and overall resource utilization efficiency (RRH or RID) for the schedule. This module is performed using the following eight main steps:

4.1) Set j=0 and calculate early start time ($ES_{A[0]}$) and early finish time ($EF_{A[0]}$) for the first activity in the array (A[0]) using Equations (4) and (5).

$$ES_{A[0]} = 1 \tag{4}$$

$$EF_{A[0]} = ES_{A[0]} + d_{A[0]} - 1 \tag{5}$$

4.2) Set j=j+1 and calculate the earliest possible start time ($EPST_{A[j]}$) and the latest possible start time ($LPST_{A[j]}$) for activity (A[j]) using Equations (6) and (7).

$$EPST_{A[j]} = \begin{cases} \text{Max}\{EF_n \mid n \in PRED_{A[j]}\} + 1; & \text{if A[j] has predecessors} \\ 1; & \text{otherwise} \end{cases} \tag{6}$$

$$LPST_{A[j]} = \text{Max}\{EF_{A[0]}, EF_{A[1]}, \ldots, EF_{A[j-1]}\} + 1 \tag{7}$$

Where, $PRED_{A[j]}$ = set of immediate predecessors of activity (A[j]).

4.3) Calculate the total number of possible start times ($TPST_{A[j]}$) for activity (A[j]) in the period from $EPST_{A[j]}$ to $LPST_{A[j]}$ and save each possible start time in Start-Days array ($SD_{A[j]}[i]$). Each possible start time saved in this array represents the day that the activity can start without having any resource conflicts with other activities during its duration.

4.4) Calculate Selected-Start-Time ($SST_{A[j]}$) for activity (A[j]) using Equation (8). This prevents activity (A[j]) to shift beyond its $LPST_{A[j]}$ and cause non-productive resource utilization periods.

$$SST_{A[j]} = \left\lfloor M_{A[j]} \times \frac{TPST_{A[j]}}{(UB_{A[j]} + 1)} \right\rfloor \quad (8)$$

Where, $M_{A[j]}$ = Maximum-Shift-Days for activity (A[j]); $UB_{A[j]}$ = upper bound of $M_{A[j]}$; and = fraction truncation.

4.5) Calculate early start time ($ES_{A[j]}$) and early finish time ($EF_{A[j]}$) for activity (A[j]) using Equations (9) and (10).

$$ES_{A[j]} = SD_{A[j]}[SST_{A[j]}] \quad (9)$$

$$EF_{A[j]} = ES_{A[j]} + d_{A[j]} - 1 \quad (10)$$

4.6) Repeat steps 4.2 to 4.5 for the remaining activities in the project.

4.7) Calculate daily resource demands for the revised schedule.

4.8) Calculate project duration (T) using Equation (11) and the overall resource utilization efficiency using the two new metrics of RRH and RID, as shown in Equations (1) and (2).

$$T = \text{Max}\{EF_1, EF_2, ..., EF_N\} \quad (11)$$

The above steps are repeated for each solution (k) in population (P_g) of each generation (g). The calculated values of the project duration (T) and the two new metrics (RRH and RID) for each solution (k) are then used as the fitness value in the Multi-objective genetic algorithm module to reproduce new offspring solutions in subsequent generations during the search for optimal/near optimal solutions. After a number of specified generations (G), each solution (k) in the final population (P_G) represents non-dominate optimal/near optimal solutions that simultaneously minimize project duration (T) and maximize resource utilization efficiency (RRH or RID).

APPLICATION EXAMPLE

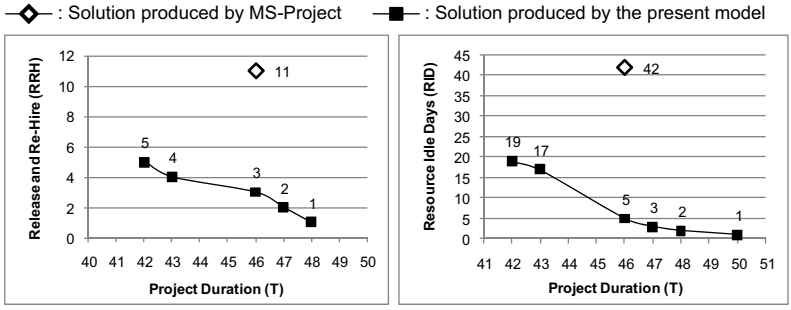
An application example is analyzed to illustrate the use of the present model and demonstrate its capabilities in generating a set of optimal tradeoff between project duration and resource utilization efficiency. The example consists of twenty activities with varying daily resource demands and a maximum availability limit of 9 resources per day, as shown in Table 1. Assuming an unlimited supply of resources, early schedule of this example can be completed in 31 days and it produces a resource profile that includes undesirable fluctuations. The example was analyzed after considering the maximum availability limit of 9 resources per day using the resource leveling feature in MS Project software, and it produced a project duration of 46 days with RRH=11 and RID=42, as shown in Figure 5. The example was then analyzed using the present model in order to (1) minimize project duration (T) and minimize Release and Re-Hire (RRH); and (2) minimize project duration (T) and minimize Resource Idle Days (RID). As shown in Figure 5, the optimal solutions generated by the present model outperform the solution produced by the MS Project, as it provides significant reduction in the project duration as well as in RRH and RID. Each of these

solutions represents an optimal schedule for the project that provides unique project duration and resource utilization efficiency. A construction planner can evaluate each of these optimal solutions and select the one that satisfies the specific requirements of the project being considered.

Table 1. Case study data

Activity	Duration	Predecessors	R/day*	Activity	Duration	Predecessors	R/day*
A	6	-	2	K	1	C,E	4
B	3	-	3	L	2	E,G,H	8
C	4	A	2	M	4	I,K	5
D	6	-	5	N	2	F,L	3
E	6	A,B	3	O	3	L	6
F	5	C	9	P	5	J,M,N	4
G	2	D	3	Q	8	O	1
H	2	A,B	5	R	2	J,O	5
I	2	G,H	3	S	5	P,Q	2
J	6	F	6	T	3	R	5
Daily resource limit = 9							

* R/day: Resource demand per day



(A) Project duration − RRH tradeoffs analysis (B) Project duration − RID tradeoffs analysis

Figure 5. Optimal solutions

SUMMARY

A robust multi-objective optimization model is developed to simultaneously optimize resource allocation and leveling in construction projects. The model is designed to search for and generate optimal and practical construction schedules that simultaneously minimize project duration and maximize resource utilization efficiency while maintaining all scheduling constraints such as job logic and daily resource limit. Two new resource leveling metrics (RRH and RID) were developed and incorporated in the present model to directly measure and minimize undesirable resource fluctuations that cause negative impacts on construction productivity and cost. An application example was analyzed to demonstrate the capabilities of model in generating optimal trade-offs between project duration and resource utilization

efficiency. This should prove useful to construction engineers and planners and can lead to significant improvements in construction productivity and costs.

REFERENCES

Chan, W. T., Chua, D. K. H., and Kannan, G. (1996). "Construction resource scheduling with genetic algorithms." *J. Constr. Eng. Manage.*, ASCE, 122(2), 125-132.

Chua D. K. H., Chan W. T., and Govindan K. (1996). "Scheduling with Co-evolving Resource Availability Profiles", J. Civil Eng. Systems, 13(4), 311-329.

Deb, K., Pratap, A., Agrawal, S., and Meyarivan, T. (2001). "A Fast and Elitist Multi-Objective Genetic Algorithm: NSGA-II" *KANGAL Report 200001,* Genetic Algorithm Laboratory, Indian Institute of Technology, Kanpur, India.

Harris, R. B. (1978). *Precedence and Arrow Networking Techniques for Construction*, John Wiley & Sons. New York.

Hegazy, T. (1999). "Optimization of resource allocation and leveling using genetic algorithms." *J. Constr. Eng. Manage.*, ASCE, 125(3), 167-175.

Kelly, J. E. (1963). "The Critical-path Method: Resource Planning and Scheduling", in: J.F. Muth and G. L. Thompson (Eds.), *Industrial Scheduling*, Prentice-Hall, New Jersey, 347-365

Leu, S. S., and Yang, C. H. (1999). "GA-based multicriteria optimal model for construction scheduling." *J. Constr. Eng. Manage.*, ASCE, 125(6), 420-427.

Popescu, C. M., and Charoenngam, C. (1995). *Project planning, scheduling and control in construction*. Wiley, New York.

Seibert, J., and Evans, G. (1991) "Time-constrained resource leveling" *J. Constr. Eng. Manage.*, ASCE, 117(3), 503-520.

Senouci, A. B., and Eldin, N. N. (2004) "Use of genetic algorithms in resource scheduling of construction projects." *J. Constr. Eng. Manage.*, ASCE, 130(6), 869-877.

Stevens, D. J (1990) *Techniques for Construction Network Scheduling.* McGraw-Hill, New York.

AUTOMATED CPM SCHEDULE GENERATION FOR EARLY PROJECT PLANNING: METHODOLOGY AND CASE STUDY

Youngsoo Jung[1], A.M. ASCE, PhD, PMP, Young Hwan Lee[2], Sungkwon Woo[3], Jin-Soo Yang[4], Sang-Mok An[5], Young-Seok Oh[6], Bok Nam Lee[7]

[1] College of Architecture, Myongji University, Yongin 449-728, South Korea, PH (8231) 330-6396; FAX (8231) 330-6487; email: yjung97@mju.ac.kr
[2] CM Div., Constr. & Economy Res. Inst. of Korea (CERIK), Seoul 135-701, Korea, PH (822) 3441-0616; FAX (822) 3441-0890; e-mail: yhlee@cerik.re.kr
[3] Dept. of Civil Engineering, Inha University, Incheon 402-751, South Korea, PH (8232) 860-7573; FAX (8232) 873-7560; e-mail: skwoo@inha.ac.kr
[4] Energy Engrg. & Constr. Div., POSCO E&C Co., Ltd., Seoul 135-769, South Korea, PH (822) 3466-3926; FAX (822) 3466-3989; e-mail: js5yang@poscoenc.com
[5] Strategic Planning Div., POSCO E&C Co., Ltd., Seoul 135-769, South Korea, PH (822) 3457-2114; FAX (822) 3011-2599; e-mail:pi@poscoenc.com
[6] Plant Engrg. & Constr. Div., POSCO E&C Co., Ltd., Seoul 135-769, South Korea, PH (822) 3457-2006; FAX (822) 3466-5069; e-mail: young@poscoenc.com
[7] CM Div., Constr. & Economy Res. Inst. of Korea (CERIK), Seoul 135-701, Korea, PH (822) 3441-0770; FAX (822) 3441-0890; e-mail: bnlee@cerik.re.kr

Abstract

The purpose of this paper is to propose a methodology to automatically generate CPM schedules for preliminary project planning. This paper mainly focuses on a process of generating CPM activities using automatically calculated durations. Historical labor productivity is utilized as a governing parameter to convey the previous experiences into a new project. Several different adjustment mechanisms are applied in order to enhance the reliability and to reduce the workload.

A real-world case of implementing the proposed methodology is introduced in order to evaluate the effectiveness and viability of the method. Managerial issues including strategic significance from a corporate perspective, cost effectiveness for this ad hoc system, and overhead efforts to maintain standardized and structured historical databases are discussed as well.

Introduction

The reliability of preliminary scheduling at the very initial stage of planning phase (before design starts) is primarily affected by the 'project details determined at the time of planning', 'specific characteristics of a construction project', 'experience of the planners', and 'retention of historical databases of the similar projects'. Most of the preliminary schedules are prepared with limited information and details. However, the planning process may require this preliminary schedule to be equipped with a capability of analyzing what-if scenarios, even including estimates for materials and labors.

The significance of "well-organized and formal pre-project planning" effort to improve the overall performance of a project is also strongly stressed and validated by an attempt to measure the relationship between "pre-project-planning-effort and cost-and-schedule-performance of a project" (Hamilton and Gibson 1996). Furthermore, the increasing adoptions of alternative project delivery methods (e.g. Design-Build, CM at Risk, Design-Build-Maintain) often impose a contractual consequence upon this rough preliminary schedule.

However, developing a reliable and detail preliminary schedule (using CPM) requires tremendous experience, knowledge, time, and effort. On the other hand, developing and maintaining an automated scheduling system for the preliminary schedules of a specific type of construction would raise an issue of effectiveness in terms of utilizing corporate resources, making standard processes (in order to collect historical database), and validating the benefits. Organizing the previous experience and knowledge to be included into the system is another challenging problem. It is extremely difficult to structure implicit scheduling knowledge. Nevertheless, no previous research investigated a regimented methodology encompassing all of these issues.

In this context, the purpose of this paper is to propose a methodology to automatically generate CPM schedules for preliminary project planning. This paper mainly focuses on an automated process of generating CPM activities using automatically calculated durations. Historical labor productivity is utilized as a governing parameter to convey the previous experiences into a new project. Several different adjustment mechanisms are applied in order to enhance the reliability and to reduce the workload.

An overall framework of the proposed methodology is developed first in order to discuss and verify the research objectives. The concepts and techniques for automatically generating CPM activities and durations are then introduced. Finally, a real-world case of implementing the proposed methodology is introduced in order to evaluate the effectiveness and viability of the method. Managerial issues including strategic significance from a corporate perspective, cost effectiveness for this ad hoc system, and overhead efforts to maintain standardized and structured historical databases are discussed as well. Findings from the entire research process are briefly summarized, and implications and lessons learned for further developed are outlined.

Research Requirements and Objectives

This study is part of a series of consecutive research projects (Jung et al. 2000; Jung and Woo 2004, Jung 2005, Jung and Kang 2007, Jung 2008) including a development of preliminary estimating and scheduling systems, mainly for still mill construction under design-build contracts. These systems have also utilized the basic concept of integrated cost and schedule control (earned value management systems, EVMS) with different level of details and different applications.

Therefore, a brief introduction of the case-project would help comprehend the overall requirements of this study. The case-company and its mother-company have a license of new steel production process, which provides the case-company with strategic advantages in continuing the same projects worldwide. As an initial effort, the case-company is planning to build the steel mill in a foreign country in near future. They had built the same facilities only three times in Korea, of which capacities are all different. For the purpose of early planning, the case-company has to prepare a preliminary estimate and schedule. At the same time, the case-company wants to develop an information system that is capable of analyzing variations under changed project scopes and also capable of accumulating historical database. This situation gives a strategic significance to the proposed system. Due to the characteristics of 'business function level' and 'project-specific' systems, standardization is also encouraged. These managerial issues were full addressed in a paper by Jung (2008).

The automated CPM schedule generation proposed in this paper is one of the core functions within the entire system. Basic research requirements included 1) generating CPM schedules automatically without plans and drawings, 2) encompassing design, procurement, and construction activities, 3) analyzing what-if scenarios with minimal human inputs, 4) predicting required man-hours and materials, 5) providing CPM templates to the design and construction phases. Incorporating these complex requirements involves the issues of standardization, cost effectiveness, reliability, and technical viability.

In a research that proposed a methodology to automatically generate work breakdown structure (WBS), Jung and Kang (2007) identified four major research objectives to effectively address the issues of structuring and standardizing a knowledge-based progress management system. These four objectives include 'making standards' (for explicit and shared knowledge), 'alleviating workload' (by reducing the number of items to be handled), 'enhancing accuracy' (by properly defining characteristics of variables), and 'sustaining adaptability' (by self-evolving mechanism) (Jung and Kang 2007).

This study adopts these four objectives formulated by Jung and Kang (2007) for the purpose of developing automated CPM schedule because the 'automated WBS generation' and the 'automated schedule activity generation' have many requirements in common. In fact, selected work packages from WBS of a project are used as activities. However, this study is much differentiated from the previous research in many aspects. Automated generation of the durations, handling CPM schedule attributes, and analyzing productivity data are major distinctions of this study.

Table 1. Research Objectives and Methods

Objectives [a]	Methods [b]
Making Standards	Defining higher level standards with embedded details
Alleviating Workload	Separating commodity from location factor Maintaining pre-defined standard attributes
Enhancing Accuracy	Cross referencing and checking within the system Utilizing many independent adjustment factors
Sustaining Adaptability	Self-evolving with historical database

[a] Research objectives identified by Jung and Kang (2007).
[b] Methods to achieve the objectives in this study.

Methodology Overview – Automated CPM Generation

A conceptual representation of the proposed methodology for automated CPM generation is depicted in the Figure 1. The basic modules of proposed systems include three groups of data (H1 & H2: Historical data, S1 & S2: Standard data, P1 & P2: Project data) and two groups of procedures (A1: Analysis, A2: Adjustment). Each group of data is then divided into two separate databases; one is productivity database (a relational database) and the other is schedule database (a CPM database). The reason for this separation within a group of data is mainly due to the proprietary characteristic of commercial CPM software. No commercially available software is capable of handling the required manipulations of productivity data in H1, S1, and P1. An interface program is developed to link this separation as shown in Figure 3.

As a first step, the historical data of previous projects (H1 & H2) are re-organized by using pre-defined standard numbering systems (S0). The historical data are accepted to be included into the database (H) only if the project has been substantially completed and the final report is reviewed and approved by the project manager. The data accumulated in the historical productivity database (H1) are regularly analyzed to update the standard productivity database (S1). The S1 then serves as a template schedule for a new project productivity database (P1). During this process, two major procedures are performed. The first procedure (A1) is to analyze and evaluate H1 in order to have a most up-to-date, practical, and reliable standard template (S1). The second procedure (A2) employs adjusting quantities, duration, and scopes. Most of these procedures are designed to be performed automatically with minimal user intervention that requires critical human decisions.

Productivity databases (H1, S1, and P1 in Figure 1) have attributes including scope of work, required drawings, a standard measurement method, major work items and quantities, productivity data, and logic relationships between preceding and succeeding activities. The basic element (each record of the relational database) of productivity database is an activity of the CPM schedule.

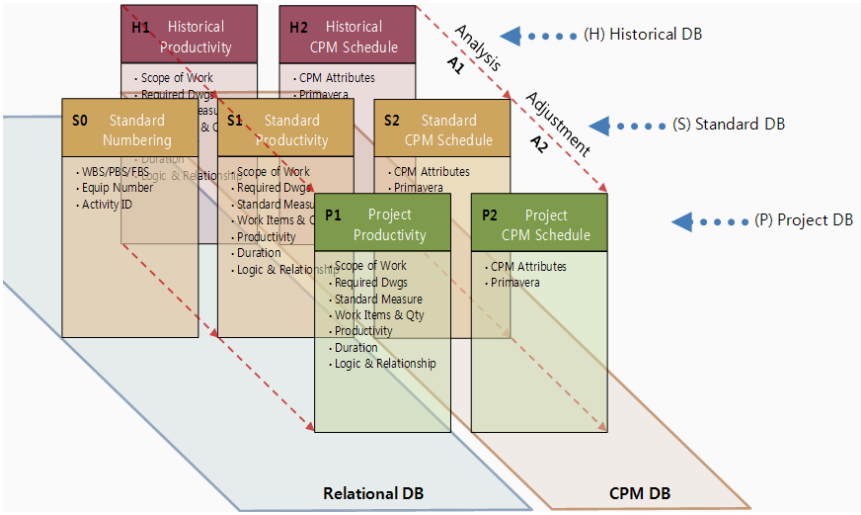


Figure 1. Preliminary Scheduling System (Upgraded from Jung 2008)

Activity Definition in the Productivity Database (H1, S1, P1)

The productivity databases (H1, S1, and P1) maintain all schedule relevant information for each activity in a relational database (RDB) format. For easier understanding, one record from P1 is shown in Figure 2. This printout was actually used for the engineers of the case-project to review the preliminary schedule. The pilot case-project that firstly utilized the proposed system had about 2,000 activities for the preliminary schedule. These 2,000 activities include 610 design activities, 670 procurement activities, and 720 construction activities.

The example in Figure 2 illustrates only one activity among the 2,000 activities. The activity definitions in a spread sheet format (i.e. 2,000 Excel sheets) were automatically generated using the P1 database. Converting to spread sheet format was for the convenience of user readability. As depicted in Figure 2, each activity definition sheet include activity code and description, scope of work, required drawings with their lead time, major work items with quantity, a standard measurement method, required man-days, an estimated duration, and relationships. The issue how this detailed data can be handled for a preliminary schedule will described in the later sections of this paper.

Construction Activity	Activity Description
144F21-M68-00	**Vertical Conveyor**

SCOPE OF WORK	
- PADDING	- EQUIPMENT & STRUCTURE INSTALLATION
- ASSEMBLY (BOLTING,WELDING)	- GROUTING
- ADJUST & ALIGNMENT	- ATTACHED PIPING
- TOUCH UP PAINTING	

REQUIRED DRAWINGS	Lead Time
- Equipment Drawing	90 Days
- Arrangement Drawing	90 Days
- Erection Manual	90 Days
- Equipment Foundation Drawing	90 Days

MAJOR WORK ITEMS	Unit	Qty	Remarks
Steel Structure	Ton	73	

PROGRESS MEASURE	Unit	Qty	Daily Output	Mandays	# of Crews	Remarks
Steel Structure	Ton	73	1.825	18	6	

DURATION		
Days	Adjustment Factor:	Remarks
40	0.304166667	

ACTIVITY RELATIONSHIP				
Activity ID	Description	Relationship Type	Lag Value	Remark
144F08-T01-00	IND.TEST	FS	0	

150.G.4	Coal Briquetting Tower

Figure 2. Activity Definition Sheet (Example)

The sheet in Figure 2 illustrates the activity definition of the 'steel structure erection (M68)' for 'vertical conveyor (144F21)' at the 'coal briquetting tower (150.G.4)'. Its duration took 40 days to install 73 tons of steel members in an actual project. In average, the productivity under standard conditions for this type of facility construction is 6 tons per day. However, the productivity of this specific activity is 1.825 ton per day. This fact yields the adjustment factor 0.304 (= 1.825/6.000). In the real process, the adjustment factor for each construction activity is pre-defined in the standard productivity database (S1). Also as shown in the Figure 2, a finish-to-start activity relationship is defined. It seems that maintaining this standard productivity requires tremendous overhead effort. But there are only 22 work items to be handled, in terms of the work section facet defined by ISO (1994), for entire 720 construction activities.

Analysis and Adjustment to a New Project (A1, A2)

As shown in Figure 2, the primary factor to generate activity duration is labor-productivity. Therefore, this system requires incorporating the resource information (materials and man-hours) within each activity. Again, for the preliminary schedules, maintaining productivity data in every activity is not feasible for practical implementation. This study utilizes the concept of separating commodity group (*work section* defined by ISO) from locator group (*facility, space, or element* defined by ISO). Basic common attributes are defined and managed in the commodity group, while additional specific characteristics are maintained in the combinations of commodity and locator (Jung and Woo 2004, Jung and Kang 2007, Jung 2008).

For the same example in Figure 2, there are 195 steel structure erection (M68) activities in this case-project. One set of commodity group definitions that includes scope of work, required drawing, work items (without quantity), progress measure, standard productivity is created and applied to all 195 steel erection activities. Each activity within this group (M68) then initially inherits the same commodity attributes except activity specific attributes including quantity, adjustment factor, and relationships. These activity specific attributes are automatically transferred from previous project (H1 & S1). By delivering the previous experiences in these two-dimensional channels, a new CPM schedule is created without human intervention. However, because the size of each project is different, the work item quantities in a new schedule (P1) should be adjusted during this process. The hierarchical six-tenth power factor rule is used in order to adjust quantities. Therefore, in the adjustment procedure (A2), the quantity is automatically changed to fit the new project, and the duration is then automatically adjusted according to the changed quantity.

Table 2 illustrates another example of activity definition of P1 in Figure 1 in further details. In Table 2, the standard characteristics of a commodity (i.e. M63 Machine Erection) are defined in several attributes (row number X5, X6, X7, and X8 in gray shading) including standard crew, man-days, and output. In order to generate activity duration, the system calculates pseudo duration (PDur in Table 2) by dividing the quantity of activity (RQty) by standard daily output (StdDailyOutput). The pseudo duration should be adjusted because even the same machine erection (M63) activities may have different productivity for a different quantity or location. In order to handle this problem, the productivity adjustment (ADJ_P) factor is developed. ADJ_P is a distinct attribute for each activity (commodity with a locator). The duration calculated using standard productivity (PDur) is then compared with actual historical duration (HDur) in order to automatically produce the ADJ_P (Jung 2008).

The major tasks required by users include reviewing the system-generated CPM schedule as a whole, posting major imposed dates, and adjusting productivity to accelerate or delay the schedule. The system basically allows users to change productivity on the commodity level as simple changes in commodity group will effectively affect many activities in the same group. However, activity-level adjustments are also allowed (Y1 & Y2 in Table 2). ADJ_E in Table 2 is also one of the mechanisms to accommodate the user's particular experience or discretion.

Table 2. Generating Standard Duration Based on Historical Database (Upgraded and Modified from Jung 2008)

No	Attribute	Code	Description	Unit	Value
X1	WBS	B.3	Reactor Tower	-	-
X2	PBS	211X31	Overhead Crane	-	-
X3	FBS	M63	Machinery Erection	-	-
X4	CrewMD	-	Total Man-Day for an M63 Crew *(Calculated view from row number X5, below)*	MD	6.00
X5	CrewMix	501	Erector	MD	2.80
		503	Welder	MD	0.40
		504	Scaffolding Worker	MD	1.10
		509	Special Laborer	MD	1.50
		590	Engineer or Administrator	MD	0.20
X6	StdNoOfCrews		Standard Number of Crews for an Activity	Crew	2
X7	StdMandays		Standard Number of Man-Days *(StdNoOfCrews*CrewMD, row number X4 * row number X6)*	MD	12
X8	StdDailyOutput		Standard Daily Productivity	Ton	2.00
Y1	NoOfCrews		Modified Number of Crews for a New Project *(Only used for schedule compression purposes)*	Crew	4
Y2	DailyOutput		Modified Daily Output for a New Project *(Applicable only if NoOfCrews was changed)*	Ton	4.00
Z1	RQty		Quantity of Representative Work Item	Ton	68.0
Z2	PDur		Duration Calculated using Productivity (RQty/StdDailyOutput)	Day	17.0
Z3	HDur		Duration of Previously Completed on Historical Data *(Only used in S1 data in order to generate ADJ_P)*	Day	15.0
Z4	Dur		Duration Calculated for a New Project	Day	12.0
Z5	ADJ_P		Productivity Adjustment Factor (PDur/HDur)	Ratio	1.133
Z6	ADJ_E		Empirical Adjustment Factor (HDur/Dur) *(Only used in order to adjust under special considerations)*	Ratio	1.250
Z7	ADJ_T		Total Adjustment (ADJ_P * ADJ_E)	Ratio	1.417

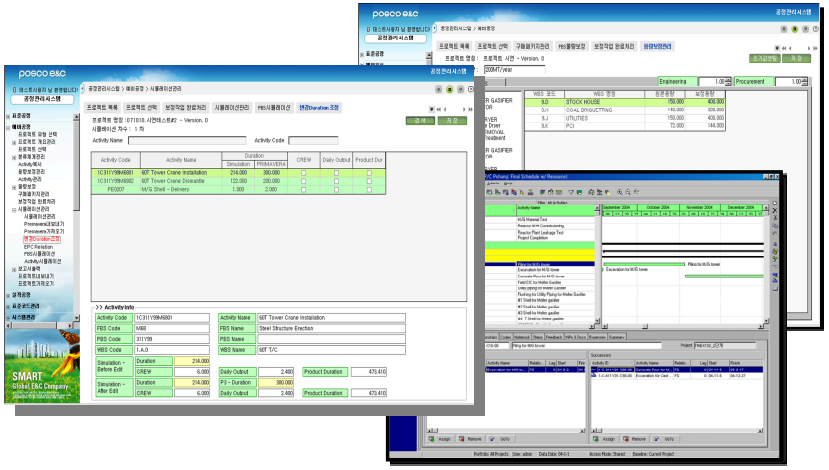


Figure 3. Web-Based Preliminary Scheduling System

Findings and Conclusions

The basic concept of the automated CPM schedule is briefly introduced in this paper, mainly focused on generating durations based on historical labor productivity. The other features such as standard logics between activities and between phases (E-P-C), standard numbering systems, and so on are not introduced herein. A methodology to analyze and to predict durations for a new activity not listed in the historical database was also developed using statistical analysis.

The research objectives set forth in this paper have been adequately fulfilled by implementing the proposed methodology. The case-company decided to implement the methodology, and a company-wide web-based preliminary scheduling system has already been developed and materialized as shown in Figure 3.

It is found that the use of historical labor productivity for the purpose of generating CPM durations for preliminary schedule is very feasible and effective. Even though the proposed methodology maintains tremendous details, the overall process for users is simple enough while it provides reliable results. The system allows the engineers to review and to adjust the preliminary schedules for the best results, not to search and to calculate details. Using more advanced tools (e.g. data-mining or AI) in order to better automate the proposed system can be achieved in the future. However, again, the managerial issue concerning the effectiveness should be reviewed for the practical application.

However, the proposed system is very applicable within the repeating same type of construction. The managerial issues in terms of strategic significance or cost effectiveness of the proposed system are fully addressed in a paper by Jung (2008). Even though the case of preliminary scheduling in this study is in the areas of industrial plant construction, the basic concepts, methods, and variables can be universally applicable to residential, building, and civil construction projects.

Acknowledgements

This study is part of a series of consecutive research efforts funded by POSCO Engineering and Construction Co., Ltd. Special thanks go out to the engineers and managers of POSCO E&C Co., Ltd, POSDATA Co., Ltd, and HKCMC for their support and participation throughout the prolonged painstaking workshops, interviews, and software development process.

References

Hamilton, M. R. and Gibson, G. E. (1996), "Benchmarking Preproject Planning Effort", *Journal of Management in Engineering*, ASCE, 12(2), 25-33.

Jung, Y. (2005). "Integrated Cost and Schedule Control: Variables for Theory and Implementation", *Proceedings of the Construction Research Congress 2005*, ASCE, 183, 34, San Diego, USA, doi:10.1061/40754(183)34.

Jung, Y. (2008). "Automated Front-End Planning for Cost and Schedule: Variables for Theory and Implementation ", *Proceedings of the 2008 Architectural Engineering National Conference*, ASCE, Denver, USA.

Jung, Y. and Kang, S. (2007). "Knowledge-Based Standard Progress Measurement for Integrated Cost and Schedule Performance Control", *Journal of Construction Engineering and Management*, ASCE, 133(1), 10-21.

Jung, Y. and Woo, S. (2004)."Flexible Work Breakdown Structure for Integrated Cost and Schedule Control", *Journal of Construction Engineering and Management,* ASCE, 130(5), 616-625.

Jung, Y., Park, H., Lee, Y., Lee, B.-N., Kim, J.-S., Oh, Y.-S. (2000). "Order of Magnitude Estimating System Based on Historical Labor Productivity", *Journal of the Architectural Institute of Korea*, 16(10), 125-134.

International Organization for Standardization (ISO). (1994). "Classification of information in the construction industry." *Technical Report 14177*, Geneva, Switzerland.

DEVELOPING EFFECTIVE VISUAL REPRESENTATIONS TO MONITOR PROJECT PERFORMANCE

Namhun Lee[1] and Eddy M. Rojas[2]

[1] Ph.D. Candidate, The Built Environment Program, University of Washington, 120 Architecture Hall, Box 351610, Seattle, WA 98195-1610, USA, namhun@u.washington.edu

[2] Associate Professor, Department of Construction Management, University of Washington, 120 Architecture Hall, Box 351610, Seattle, WA 98195-1610, USA, er@u.washington.edu

ABSTRACT

During construction, project managers constantly review actual project performance and resolve any discrepancies between as-planned and as-built progress. However, it is not always easy to perform these activities since numerous individuals and parties are involved in a typical project. This is where visual representations may be helpful. Several charts and diagrams have been traditionally used in construction to visually track performance. This paper analyzes the advantages and disadvantages of traditional visual representations such as bar charts, network diagrams, line of balance charts, and S-curve graphs, and introduces a set of design principles for the development of non-traditional visual representations to effectively monitor project performance. The paper closes with examples of new visualization schemes built according to those principles.

INTRODUCTION

Due to the dynamic nature of a construction project, there is continual pressure to change the initial plan from inception through completion. To complete a project within the planned budget and timeframe, construction managers must track project status and identify a problem as early as possible. The success of a project usually depends on responsiveness and agility in managing inconsistencies between planned and actual progress. The ability to communicate project data among participants is a prerequisite for monitoring and controlling the inconsistencies in timely manner.

In large-scale projects, project failure often results from flawed perception of discrepancies between planned and actual progress caused by complexity and significant amounts of data while operating under tight budgets and timeframes. Therefore, a major factor essential to project success is the availability of an effective and intuitive communication tool. This is why construction managers are seeking new and better means of presenting project data.

The writers believe that visual representations will provide not only a useful means to understand key aspects in project management, but also enable numerous participants to better understand their assignments. However, not all visual representations are effective. In most cases, visual representations fail because of poor designs rather than inadequate

technology. The main purpose of this paper is to suggest design principles that could benefit future researchers in the process of developing effective visual representations to monitor project performance.

ANALYSIS OF TRADITIONAL VISUAL REPRESENTATIONS

It is essential to analyze the visual representations that have been traditionally used to monitor construction projects. Of course, there are several advanced visual aids in construction. State-of-the-art visual aids have been developed with advanced computer technology such as computer animation, virtual reality, and 4D CAD. In these types of visual representations, the current state of a project can be displayed on geometric models (Lee and Peña-Mora 2006) and work in progress and schedule adherence can be also illustrated by color-coding. However, this section focuses on the traditional visual representations popularly used in construction management. Therefore, bar charts, network diagrams, line-of-balance charts, and S-curve graphs are the main targets of this analysis. For each tool, this section describes what information is presented, why the tool became popular, and what shortcomings it may have.

Bar Charts: Bar charts are the most common tool that provides an overview of project progress in the form of a master schedule. Because of their visibility and simplicity, bar charts are widely accepted as a project representation tool in the field. Bar charts illustrate all activities necessary to complete a project as well as the scheduled time, referring the listed activities to a calendar. A simple example of a typical bar chart is shown in Figure 1. In bar charts, activities are listed in the vertical axis while time is shown along the horizontal axis. Each activity is represented by a horizontal bar, which indicates the scheduled time including start date, finish date, and duration. Arrows connecting individual bars depict dependencies between activities. During project monitoring, useful additions are included: a vertical line to indicate current time, inner lines to indicate the progress-to-date of work on each activity, and small marks to display milestones or other important information.

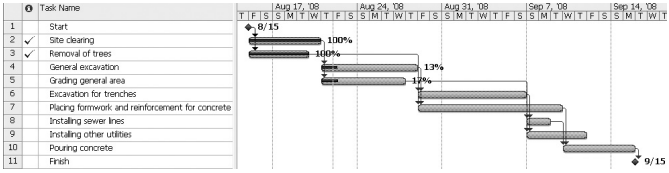


Figure 1: Bar Chart

The major benefit of bar charts is that all participants can easily understand and modify the schedule of activities on a project with little or no knowledge. In addition, bar charts are very useful for quickly identifying if a project is behind or ahead of schedule. However, typically bar charts cannot show a clear and comprehensible overview of a project containing hundreds of activities presented in either separate pages on a computer screen or a big paper on a wall. According to Milosevic (2003), the number of activities presented should be limited to 25 or fewer for the effective use of bar charts. Regarding the major shortcoming, bar charts do not clearly show the logical relationships of activities as well as the interrelated impacts among time, cost, and performance; consequently, bar charts cannot reflect true project status. For example, in a bar chart, the actual percentage complete of an activity is the same as the planned percentage complete, which means the construction progress of the activity is going as planned. But, what if the activity spent fifteen percents more than the

planned budget to keep the schedule balance? The cost overrun cannot be shown in bar charts because they are time-based.

Network Diagrams: Network diagrams clearly show dependencies of activities that are not obvious with bar charts. Even though there are a variety of network diagramming techniques, the construction industry has traditionally used only two methods: 'activity-on-node' and 'activity-on-arrow' (Callahan et al. 1992). Figure 2 shows an example of an 'activity-on-node' network diagram for the activities shown in Figure 1.

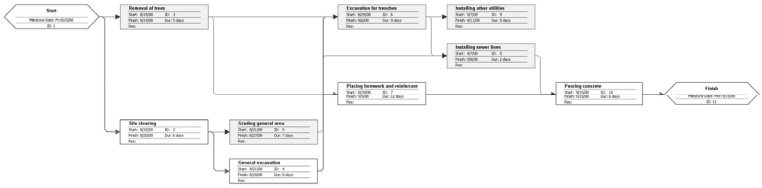


Figure 2: Network Diagram

Each activity is drawn as a rectangle and the critical path is represented. Network diagrams requires two inputs, the scheduled time and the logical sequences of activities, to analyze early start, late start, and float of each activity, identify the critical path, and determine the overall project duration.

Network diagrams explicitly show logical sequences of dependent activities in a simple and direct way, which makes job coordination easier among project participants. In addition, due to the ability to immediately show the effect of schedule changes, network diagrams facilitate what-if exercises and are used as a basis for decision-making (Fleming 1988). However, in large and complex projects containing hundreds of activities, it is overwhelming and time-consuming to find alternatives on the schedule, especially when various logical relationships between activities are used. Moreover, maintaining network diagrams is complex and confusing to inexperienced users due to the multitude of activities connected by arrows. Another shortcoming of most network diagrams, except time-scaled diagrams, is the lack of a timescale which makes it difficult to check the current status of a project.

Line of Balance Charts: Line of balance charts are very useful for tracking progress of repetitive activities. They can be used to evaluate rates of progress among activities repetitively performed by the same crew in a planned sequence. Line of balance charts show the number of units that will be completed within any period of the activity's duration.

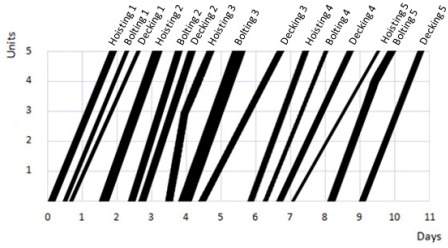


Figure 3: Line of Balance Chart

Figure 3 gives an example of a line of balance chart. The horizontal axis plots time, while the vertical axis plots the number of units. Each diagonal line represents an activity and the thickness of each line indicates the proportion of the duration of the activity to a single unit. The slope of each line shows the planned rate of progress at a unit for the duration of the activity. Figure 3 shows that, sometimes, there are bent lines for activities, which indicate time buffers. The main objective for the manager when using line of balance charts is to keep actual progress line of activities as parallel to its planned diagonal line as possible.

Line of balance charts are suitable only for the repetitive portion of projects. Hence, they can be ineffective when the repetition of activities is interrupted. In spite of this significant shortcoming, there are several benefits of line of balance charts as compared to bar charts and network diagrams. Line of balance charts can easily identify possible interference between activities, which results from changes in activity intensity (Hajdu 1997). In addition, they can be used to identify the best progress rates of activities (Lock 2007).

S-Curve Graphs: S-curve graphs have been used to visually track actual project performance, comparing it to the plan over a period of time. A good example of these S-curve graphs is the earned value chart. Earned value charts (Figure 4) are very useful for evaluating if a project is behind schedule or over budget and to what extent. Earned value charts also show the projected curve line indicating whether or not the project is likely to be completed within the time and budget limitations.

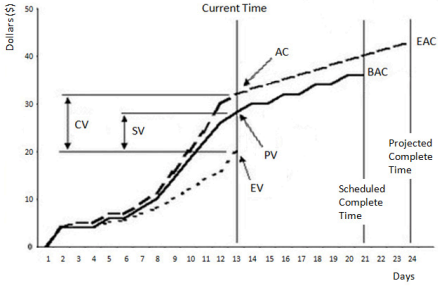


Figure 4: Earned Value Chart

Earned value charts typically illustrate three S-curves which represent planned value (PV), earned value (EV), and actual cost (AC). The curves show the time duration on the horizontal axis and the cumulative expenditures of the project on the vertical axis. Earned value charts provide meaningful information on both the current and forecasted state of the project , which includes schedule and cost variances, schedule and cost performance indices, estimate to complete, and estimate at completion.

S-curve graphs have been widely used in the management of construction projects due to the simplest form. However, it may be difficult for the novice to understand their underlying meanings. Moreover, S-curve graphs themselves should not be used as a project-monitoring tool because significant information may be disguised by manipulating the unit of either the vertical or horizontal axis (Tufte 2001). Finally, earned value charts do not necessarily provide a realistic representation of schedule performance as they rely on cost data to estimate schedule variance without regard to the criticality of activities. Therefore, a schedule variance that shows the project ahead of schedule may be due to most of the non-critical activities being completed ahead of time while some critical activities may actually be delayed.

In summary, bar charts and network diagrams are the most common means of communicating planned information among project participants and monitoring actual project progress. They can be considered as project roadmaps. However, they can easily become complex and confusing when displaying numerous activities. In addition, neither one shows rates of progress for individual activities. This is why line of balance charts have been used in construction. However, the application of line of balance charts is limited to only the repetitive portion of a project or certain repetitive projects such as highway, pipeline, and house building construction. Finally, S-curve graphs can be easily prepared and used, but their underlying meanings may be difficult to interpret without significant experience.

RECOMMENDED DESIGN PRINCIPLES

Developers of visual representations should focus on the user because effective representations communicate with the user clearly and immediately. Thus, it is essential to define who the intended user will be. Specifically defining the intended user also helps the developer identifying the information to be visualized. In practice, the information necessary to different levels in a hierarchical communication structure is different, especially in the degree of detail.

Before designing a visual representation, a developer should identify what the intended user will do to achieve an overall goal. By doing this, the developer can determine what data are appropriate and important to generate the information displayed in a visual representation. Further, a developer should create an ontology of all the data considered appropriate and important. This is useful in clarifying the scope of the visual representation as well as grouping all related data into cohesive pieces of information.

A visual representation with a good design not only assists in the perception of information, but also allows users to assimilate that information quicker. This section introduces design principles to generate effective visual representation.

Principle 1: Display High-Level Information

High-level information should be displayed so that users can clearly and immediately understand visual information. If significant amounts of data are displayed in great detail, users can become disoriented or confused. Thus, unnecessary pieces of information should not be displayed. The developer should study what information is required to accomplish specific tasks and display only that information. This makes it possible for the user to monitor a great deal of issues at a glance, but at a high-level of abstraction. A visual representation does not have to provide all the detail associated with a particular issue. Rather, the visual representation should be seamless as much as possible so that users can easily obtain the required information (Few 2006).

Principle 2: Choose a Visualization Technique Appropriate to the Data

There are various techniques for presenting data. Choosing appropriate techniques is one of the most challenging tasks for a developer. This decision should be based on the nature of the information. A developer must decide if the information should be encoded as text, graphs, or both. Sometimes, simple text or a simple table may work better than using a graph. For this reason, it is significant for the developer to decide which techniques will be used to support a rich and meaningful display of data. Thus, the developer should understand the characteristics of different visualization techniques such as standard 2D/3D displays, geometrically transformed displays, iconic displays, dense pixel displays, and stacked displays (Keim 2002).

Principle 3: Properly Lay out Information

When visual representations must present information in a limited space without sacrificing meanings, information should be divided into meaningful groups and appropriately organized in an effective manner. Otherwise, visual representations will look convoluted. For example, information may be arranged in either 'side-by-side' or 'over-under' arrangements according to its use sequence. Empty spaces can be sometimes useful to reduce clutter (Tufte 1990). In addition, information that requires immediate attention should be displayed in the most visually prominent areas for users to easily make sense of it.

Principle 4: Use Proper Visual Attributes

It is essential for a developer to understand how human beings perceive visual attributes such as colors, sizes, shapes, and motion and to choose them carefully. Some colors demand our attention while others are less visible. For example, red can be used to indicate an important message. An interesting fact on color is that, when any color appears as a sharp contrast to the color pattern, human eyes pay attention and the human brain tries to assign a meaning to the contrast (Ware 2004). When it comes to sizes, different sizes of visual elements can rank their relative importance. In addition, motion such as a simple flicker can be used as an alternative to static highlighting strategies (Ware and Bobrow 2004).

Principle 5: Design a Simple but Attractive Interface

Developers sometimes consider using various visualization techniques to prevent users from getting bored by the same type of visual representation. However, it is important to provide valuable information for users to achieve their goals and as long as users can easily get what they need through a visual representation, no one should complain about monotony of display. In fact, simplicity and consistency are the most important issues in terms of usability because users apply the same perceptual strategy for understanding the information, which results in reductions in user's working memory load (Barnum 2002). Simplicity, on the other hand, does not mean that a developer does not have to be concerned about attractiveness. The more attractive a visual representation is, the better a user tend to understand it. Therefore, a developer should focus on attractively visualizing information, while also focusing on keeping it as simple as possible.

Principle 6: Appropriately Highlight Important Information

When users see a visual representation, their attention should be first directed to the most important information no matter where it is displayed. Otherwise, every piece of visual information would just be there like a picture with nothing standing out. In such a case, no matter how well a representation is presented and organized, it may not be as effective as it can. A developer should apply an appropriate highlighting strategy for the most important information to become conspicuous from the rest. The most common highlighting styles include color-based highlighting and transparency (Nguyen and Huang 2004). Although every piece of information deserves to be emphasized in a visual representation, a developer should decide which one is the most important. All visual information should not be equally highlighted.

APPLYING THE PRINCIPLES: A FEW EXAMPLES

In order to apply the design principles outlined above, we decided to focus on senior project managers as intended users. In most cases, senior project managers are interested in summary level information regarding time, cost, quality, and safety. They need this information in a timely manner to monitor the status of a project, communicate with stakeholders, and take corrective actions as required in order to satisfy contract requirements.

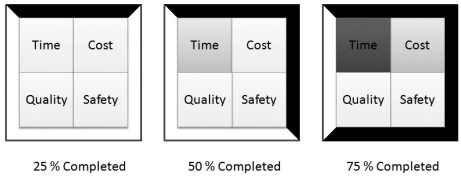


Figure 5: Activity Icon

Our first example, Figure 5, illustrates a new visualization scheme of the current status of ongoing activities that we have termed 'Activity Icon.' We decided to concurrently showcase four main summary parameters (time, cost, quality, and safety) and the percentage of completion as high-level information (Principle 1). The four key control parameters of time, cost, quality, and safety are represented by the inside squares shown in Figure 5. The names of the squares are shown in the figure for illustrative purposes, but they are not displayed in the scheme unless the user mouse-over each square to obtain more information. Each square has its own color representing the performance of each category. The external borderline indicates the percentage of completion. Thus, each side of the square represents 25% completeness (percentage of completion advances in 5% increments). Over time, both the color of each inner square and the length of the borderline may change to reflect activity status. This visualization scheme can also be applied to represent the current status of the entire project since the status of a project can be determined by aggregating the status of all activities.

An icon-type display was selected as the most appropriate form for indicating the current status of each one of the four parameters and a variation of a bar graph was selected to represent the percentage of completion (Principle 2). Since most people process information from left to right and top to bottom, we decided to show the most important information in the upper-left area and the least important in the bottom-right area (Principle 3). Our focus group of senior project managers ranked the four control parameters in the following order according to their importance in controlling a project: time, cost, quality, and safety. Of course, the visualization scheme can be customized to support any preference.

Although the degree of importance of the four key elements might be different, we have decided to incorporate this characteristic in the order in which they are displayed rather than in the visual attributes. Thus, the visual attributes of all parameters are the same (Principle 4). However, the color of each element can be different based on performance. Indeed, the colors of the four elements are determined based on the values described in Table 1. Users can see the values of the parameters directly on the visualization scheme with mouse-over action. This scheme can be customized and calibrated according to user preferences. In other words, the number of colors, its sequence, and the ranges of the values of the parameters can be adjusted.

Finally, since large-scale projects may have dozens of ongoing activities, simplicity was one of our most important criteria (Principle 5). We decided to use a simple square shape for our visualization scheme since this shape allows the generation of a matrix showing several activities at a glance. In fact, a user could easily see information on 120 activities at a time with a 12 by 10 matrix. In addition, any serious issues with an activity can be identified almost immediately (Principle 6). Furthermore, activities can be organized based on user preferences. For example, those activities with the smallest percentages of completion could be shown first (upper-left corner of the screen) to call attention to those activities for which the project manager has the greatest influence. Activities almost completed would be shown last (lower-right corner). Alternatively, users may want to see critical activities first.

Table 1: Color Scheme for Activity Icon

Color	Parameter			
	Time	**Cost**	**Quality**	**Safety**
Red	SPI < 0.9	CPI < 0.9	NOR ≥ 1	NOIA ≥ 1
Yellow	0.9 ≤ SPI < 1.0	0.9 ≤ CPI < 1.0	NUI ≥ 1	NSV ≥ 1
Green	SPI ≥ 1.0	CPI ≥ 1.0	NUI = 0	NSV = 0

Where:

SPI: Schedule Performance Index
CPI: Cost Performance Index
NOR: Number of Reworks
NUI: Number of Unchecked Items on Checklist
NOIA: Number of Incidents or Accidents
NSV: Number of Safety Violations

Another example of the application of the design principles outlined above is shown in Figure 6, which illustrates a new visualization scheme of project performance that we have termed "Map of Activities."

When designing this visual representation, all activity information is displayed at a high-level of abstraction (Principle 1). However, based on our analysis of traditional visual representations, users can easily become confused when presented with numerous data. Thus, activities are categorized into meaningful groups (Principle 3). A work breakdown structure based on the CSI divisions has been used for this purpose. We decided to show the first CSI division in the upper-left area while the last one is displayed in the lower-right area. This was done not to imply that the first division is more important than the second division and so on. Rather, the objective was to find a proper way of organizing categories taking into consideration that CSI division numbers tend to follow the sequence of construction (Principle 3).

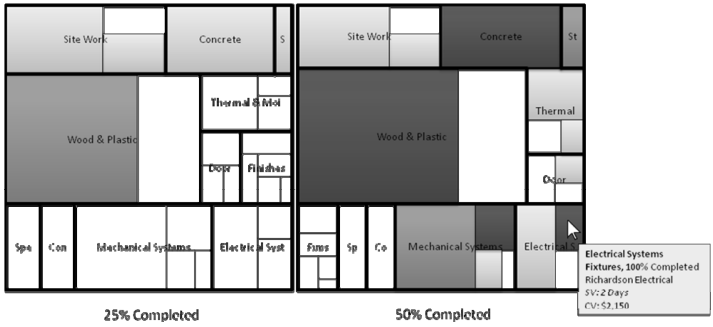


Figure 6: Map of Activities

We decided to use stacked displays because we considered them to be the most appropriate visualization technique given the hierarchical nature of activities in the work breakdown structure (Principle 2). A Treemap (Shneiderman 1992) with space-constrained visualization of hierarchies is used. This kind of visualization technique is simple while effective for displaying numerous activities within a limited space (Principle 5). Users can

apply the same perceptual strategy for understanding all visual information shown in this visualization scheme.

The size of each sub-rectangle representing an activity has been defined as the proportion of its cost to the total project cost. Therefore, size indicates the cost criticality of each activity (Principle 4) and changes over time as the percentage of the actual cost distribution changes. The color of each sub-rectangle indicates schedule and cost performance (Principle 4) and it changes over time based on the color scheme described in Table 2. For example, green means than neither schedule delay nor cost overrun is present, orange means that only schedule delay is present, while red means that both schedule delay and cost overrun are present.

Table 2: Color Schemes for Map of Activities

Color	Parameter	
	Schedule Delay	**Cost Overrun**
Black	Completed	Completed
Red	Yes	Yes
Orange	Yes	No
Yellow	No	Yes
Green	No	No
White	Not Started	Not Started

For this visual representation, only a few colors have been selected to avoid distracting users. Red, which appears as a contrast relative to the norm, has been selected to highlight those activities that need user's special attention (Principle 6). In addition, when users move their mouse over each sub-rectangle, a small window containing relevant information on the activity pops-up to draw immediate attention (Principle 6) as shown in Figure 6.

Finally, the effectiveness of the sample visualization schemes described in this section will be determined by performing testing with users using a simulated construction environment known as the Virtual Coach (Rojas and Mukherjee 2006). In the Virtual Coach, user monitor the current status of a simulated project, identify any discrepancies between as-planned and as-built progress, and take corrective actions to bring the project as close as possible to baseline parameters.

CONCLUSIONS

Construction managers are continually seeking better monitoring techniques to cope with the complexities of large-scale projects. Even though traditional visual representations (CPM, PERT, Linear Scheduling, etc.) can be used to track inconsistencies between as-planned and as-built progress, it can be argued that these techniques were primarily developed for planning rather than monitoring purposes. Therefore, they exhibit several shortcomings when used for project monitoring, especially in large and complex projects. This paper presents a set of recommended design principles that developers could use as a basis for the development of alternative visualization schemes. The design principles recommended in this paper are based on the state-of-the-art of interface design, usability, and visual representation as interpreted and applied in the development of our own alternative representations of project information. It is our hope that our experience can benefit others inclined to develop alternatives to current project management tools. However, these principles cannot replace creativity. Therefore, developers should find their own ways to make their designs effective.

REFERENCES

Barnum, C. M. (2002). *Usability Testing and Research*. NY: Longman.

Shneiderman, B. (1992). "Tree Visualization with Tree-Maps: 2-D Space-Filling Approach." *ACM Transactions on Graphics*, 11 (1), 92-99.

Callahan, M. T., Quackenbush, D. G., and Rowings, J. E. (1992). *Construction Project Scheduling*. NJ: McGraw-Hill.

Few, S. (2006). *Information Dashboard Design: The Effective Visual Communication of Data*. CA: O'Reilly.

Fleming, Q. W. (1988). *Cost/Schedule Control Systems Criteria: The Management Guide to C/SCSC*. IL: Probus Publishing Co.

Hajdu, M. (1997). Network Scheduling Techniques for Construction Project Management. Kluwer Academic Publishers, Netherlands.

Keim, D. A. (2002). "Information Visualization and Visual Data Mining." *IEEE Transactions on Visualization and Computer Graphics*, 7 (1), 100-107.

Lee, S., Peña-Mora, F. (2006). "Visualization of Construction Progress Monitoring." *Proceedings of Joint International Conference on Computing and Decision Making in Civil and Building Engineering*, Montreal, Canada, June 14-16.

Lock, D. (2007). *Project Management*. Ninth Edition, VT: Gower Publishing.

Milosevic, D. Z. (2003). *Project Management Toolbox: Tools and Techniques for The Practicing Project Manager*. NJ: John Wiley & Sons.

Nguyen, Q. V. and Huang, M. L. (2004). "A Focus+Context Visualization Technique Using Semi-Transparency." *Proceedings of the 4th International Conference on Computer and Information Technology*, Wuhan, China, September 14-16.

Rojas, E. and Mukherjee, A. (2006), "A Multi-Agent Framework for General Purpose Situational Simulations in the Construction Management Domain," *Journal of Computing in Civil Engineering*, ASCE, 20(6), 1-12.

Tufte, E. R. (1990). *Envisioning Information.* CT: Graphics Press.

Tufte, E. R. (2001). *The Visual Display of Quantitative Information.* Second Edition, CT: Graphics Press.

Ware, C. (2004). *Information visualization: Perception for design*. Second Edition, CA: Morgan Kaufman.

Ware, C. and Bobrow, R. (2004). "Motion to Support Rapid Interactive Queries on Node-Link Diagrams." *ACM Transactions on Applied Perception,* 1(1), 1-15.

LIFE-CYCLE ASSESSMENT OF TITANIUM DIOXIDE COATINGS

Marwa Hassan, PhD[1]

[1] LOUISIANA STATE UNIVERSITY, CMIE DEPARTMENT, ASSISTANT PROFESSOR, 3128 PFT HALL, BATON ROUGE LA 70803, TEL: (225) 578-9189, FAX: (225) 578-9189, EMAIL: MARWA@LSU.EDU

ABSTRACT

The use of Titanium Dioxide (TiO_2) ultrafine particulates as coating for concrete pavement have received considerable attention in recent years as these coatings can trap and absorb organic and inorganic air pollutants by a photocatalytic process. Despite these promising benefits, the promotion of TiO_2 coatings based on a single factor such as air quality does not provide a complete evaluation of this technology and may omit critical environmental factors that should be considered in sustainable material selection decision-making process. The objective of the research reported in this paper was to determine the life-cycle assessment of TiO_2 coating technology. To achieve this objective, a life-cycle inventory (LCI) that quantifies the energy, abiotic raw material inputs, and emission of TiO_2 coatings from cradle to grave was developed. Based on this inventory, life-cycle impact assessment of TiO_2 coatings for concrete pavement was determined using the BEES impact assessment model. Results showed that the use of titanium dioxide coating reduces the environmental impact of four main categories: acidification, eutrophication, criteria air pollutants, and smog formation. However, during production phases and due to the consumption of fossil energy, titanium dioxide will cause an increase in global warming, fossil fuel depletion, water intake, ozone depletion, and impacts on human health. Based on the overall environmental performance of this product, life cycle assessment shows that titanium dioxide coating has an overall negative score of -0.70 indicating that the addition of this surface layer will have an overall positive effect on the environment.

Keywords: Titanium dioxide, sustainable concrete pavement construction, life-cycle assessment, life-cycle inventory.

INTRODUCTION

Major forces like climate change and rapid depletion of resources have resulted in initiating a strong movement toward sustainability as consumption of raw materials has dramatically increased and air quality in the vicinity of large cities has been linked with serious health hazards to the public. As a result, air pollution has been gradually decreasing in recent years to reach its lowest level in 2003. Even though the economy has expanded by over 150% since the 1970s, the aggregate total emissions for the six major air pollutants (Carbon Monoxide [CO], Nitrogen Oxides [NO_x], Sulfur Dioxide [SO_2], Particulate Matter [PM], Volatile Organic Compounds [VOCs], and Lead [P_b]) have been cut from 301.5 million tons per year to 147.8 million tons per year (Bergman 2003). To further improve air quality, the federal government issued an executive order in 2007 to the Environmental Protection Agency (EPA) to cut greenhouse gas emissions from motor vehicles by taking action under the Clean Air Act.

In spite of the aforementioned accomplishments, air quality is still a major problem in many states including Georgia, Louisiana and California as the Air Quality Indicator (AQI) level of particle matter (PM 2.5) and ground level ozone frequently goes up to 200 indicating unhealthy conditions for the public (Air now 2008). These high ground level ozone ratings are caused by nitrogen oxides and volatile organic compounds in the air which in turn are caused by high traffic volumes and combustors. Many organic compounds and air pollutants including nitrogen oxides and sulfur dioxide can be decomposed by Ultraviolet (UV) radiation but this process is extremely slow. Photocatalysis compounds such as titanium dioxide can accelerate oxidation and decomposition of organic and inorganic compounds extensively (Fujishima et. al. 2000). Photocatalysis compounds can be utilized to construct air purifying concrete pavements by integrating titanium dioxide particles within the pavement surface. These particles can trap and absorb organic and inorganic particles in the air removing harmful NO_x gases in the presence of UV light (sunlight). Implementation of this technology by coating 7000m^2 of road resulted in a 60% drop in nitrogen oxides concentration in the air in Milan in 2002 (Zhu et. al. 2004). In addition, their super hydrophilic properties allow them to self clean in the presence of rain.

Despite these promising benefits, the promotion of TiO_2 coatings based on a single factor such as air quality does not provide a complete evaluation of this technology and may omit critical environmental factors that should be considered in the selection of sustainable materials. This single-factor selection approach has long been used in the transportation industry to select products based on minimum initial cost or minimum life-cycle economic analysis. However, with the current trend towards sustainable construction, the deficiencies of conventional economic approaches became apparent and a life-cycle approach, known as life-cycle assessment (LCA), has been introduced to quantify the impacts of a product across its entire service life on the environment including climate change, fossil fuel depletion, human health, and acidification potential.

The objective of this study is to determine the life-cycle assessment of titanium dioxide coating that may be used in concrete pavement. To accomplish this objective, this study compiled a life cycle inventory (LCI) that quantifies the energy

and emission of these coatings. Based on this inventory, life-cycle impact assessment of TiO_2 coating was conducted based on the Building for Environmental and Economic Sustainability (BEES) model, which was developed for life-cycle assessment of sustainable construction alternatives in the US. Life-cycle assessment was based on a hybrid life cycle methodology that followed both the International Organization for Standardization (ISO) 14040 standard for life cycle assessment and Input Output Analysis (IOA).

BACKGROUND

Life-Cycle Assessment

Life-cycle assessment (LCA), also known as cradle-to-grave analysis, is a methodological framework for quantifying the impacts and damages of a product or a service across its entire service life on the environment including climate change, fossil fuel depletion, human health, and acidification potential (Rebitzer et. al. 2004). Despite LCA is still an evolving methodology, it has found wide-spread applications in many areas such as auto-manufacturing, cleaning products, communication tools, and sustainable construction. As defined by the international organization for standardization (ISO) 14000 series, life-cycle assessment consists of four major steps (SETAC 2330*; ISO 1997*): Goal and scope definition, Life cycle inventory (LCI), Life-cycle impact assessment (LCIA), and Life cycle interpretation.

Despite its simplicity, the scope of LCA as defined by the ISO standard is limited due to the difficulty in obtaining reliable data in consumption and environmental releases associated with manufacturing processes and that cut-offs are needed in many cases (Hendrickson 1998). To address these shortcomings, economic input-output analysis (IOA) has been extended to assess the environmental impacts of manufacturing processes. This approach, which is based on the early work of Leontief (Leontief 1970), uses a matrix representation of the nation's economy to predict the effect of changes in one industry on others. Input-output analysis considers the relationship between the different economic sectors to determine how the output of one industry goes to another industry where it serves as an input. The economic outputs of the various industrial sectors were compiled in Input-Output (IO) tables that represent a fairly accurate representation of inter-industry flows (US Dept. commerce 1997).

While research had focused on determining the accuracy of IOA vs. conventional LCA, it appears that each approach provides a level of strength and weakness. While LCA utilizes specific data, it may provide an incomplete picture of a given technology due to cut-off practices that assume that components and processes with minimal mass representation may be omitted. In contrast, while IOA provides a complete representation of a given technology; the adopted data are less specific and aggregated. This has led to the development of hybrid analysis, which combines the strengths of both conventional LCA and IOA (Heijungs et. al. 2002). Therefore, this approach was adopted in this research. Compilation of the required raw data was conducted manually.

The impact assessment was conducted based on the BEES 4.0 model. Equivalency factors are provided by the BEES model based on research conducted by the U.S. Environmental Protection Agency. A similar approach is adopted for each environmental factor considered in the assessment process (Bare et. al. 2002). In

all, the BEES model considers 12 weighted factors in its assessment of the net environmental benefits of a construction alternative. Out of these 12 factors, two impacts were not considered in the assessment of photocatalytic titanium dioxide coating: Indoor Air Quality and Habitat Alteration. The reason for omitting the assessment of indoor air quality is evident as it is not applicable to outdoor construction activities. Habitat Alteration measures the potential for land use by humans to impact endangered species. It is mainly applied to assess the contribution of a product to landfills throughout its service life. Since the titanium dioxide layer will be applied to existing pavements, it was assumed that it may not increase the damage to endangered species. The environmental impact was weighted as follows (modified after BEES to reflect that the Indoor Air Quality and Habitat Alteration categories were not considered): global warming (29%), acidification (5%), eutrophication (6%), fossil fuel depletion (11%), water intake (8%), air pollutants (11%), human health cancerous and non cancerous (8% and 5%), smog formation (4%), ozone depletion (3%), and ecological toxicity (10%). These modified weights reflect the importance of fossil fuel depletion, ozone depletion, ecological toxicity, air pollution, eutrophication potential, and acidification potential. Applying these weights provides a single performance score for the environmental impacts of a given product. A lower score indicates a technology that is more sustainable and environmentally-friendly and a negative score indicates that the product has a positive impact on the environment.

Titanium Dioxide

Titanium dioxide is produced by the wet sulphate process or the dry chloride process from ilmenite or rutile (Reck et. al. 1999). The chloride process mixes natural or synthetic rutile with coke and chlorine to produce titanium tetrachloride and impurities are removed as chlorides. The resulting pure titanium tetrachloride is burnt in an oxygen flame to form titanium dioxide (TiO_2) and chlorine. These processes produce large size particulate materials (220-300nm). To produce nano-sized titanium dioxide particles, the intermediate product of the chloride process titanium tetrachloride vapor is oxidized in a flame aerosol reactor with organic precursors and organic compounds. Hydrochloric acid is sometimes circulated for regeneration of chlorine. In these processes, the particle growth is stopped by quenching the flame inside a critical flow nozzle of 1.5mm diameter which results in particle size with 5nm diameter (Stark et. al. 2002).

Titanium dioxide particles crystallize in two forms, anatase and rutile. Anatase is a meta-stable phase that transforms into rutile at high temperatures (Znaidi et. al. 2001). Research has shown that titanium dioxide in the anatase phase is a more powerful photocatalyst than rutile in environmental purification (Bilmes et. al. 2000). Anatase titanium dioxide under UV-light can be used to remove harmful organic toxics and pollutants from the air and aqueous environments including nitrogen oxides (NO_x), ammonia, volatile organic compounds (VOC) including toluene, sulfur oxides (SO_x), and chlorophenol (Benedix et. al. 2000, Dalton et. al. 2002, Pozzo et. al. 1997, Watts et. al. 2008). Therefore, recent studies have attempted to utilize it as concrete pavement coating to purify the air (Beeldens 2006). To accomplish this, ultrafine/nano titanium anatase particles are mixed with cement, water, and aggregates to produce a thin surface layer that is applied to concrete pavements and

used for air purification. In the presence of light, the pollutants are oxidized and precipitated on the pavement surface. These pollutants are then removed from the surface by rain using a self-cleaning process.

Evaluation of concrete pavements treated with titanium dioxide provided promising results as recent research shows that a thin surface coating is able to remove a significant portion of NO_x and SO_x pollutants from the atmosphere when placed as close as possible to the source of pollution (Beeldens 2006). The efficiency of this technology depends on the size of the surface exposed, the concentration of pollutants, the light intensity, and the ambient temperature. Porosity of the surface is also important as the NO_x removal ability is improved as the porosity is increased. Photocatalytic activity decreased by approximately 8% with aging of the surface but stabilized at the age of 90 days (Poon 2007).

PROBLEM FORMULATION

A life-cycle inventory (LCI) was developed for a titanium dioxide coating to provide a compilation of the energy requirements, material inputs, and the emissions associated with its extraction, production, installation, use and end of life options. Prior to development of the LCI, the system boundary, which defines the limits of the life-cycle inventory, was set. Figure 1 presents the system boundary for the developed life-cycle inventory.

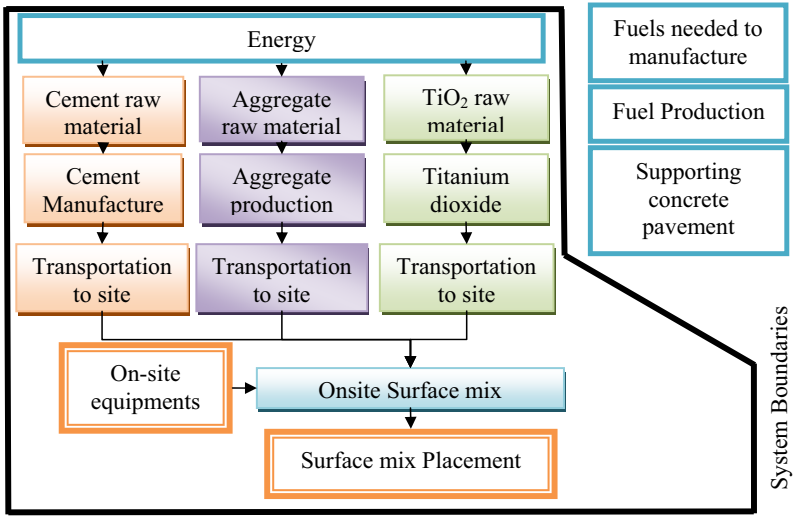


FIGURE 1. Titanium dioxide coating system boundary

As shown in Figure 1, the developed LCI considers energy and emissions associated with the manufacturing of titanium dioxide, production of aggregate, plant operations, cement and surface mix production, and titanium dioxide coating placement (including transportation to the site and site worker transport). However, the developed LCI does not consider energy, materials, and emissions associated with the production or construction of the supporting concrete pavement. In addition, it

does not consider energy associated with the production of fuels known as precombustion, or energy associated with manufacturing of equipment needed to produce titanium dioxide. Emissions associated with background processes including production of fuels and equipment were quantified using Input-Output life cycle assessment.

For the purpose of this study, the surface mix thickness was assumed to be 5mm and the nominal maximum aggregate size used in the mix was 2.36mm. In addition, it is assumed that the surface mix consists of ultrafine titanium dioxide anatase, cement, filler (sand with a maximum nominal size of 2.36mm), and water in the ratio of 0.1:1:3:0.4 and is applied on the pavement surface. These mixture properties were based on lab tests conducted to quantify the air pollutants removal rate (Poon 2007).

DATA SOURCES

A wide range of published reports and databases were reviewed to identify energy and emission data for each process and activity defined as part of the system boundary (Marceau et. al. 2007, Osterwalder et. al. 2006, US Census Bureau 2004, USEPA 2004). Whenever data was limited or not available, the economic input output life cycle assessment (EIO-LCA) model developed at Carnegie Melon was used (Carnegie Mellon 2008). This model calculates the economic and environmental impact from production across the entire supply chain in any of the 491 commodity sectors in the US economy. The net environmental impact of the titanium dioxide coating was calculated as follows:

$$\text{Net Environment Impact} = \text{Environmental Impact of the Surface Mix} - \text{Environmental Purification Effect of the Mix} \quad (2)$$

While a number of environmental damages are associated with the production of the titanium dioxide surface coating and its components, the use of this technology is expected to contribute positively to the purification of the atmosphere during service. Therefore, a negative net environment impact as predicted from Equation (2) would indicate that the use of this technology is beneficial to the environment. In contrast, a positive net environmental impact as predicted from Equation (2) would indicate that this technology has an overall detrimental effect on the environment. The functional unit considered was the mix needed to cover one lane-kilometer of pavement surface (3.2m x 1000m). It is worth noting that energy consumption was divided in terms of the type of fossil fuel used (i.e., natural gas, fuel, and coal) since the rate of fuel depletion differs from one type to the other.

COST DATA

In a competitive industry like the construction industry, it is very important to quantify the economic performance of the proposed titanium dioxide coating. Therefore, ultrafine/nano titanium dioxide producers were contacted. Contacts with the producers showed that the average market price of this technology was $15/kg. Based on the selected surface mix design, this translates into an added cost of $4.3 per m^2 of surface mix or an added cost of $17.1 per m^3 of installed concrete pavement assuming a concrete layer thickness of 254mm. Assuming a concrete cost of $420 per m^3, the use of titanium dioxide coating will result in an added cost of approximately 4% per m^3 of installed concrete. As the interest in this technology

increases especially in the neighborhood of large metropolitan areas, it is expected that the unit cost of titanium dioxide coating will significantly decrease as this technology has the potential of achieving economy of scale.

RESULTS

Figure 2 presents the normalized environmental burdens and relieves associated with titanium dioxide coating in a logarithmic scale. Environmental burdens relate to the manufacturing processes taking place during production, construction, and installation of this product. Environmental releases relate to the ability of this product to purify the atmosphere during service. As shown in this figure, the use of titanium dioxide will have a positive effect on acidification, eutrophication, critical air pollutants, and smog formation. During production phases and due to the consumption of fossil energy, titanium dioxide will cause an increase in global warming, fossil fuel depletion, water intake, ozone depletion, and human health. However, based on the overall environmental performance of this product as predicted from Equation (2), life cycle assessment shows that titanium dioxide coating has an overall negative score of -0.70 indicating that the addition of this surface layer will have an overall positive effect on the environment.

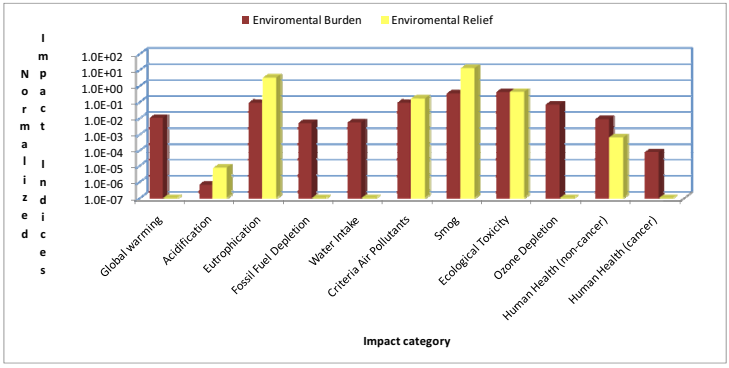


FIGURE 2. Environmental burdens and relieves of titanium dioxide coating

With respect to smog formation, titanium dioxide coating reduces the emission of nitrogen oxides and toluene to the atmosphere. These pollutants react with sunlight to result in detrimental effects on human health and vegetation. With respect to critical air pollutants, titanium dioxide coating reduces the emission of nitrogen oxides, which relate to combustion activities and traffic operations. The reduction of these pollutants help avoid aggravate respiratory conditions such as asthma. With respect to eutrophication, titanium dioxide reduces the emission of ammonia, nitrate, and phosphorus. These pollutants cause an increase in algae growth, which consumes significant portion of the oxygen under water and leads to death of other species such as fish. With respect to acidification, titanium dioxide absorbs nitrogen compound and ammonia. These pollutants affect the health of humans, trees, and animals.

It is worth noting that the environmental burdens associated with titanium dioxide as shown in Figure 2 are not significant but are nonetheless considered sources of concerns that should be assessed for the viability of this technology. For instance, the normalized impact index for global warming associated with the production and installation of normal concrete required for one lane-km is 3.92. Therefore, the increase in global warming potential due to the use of titanium dioxide coating is only 0.07%. Similarly, Figure 3 presents the increase in the environmental impacts of normal concrete when titanium dioxide coating is used. These results indicate that while titanium dioxide may effectively purify the atmosphere from harmful pollutants such as nitrogen oxides (NO_x), toluene, and ammonia, its contribution to the overall environmental impacts of concrete construction is minimal.

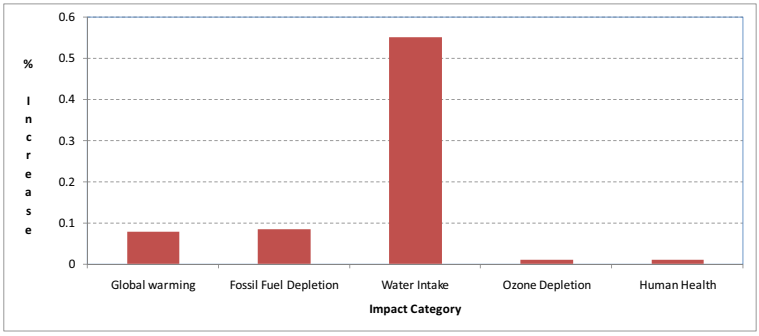


FIGURE 3. Contribution of titanium dioxide coating to the overall environmental impact of concrete (1 lane-km)

CONCLUSIONS

The use of titanium dioxide coating for pavements has received considerable attention in recent years to improve air quality in the vicinity of large metropolitan areas. Despite its promising benefits, the promotion of titanium dioxide based on a single factor such as air purification, does not provide a realistic and complete evaluation of this technology and may omit critical environmental factors that should be considered in the decision-making process. Therefore, this study adopted a life-cycle assessment methodology to quantify the environmental impacts of this technology. Life-cycle assessment was based on a hybrid life cycle methodology that followed both the International Organization for Standardization (ISO) 14040 standard for life cycle assessment and Input Output Analysis (IOA). Based on the analysis conducted, the following conclusions may be drawn:

- The use of titanium dioxide coating has a positive effect on four main environmental categories: acidification, eutrophication, criteria air pollutants, and smog formation. However, during production phases and due to the consumption of fossil energy, titanium dioxide coating will cause an increase in global warming, fossil fuel depletion, water intake, ozone depletion, and human health.

- Based on the overall environmental performance of this product, life cycle assessment shows that titanium dioxide coating has an overall negative score of -0.70 indicating that the addition of this surface layer will have an overall positive effect on the environment.
- The use of titanium dioxide coatings is considered a positive improvement and support further evaluation of this technology. However, in order to achieve full potential of the technology further fate and exposure studies are needed to quantify the effects and quantities of by products resulting from the photocatalysis process and to determine the toxicological effects of nano particles such as titanium dioxide.

This study represents a first step towards evaluating the ecological footprint of ultrafine/nano materials in construction applications and guiding the development of new ultrafine products towards a net reduction of resource requirements and emissions. Based on the results presented in this study, further research is recommended to consider factors omitted in the analysis such as maintenance and rehabilitation activities, end-of-life recycling options, and variation of adopted data with project size and location. Research is also needed to quantify effects of byproducts resulting from purification and long-term effectiveness of this technology.

REFERENCES

Air now. (2008). http://airnow.gov/.

Bare, J., G. Norris, D. Pennington, and T. McKone. (2002). TRACI: The Tool for the Reduction and Assessment of Chemical and other Environmental Impact. *Journal of Industrial Ecology*, 6(3-4), 49-78.

Beeldens, A. (2006). An Environmentally Friendly Solution for Air Purification and Self Cleaning Effect: the Application of TiO_2 as Photocatalyst in Concrete. Proceedings of Transport Research Arena Europe – TRA, Göteborg, Sweden.

Benedix, R., F. Dehn, J. Quaas, and M. Orgass. (2000). Application of Titanium Dioxide Photocatalysis to Create Self Cleaning Building Materials. *Lacer*, 5, 157-168.

Bergman, C. (2004). "2003 Status Report Shows U.S. Air Cleanest Ever Since 1970', EPA.

Bilmes, S., P. Mandelbaum, F. Alvarez, and N. Victoria. (2000). Surface and Electronic Structure of Titanium Dioxide Photocatalyst. *Journal of Physical Chemistry B*, 104, 9851-9858.

Carnegie Mellon University Green Design Institute. (2008). Economic Input-Output Life Cycle Assessment (EIO-LCA) Model [Internet], Available from: http://www.eiolca.net/> [Accessed July 2008].

Dalton, P., P. Janes, N. Jones, J. Nicholson, K. Hallam, and G. Allen. (2002). Photocatalytic Oxidation of NO_x Gases Using TiO_2: A Surface Spectroscopic Approach. *Environmental Pollution*, 120, 415-422.

Fujishima, A., T. Rao, and D. Tryk. (2000). Titanium dioxide photocatalysis. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews*, 1, 1-21.

Heijungs, R., and S. Suh. (2002). The Computational Structure of Life Cycle Assessment. Kluwer academic publishers, Boston.

Hendrickson, C., S. Horvath, and L. Lave. (1998). "Economic Input-Output Models for Environmental Life Cycle Assessment. *Environmental Science and*

Technology, 32(7), 184A-191A.
ISO. (1997). International Organization for Standardization. Environmental Management – Life Cycle Assessment – Principals and Framework. ISO 14040.
Leontief, W. (1970). Environmental Repercussions and the Economic Structure: An Input-Output Approach. *Review of Economics and Statistics*, (LII) 3, 262-271.
Lippiat, B., (2007). *Building for Environmental and Economic Sustainability (BEES) Technical Manual and User Guide*, National Institute of Standards and technology, Wellington.
Marceau, M.L., M. Nisbet, and M. Van Geem. (2007). Life Cycle Inventory of Portland Cement Concrete. Report No. PCA R&D Serial 3011, Skokie, IL.
Osterwalder, N., C. Capello, K. Hungerbuhler, and W. Stark. (2006). Energy Consumption during Nanoparticle Production: How Economic is Dry Synthesis. *Journal of Nanoparticle Research*, 8, 1-9.
Poon, C., and E. Cheung. (2007). NO Removal Efficiency of Photocatalytic Paving Blocks Prepared with Recycled Materials. *Construction and Building Materials*, Elsevier, 21, 1746-1753.
Pozzo, R., M. Baltanas, and A. Cassano. (1997). Supported Titanium Oxide as Photocatalyst in Water Decontamination: State of the Art. *Catalysis Today*, 39, 219-231.
Rebitzer, G., T. Ekvall, R. Frischknecht, D. Hunkler, T. Norris, W. Rydberg, S. Suh, B. Weidema, and D. Pennington. (2004). Life Cycle Assessment Part 1: Framework, Goal and Scope Definition, Inventory Analysis, and Applications. Environment International 30, 701-720.
Reck, E., and M. Richards. (1999). Titanium Dioxide Manufacture and Life Cycle Analysis. *Pigment Research Technology*, 28(3), 149-157.
SETAC.(1993). Guidelines for Life Cycle Assessment: A Code of Practice. Society of Environmental Toxicology and Chemistry, Pensacola, FL.
Stark, W., and S. Pratsinis. (2002). Aerosol Flame Reactors for Manufacture of Nanoparticles. *Journal of Powder Technology*, Elsevier, 126, 103-108.
US Census Bureau. (2004). Construction Sand and Gravel – Mining: 2002. Report No. ECO2-211-212321, US Department of Commerce.
US Department of Commerce. (1997). Bureau of Economic Analysis. Regional multipliers: A User Handbook for Regional Input-Output Modeling System (RIMS II). 3rd edition, Washington, D.C.: U.S. Government Printing Office.
US Environmental Protection Agency (EPA). (2004). Factor Information Retrieval (FIRE) Data System, Version 6.25, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, USA.
Watts, M., A. Cooper. (2008). Photocatalysis of 4-Chlorophenol Mediated by TiO_2 Fixed to Concrete Surfaces. *Solar Energy*, 82, 206-211.
Zhu, W., P. Batros, and A. Porro. (2004). Application of nanotechnology in construction, Summary of a state of the art report. *Journal of Materials and Structures.* 37(9), 649-658.
Znaidi, L., R. Seraphimova, J. Bocquet, C. Colbeau-Justin, C. Pommier. (2001), A Semi-Continuous Process for the Synthesis of Nanosize TiO2 Powders and Their Use as Photocatalysts. *Material Research Bulletin*, 36, 811-825.

GLOBAL OPTIMIZATION OF DYNAMIC SITE LAYOUT PLANNING IN CONSTRUCTION PROJECTS

Khaled El-Rayes[1] , Member, ASCE, and Hisham Said[2]

[1]Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, 61801, PH (217) 265-0557, FAX (217) 265-8039, e-mail: elrayes@illinois.edu
[2]PhD Candidate, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, 61801, PH (217) 265-5215, e-mail: hsaid@illinois.edu

ABSTRACT: Dynamic site layout planning in construction projects focuses on identifying the location and space of temporary construction facilities on sites while considering the dynamic changes in the needs and availability of site space over the project duration. Existing dynamic site layout planning models generate layout plans of construction stages chronologically without considering their future effects which may lead to non-optimal or infeasible solutions. This paper presents the development of an Approximate Dynamic Programming (ADP) model that is capable of globally optimizing dynamic site layout plans of construction projects in order to minimize overall site layout costs. The developed model is equipped with the look-ahead capabilities of ADP to consider the future effects of site layout decisions in early stages on layout quality and feasibility in future stages. An application example is analyzed to illustrate the use and capabilities of the developed model in generating global optimal solution for dynamic site layout planning of construction projects.

INTRODUCTION

Construction site space is a vital resource that greatly participates in achieving project objectives, in the condition of being properly managed and allocated. Site space is used to accommodate site-level construction activities and temporary facilities that are used to support the project such as office trailers, warehouses, fabrication areas, and parking lots. Similar to other construction resources (i.e. labor, equipment, and materials) site space demand fluctuates over time as the project proceeds because the type and intensity of construction activities vary over time. Accordingly, construction planners and contractors need to allocate the available site space in advance to the temporary facilities and prepare site layout plan that evolves over the project duration. Despite its importance, planners tend to pay less attention to plan their site layouts before construction because of the complexity and remarkable time and effort

required. Thus, researchers provided through the past two decades dynamic site layout planning (DSLP) models to help contractors plan and optimize the allocation of their site spaces.

Existing DSLP models are majorly optimization models that adopt operation research (OR) to generate optimal site layout plans that represent successive time periods in the project duration. Zouein and Tommelein (1999) used liner programming and heuristics to position temporary facilities one by one in order to minimize the resource-based travel distances on site. Osman et al (2003) utilized Genetic Algorithms (GA) equipped with CAD interface capabilities to generate optimal dynamic layout plan considering minimizing travel cost. Elbeltagi et al (2004) used GA to simultaneously minimize resource-based travel distances and maximize safety using facilities pair-wise dimensionless weights to represent planner preferences. AbdelRazig et al (2005) used Ant Colony to minimize both travel and facilities relocation cost by representing DSLP as a Quadratic Assignment Problem. Previous models divide the project duration into successive stages, where temporary facilities and available construction site space are identified for each stage. Dynamic layout plan is generated by planning site layout in each stage starting from the first stage with the consideration of facilities positions in previous stage. Such chronological approach of generating the dynamic layout plan, where future effects of the current layout actions are considered and evaluated, may result in infeasible of non optimal solutions. This approach still mimics the current practice of construction managers in planning their site layout by adopting the first-come-first-serve principle.

The main objective of this paper is to present a DSLP global optimization model that compensates the inefficiency of the previous models. The present model is capable of: (1) modeling different types of temporary facilities that are utilized in construction sites; (2) modeling various layout constraints that represent physical, operational, and safety site restrains; and (2) generating global optimal dynamic site layout with the minimum site layout cost. As shown in Figure 1, the main output of the model is a set of successive site layout plans which represent the evolution of the site layout over time, which is produced in three main stages: (1) input stage where the planners identifies the space-related and time-related input of the project under consideration; (2) dynamic modeling phase where the layout planning problem is modeled using Approximate Dynamic Programming (ADP) approach; and (3) solution generation phase where the optimal dynamic layout is generated using an ADP iterative algorithm. The following sections describe in more detail each one of these phases.

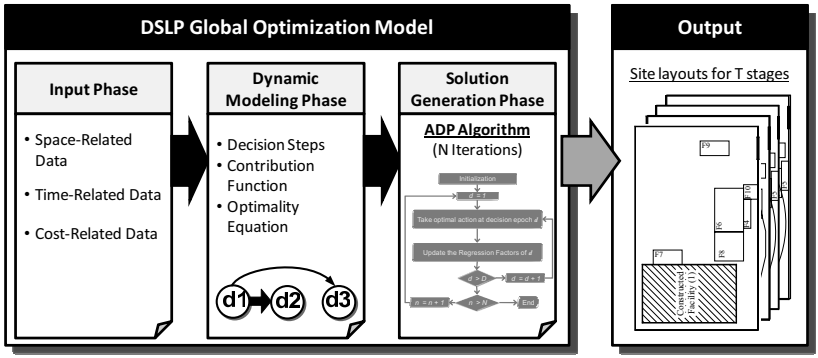


FIGURE 1. Proposed DSLP global optimization model

INPUT PHASE

The first phase of the proposed model is the input phase where the construction planner provides the input data of the project under consideration which include space-related, time related, and cost-related data. Space-related data describe space availability and demand by providing: (1) the geometry of the construction site, (2) the geometry of the temporary facilities, (3) the site space grid, and (4) layout constraints. The construction site and temporary facilities are represented using 2D rectangular shapes. The site space is represented using a set of grid positions created based on the grid pitch defined by the planner. Layout constraints are geometric restrictions imposed on facilities positions to reflect operational or safety issues during construction. The present model utilizes four types of layout constraints used before in previous site layout models (Zouein and Tommelein 1999, El-Rayes and Khalafallah 2005), which are: (1) boundary constraint, (2) overlap constraints, (2) distance constraints, and (3) zone constraints.

Time-related input are the data that describe the dynamics of the project space demand by providing: (1) the construction stages, (2) facilities existence on site, and (3) the types of used temporary facilities. First, construction planners are required to divide the project duration into stages, where temporary facilities are positioned or relocated at the beginning of each stage. Planners can use schedule milestones as the start or end of the stages where they represent the start or finish of major construction activities with remarkable space needs. Second, the on-site existence of the temporary facilities is provided by identify the construction stages where they are used. Finally, the type of each temporary facility is defined to be either stationary of moveable facility. The former type is used to represent temporary facilities that cannot be relocated in next stages after it was positioned in its first stage because of the infeasible cost or effort required for such relocation. For example, stationary facility can be used to represent batch plant or heavy fabrication areas. The later type of temporary facility (moveable facility) can be used to represent facilities that can be relocated at the beginning of each stage of their existence with the occurrence of relocation cost.

Cost-related input are used to quantify the nonproductive site tasks that are affected by DSLP decisions. Nonproductive site tasks include: (1) the travel of construction resources on site between the temporary facilities; and (2) the relocation of these facilities at the beginning of construction stages. The travel cost is represented using a pair-wise cost rate ($/m) for each pair of temporary facilities in each construction stage. The relocation cost of a temporary facility is represented by a fixed cost and a variable cost that is dependent on the relocation distance.

DYNAMIC MODELING PHASE

In this phase, the model analyzes the construction project under consideration and represents it as a dynamic problem using the concepts of Dynamic Programming (DP). The problem of dynamic site layout planning is broken down using DP into a sequence of simpler and more easily solvable problems (Si et al 2004) benefitting from the dynamic nature of the problem. The dynamic modeling of DSLP problem is performed by identifying its main components (Powell 2007): (1) decision steps, (2) contribution function, and (3) optimality equation. The following sections describe in more detail each of these dynamic modeling components of DSLP.

Decision steps

DSLP problem is modeled by breaking it down into smaller and easier problems, called decision steps that represent layout decisions of temporary facilities over the construction stages. Decision steps encompass the layout decisions of all moveable facilities and new stationary facilities in each construction stage. For example, *d1* (see Figure 2) represents the layout decision of the batch plant (new stationary facility) in the first stage. On the other hand, *d2* and *d4* represent layout decisions of the office trailer (moveable facility) in the first and second stages, respectively. The layout decision in any step includes determining about the grid location and the orientation angle (0 or 90°) of the corresponding facility in the current stage.

Decision steps are solved sequentially considering the future effects on subsequent steps and considering the actions taken in previous steps. Each decision step has two types of future effects: short-term and long-term effects. Short-term effects exist between any pair of successive decision steps that refer to temporary facilities in the same construction stage, such as the short term effects of *d1* on *d2* and *d2* on *d3* in the first stage, as shown in Figure 2. Long-term effect exists between decision steps that refer to layout decision of temporary facilities that reside in two different stages. As shown in Figure 2, d2 has a long-term effect on d4 because they represent the positioning of the same moveable facility (the office trailer) in two successive stages. On the other hand, d1 has a long-term effect on all decision steps in the subsequent stage (i.e. d4 and d5) because it represents the layout decision of a stationary facility (the batch plant).

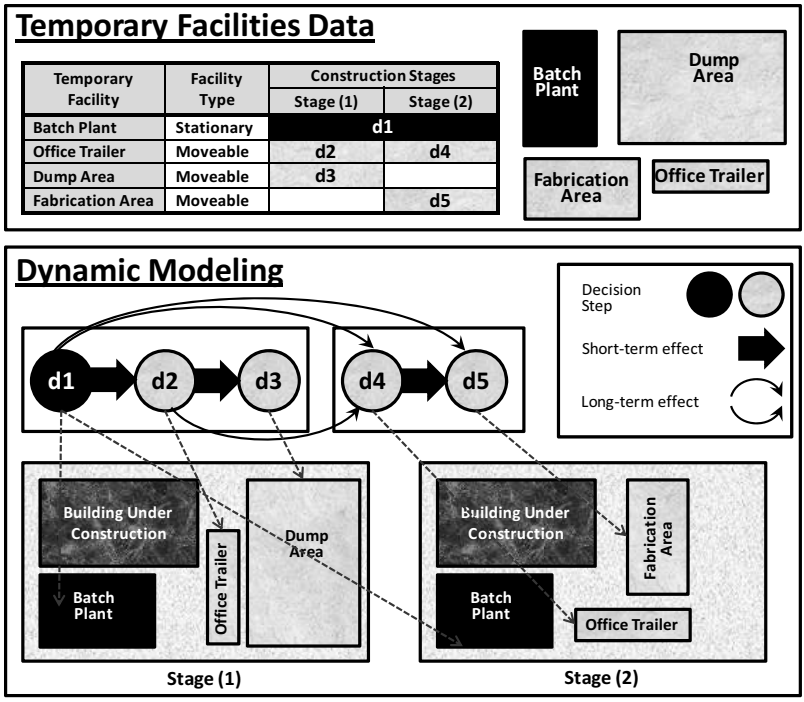


FIGURE 2. Representation of DSLP decision steps

Contribution Function

The contribution function returns the site layout cost that occurs as a result of a decision step based on the layout decisions taken in previous steps. As shown in Figure 3, the layout cost of decision step d4 comprises three cost components: the travel cost, the relocation cost, and constraint-violation cost. The travel cost of d4 is calculated between the positioned facility (the office trailer) in the second stage and: (1) the batch plant that was position in the first stage by step d1; and (2) the building under construction. The relocation cost of d4 occurs if the taken layout action (i.e. grid location and orientation) is different than the one taken for the same facility in the previous stage (i.e. d2). The constraint-violation cost is a penalty function that occurs if the taken action violates any of the layout constraint imposed on the office trailer in the second stage. For example, the layout decision of d4 is penalized if it violated the layout constraints with: (1) the batch plant positioned in the first stage by d1; (2) the building under construction in the second stage; and (3) the site boundary. It has to be noted that decisions of positioning stationary facilities have only travel and constraint-violation cost components because they are positioned only one time and cannot be relocated in future stages.

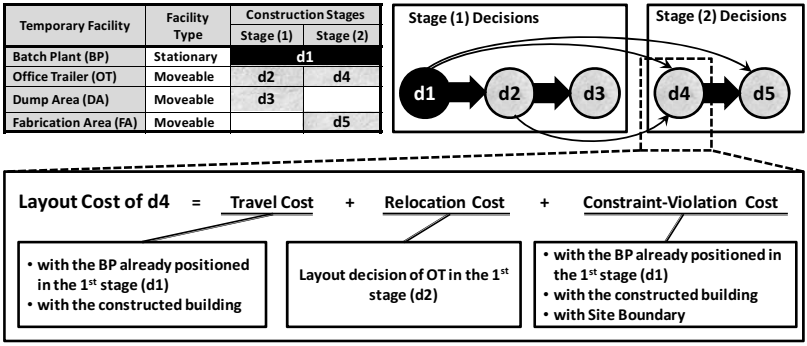


FIGURE 3. Cost components of the contribution function

Optimality Equation

The optimality equation mimics the tradeoff of the planner desire to obtain the lowest possible layout cost in the present decision against the implications of such decision on the layout cost of future decisions (Bellman 2003). As shown in Figure 4, the optimality equation is used to choose the optimal action at each decision step that minimizes the sum of: (1) the layout costs incurred by the current decision that is calculated by the contribution function; and (2) the future layout cost that incurred by all subsequent decision steps. The calculation of the exact value of the future cost is infeasible because it requires remarkable computational time and cost especially for the multidimensional nature of the present DSLP problem. Accordingly, Approximate Dynamic Programming (ADP) (Powell 2007) introduces an approach to overcome this "curse of dimensionality" approximating the future cost using linear regression model. The following section introduces in more details the usage of an ADP algorithm to search for and generate the optimal dynamic layout plan.

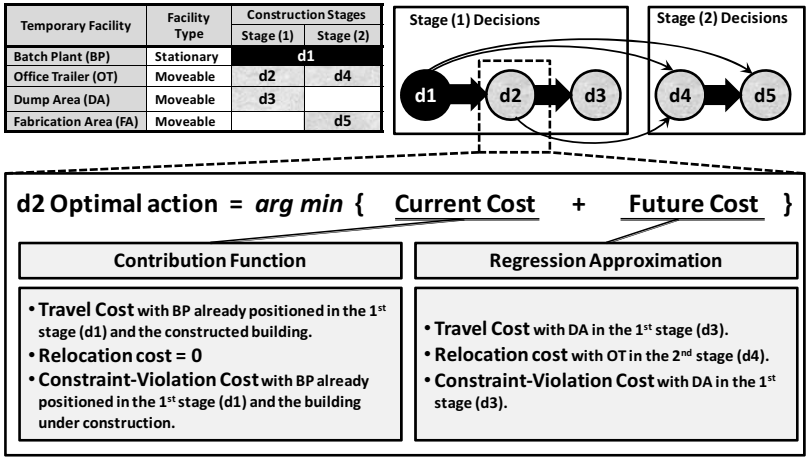


FIGURE 4. Optimality equation

SOLUTION GENERATION PHASE

Optimal dynamic layout is generated in the present model using an ADP algorithm that depends on improving the approximation in the optimality equation in an iterative manner. As shown in Figure 5, solution generation includes three major steps. The first step is to initialize the model by: (1) setting the value of the regression factors used in the approximation in the optimality equation to zero values; and (2) defining the initial status of the site layout and the current locations and orientations of the temporary facilities. The latter option provides the present model with the capability of updating the dynamic layout planning in any point of time based on the current site layout. The second step is to take the optimal action of the first decision epoch using the optimality equation. The third step is to update the values of the regression factors (supervised learning process) using the correct layout cost and the approximated cost calculated in the previous step. The second and third steps are repeated for all decision steps (D) as an inner loop of the algorithm. An outer loop is performed by replicating the inner loop for N iterations to update the regression factors and enhance the approximation of the optimality equation. Finally, the model output the optimal dynamic layout plan, which consists of T successive site layouts that represent the evolution of the site layout over time.

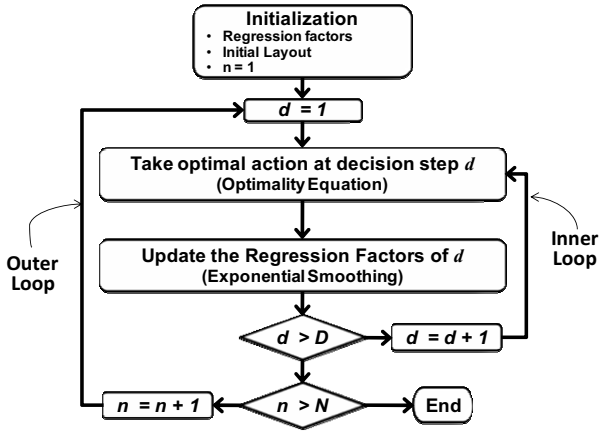


FIGURE 5. ADP Algorithm and optimal solution generation

APPLICATION EXAMPLE

The present model is evaluated using an application example to illustrate its performance and capabilities in generating global optimal dynamic site layout plans. The application example (Zouein and Tommelein 1999) represents a hypothetical 20 × 10 construction site that uses five temporary facilities over two construction stages, as shown in Table 1. A minimum distance constraint in the X direction is applied on facilities F1 and F3. More details of the application example are provided in Zouein and Tommelein (1999).

TABLE 1. Construction facilities of the application example

Facilities with fixed positions			
Facility	Dimension ($L_x \times L_y$)	Stages	Fixed Positions (x, y, orient)
F2	2 × 1	1	(16, 8.5, 0)
F5	4 × 2	1	(11, 6, 90)
Temporary Facilities			
Facility	Dimension ($L_x \times L_y$)	Stages	Relocation Cost
F1	8 × 8	1 → 2	75
F3	2.8 × 2.8	2	50
F4	4 × 2	1 → 2	75
F6	4 × 3	2	75
F7	4 × 2	2	50

The present model succeeded to generate a more optimal dynamic layout plan by having a look-ahead capability provided by its dynamic modeling of the problem. As shown in Figure 6, the model positioned facilities F1 and F4 to produce higher layout cost in the first phase that led larger cost savings in the second stage. The remarkable cost saving in the second stage is majorly caused by the elimination of the relocation cost of F4 introduced in the opposite solution. The present model achieved this cost saving by utilizing DP and ADP approaches to predict the future implication of early layout decisions in the first stage on the layout costs of the second stage. The present model utilizes its dynamic formulation to anticipate future implications of layout decisions in early stages. Accordingly, local optimal decisions in early stages can be excluded to enable feasible and more global optimal decision in subsequent stages.

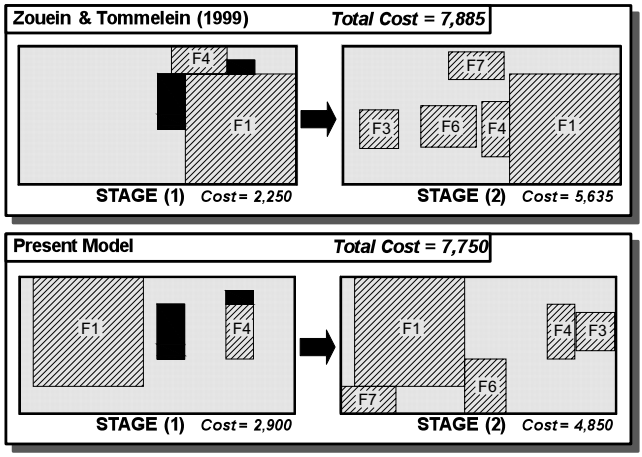


FIGURE 6. Generated dynamic site layout plan

CONCLUSIONS

This paper presents a newly developed dynamic site layout planning model that would help the construction planners to globally minimize the total layout cost. The proposed model generates the optimal dynamic layout plans in three phases. First, the planner feeds the model with space-related, time-related, and cost-related data to describe the project under study. Second, a dynamic model of the project is built using the approach of DP to enable the global optimization of the problem. Finally, the model searches for and generates the optimal dynamic layout plan using an ADP algorithm with reasonable computational time and cost. An application example from the literature is used to analyze the performance of the proposed model and illustrate its capabilities. The analysis results indicate the outperformance of the proposed model in providing optimal dynamic layout plan because of its look-ahead capabilities that enables predicting future implications of current layout decisions on the layouts of future construction stages. This should prove useful to construction planners in managing and planning their construction sites especially in complex and congested projects.

ACKNOWLEDGEMENTS

The writers gratefully acknowledge the financial support provided for this research project by the National Science Foundation under the NSF CAREER award number CMS 0238470 and Award No. CMS 0626066.

REFERENCES

AbdelRazig, Y., El-Gafy, M., and Ghanem, A.(2005) "Dynamic Construction Site Layout Using Ant Colony Optimization." Transportation Research Board 85th Annual Meeting, Transportation Research Board, Washington DC, USA.

Bellman, R. (2003). Dynamic Programming, Dover Publications, Inc., N.Y., USA.

Elbeltagi, E., Hegazy, T., and Eldosouky, A. (2004). "Dynamic Layout of Construction Temporary Facilities Considering Safety." Journal of Construction Engineering and Management, 130(4), 534 – 541.

El-Rayes, K., and Khalafallah, A. (2005). "Tradeoff between Safety and Cost in Planning Construction Site Layouts," Journal of Construction Engineering and Management, ASCE, 131(11), 1186-1195.

Osman, H., Georgy, M., and Ibrahim, M. E. (2003). "An Automated System for Dynamic Construction Site Layout Planning." 10th International Colloquium on Structural and Geotechnical Engineering, April 22-24, Ain Shams University, Cairo, Egypt.

Powell, W. B. (2007). Approximate Dynamic Programming: Solving the Curse of Dimensionality. John Wiley and Sons, Inc., Hoboken, NJ, USA.

Si, J., Barto, A. G., and Powell, W. B. (2004). Handbook of Learning and Approximate Dynamic Programming. The Institute of Electrical and Electronics Engineers (IEEE), Inc., N.Y., USA.

Zouein, P.P., and Tommelein, I.D. (1999). "Dynamic Layout Planning Using a Hybrid Incremental Solution Method." Journal of Construction Engineering and Management, 125(6), 400 – 408.

UNDERSTANDING COLLABORATIVE WORKING PROCESSES OF TEMPORARY PROJECT TEAMS IN LARGE-SCALE CONSTRUCTION PROJECTS

JeongWook Son[1] and Eddy M. Rojas[2]

[1] Graduate Student, Ph.D. Program in The Built Environment, University of Washington, 130E Architecture Hall, Box 351610, WA 98195, USA, json@u.washington.edu
[2] Associate Professor, Dep. of Construction Management, University of Washington, 130G Architecture Hall, Box 351610, WA 98195, USA, er@u.washington.edu

ABSTRACT

Current construction planning and control practices have proven to be less than ideal when applied to large-scale projects. This derives, in part, from the lack of explicit methods to model organizational and information-handling issues of temporary project teams. An emerging approach called social network analysis (SNA) is introduced in this paper as a way to overcome this limitation.

INTRODUCTION

As construction projects have been getting larger and more complex, project failure such as cost overruns or schedule slippages are becoming pandemic (Flyvbjerg et al. 2003). Particularly, effective communication, coordination, and information-handling processes, either in pre-construction or construction, have turned out to have substantial impacts all the way from the productivity of tasks at the operational level to overall project performance (Haymaker and Fischer 2001). However, current planning and control methods used in large-scale construction projects do not explicitly consider these organizational and information-handling issues, albeit their vital influences on productivity. It seems that construction planners suffer from optimism bias (Flyvbjerg 2004) regarding organizational issues where they estimate future events in more positive views than are warranted by actual experience.

Social Network Analysis (SNA), the study of social relations among a set of actors to uncover their interaction patterns, is thought to provide a way to overcome the drawbacks of current planning practice by presenting analytical implications of organizational settings as information-processing and communication systems from a network viewpoint. In the domain of organizational study, SNA has been used to investigate various relationships among organizations, information seeking processes, and the diffusion of knowledge. We argue that by taking advantage of the theories and applications of SNA, we may be able to begin the process necessary to overcome the limitations of current planning and control methods with respect to organizational and

information-handling issues.

CURRENT CONSTRUCTION PLANNING AND CONTROL PRACTICES

Whereas current construction planning practices, usually based on the critical path method (CPM), have served project managers well for purposes such as preparing project proposals, managing resources, tracking delays and change orders, approving progress payments, and coordinating with subcontractors (El-Bibany 1997), they lack the ability to model many of the complex and dynamic processes present in large-scale construction projects such as activity interdependences, process flexibility (Levitt et al. 1999), organizational and information-handling issues (Laufer and Tucker 1987), and errors and changes management (Lee and Pena-Mora 2007) among others. Consequently, current construction planning practices may be of little value to actual operations; cause inefficient schedules and poor productivity (Hendrickson and Au 1989); and be ineffective at preventing cost and schedule overruns in large-scale projects (Majid and McCaffer 1998).

Morris and Hough (1987) indicate that some of the reasons for large-scale project failures originate from unique organizational features of construction project teams including ignorance of what other project team members are doing. According to Cornick and Mather (1999), these unique features of construction project teams can be defined as *temporary organizations*. Temporary organizations do not have features that permanent organizations may have, such as a shared philosophy, an established organizational structure, an established set of work procedures, and a cost and price structure. Accordingly, temporary organizations need to be re-engineered and re-structured all over the life of the project as it progresses (Ballard 2005) so that they can cope with numerous interdependent tasks each of which requires collaborative multi-disciplinary practices among heterogeneous organizations. However, temporary organizations in large-scale construction projects have not been very successful and it is not unusual for them to fail. Nevertheless, "*Delusion of Success*" (Lovallo and Kahneman 2003) for likely organizational and information-handling problems to thwart successful completion of projects seems of great prevalence throughout the construction planning phase. In other words, project planners seem to have over-optimism for organization and information-handling issues without explicit reasoning processes.

ORGANIZATIONAL STUDIES IN CONSTRUCTION

Several studies have attempted to develop analytical and quantitative methods to investigate temporary project teams, such as simulation and social network analysis (SNA). Jin and Levitt (1996) have developed the Virtual Design Team (VDT), a stochastic discrete simulation model of project organizations using agent-based modeling (ABM) philosophy, based on organizational contingency theory and observations about collaborative and multidisciplinary work in large and complex projects. However, as Levitt and Nissen (2003) and Macal and North (2005) pointed out, VDT uses assumptions that might not be valid as projects become more complex and involve higher uncertainty.

Several studies using SNA have also been performed to analyze organizational issues in construction, which aim to introduce the fundamental ideas and theoretical

backgrounds of SNA and illustrate case studies (Loosemore 1998; Mead 2001; Pryke 2004), and to study the relation between web technology and information network (Thorpe and Mead 2001), project coalition (Pryke 2005), the effect of financial incentives (Pryke and Pearson 2006), and the role of trust in project teams (Swan et al. 2007). Whereas these studies provide comprehensive knowledge and present implications for specific topics, there does not seem to be studies that examine temporary project teams in-depth in the context of large-scale construction projects.

SOCIAL NETWORK ANALYSIS OF TEMPORARY PROJECT TEAMS

Social network analysis (SNA) is an interdisciplinary research area driven from sociology, statistics, mathematics, information sciences, psychology, and other disciplines. SNA aims at understanding the network structure composed of nodes (actors) and ties (relationships) by description, visualization, and statistical modeling (van Duijn and Vermunt 2006).

The power of SNA arises from a different viewpoint than traditional studies. Whereas traditional studies are concerned about the attributes of individual actors, SNA takes an alternate view that *ties* (relationships) among *nodes* (actors) within the network are more crucial to matters under consideration than their attributes. This viewpoint has turned out to be applicable to explaining many real-world phenomena such as organizational networks, inter-firm alliances, knowledge management, social cognition, and group processes. Indeed, social network research in the management area has increased radically in recent years (Borgatti and Foster 2003). From this light, it can be argued that we may be able to take advantage of SNA to overcome some of the limitations of current construction planning practices, as described earlier, by analytically examining temporary project teams as knowledge-creating and communication entities from a SNA viewpoint.

The construction domain could benefit from the network point of view of temporary project teams, which can be rationalized by organizational knowledge creation theory (Nonaka 1994) and transactive memory theory (Wegner 1987), to answer questions such as:

- What are the unique organizational characteristics of temporary project teams in large-scale construction projects?
- What factors influence the characteristics of temporary project teams? Who are the key actors in temporary project teams?
- Are current organizational settings of temporary project teams effective and efficient? Are we overlooking ways to be more effective and efficient? Are we over-optimistic regarding organizational issues?

An Illustrative Case Study: We used data from a non-construction company to develop a methodology to analyze temporary project teams. The company is a multi-national corporation working in areas such as healthcare, pharmaceuticals, information technology, oil & gas, and industrial. Figure 1 shows the organizational diagram for this company. The data was collected by researchers at the University of Virginia (Cross 2008) for purposes other than those in this paper. Participants were asked how often they have turned to other people for information or advice on work-related topics over the three months prior to the study.

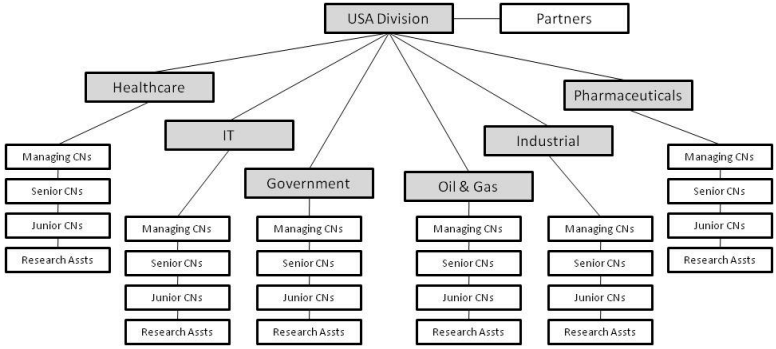


Figure 1: Formal Hierarchical Structure

The sample consisted of 46 individuals with a density of 0.081. This density means that, on average, people have relations with only 3.6 out of 45 people in the network. Figure 2 shows the sociogram for this network. A sociogram graphically depicts the interaction among network participants.

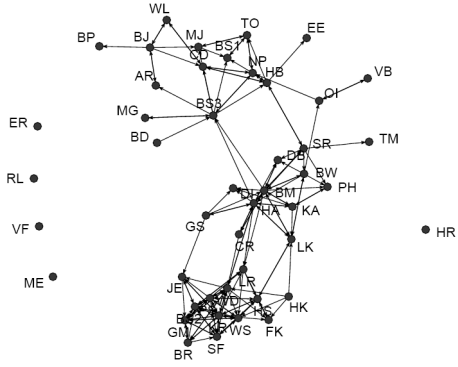


Figure 2: Sociogram of the Advice Network

We found that 17 people have equal or less than 2 out-degrees (asking advice), 6 have more than 9 out-degrees. Also, whereas 13 people have less than 2 in-degrees (being asked advice), 4 have 9 in-degrees or more. In other words, it can be argued that there are very active inquirers in the network even if a few people are uncommunicative. Further analysis using the mixing matrixes of people's attributes indicates that (1) both male and female tend to ask advice to males; (2) people have strong propensity to ask advice to people in the same region and location; and (3) managing consultants are the most dominant people in the network with the highest in-degree and out-degree. Therefore, it can be argued that there are people who have higher involvement in relations within the advice network and this *centrality* is likely to be originated not only from their central positions in the hierarchical structure of the organization, but also from people's appealing characteristics to other people.

Further evidence is provided by comparing the shape of the sociogram (Figure 2) with the shape of the organizational diagram (Figure 1). Indeed, the sociogram should have a tree-shape if people were to communicate only through formal routes. Therefore, factors other than hierarchical workflow are determining the pattern of the network.

This phenomenon also can be identified through visualization of network data which is another powerful analysis method in SNA. We can recognize the current status of a social network by means of exploring sociograms from different perspectives. For example, the sociogram shown in Figure 3 is drawn by position. At a first glance, there are five *isolates* (VF, RL, HR, ER, and ME) with different hierarchical position that have no relations with others. We can also deduct that managing consultants are inclined to form *cohesive subgroups* (CD, BS1, TO, and NP and BR, WS, KR, BS2, and PS). Interestingly, partners of BS3, HA, and WD are filling roles to connect people with different positions in the network. BS3 is a *bridge* among subgroups composed of junior consultants and managing consultants in the upper part. HA is located in the middle of the overall network and connects the left and right parts of the graph; and WD is also a *bridge* between the subgroup of managing consultants in the lower right and others.

Another sociogram drawn by practice is shown in Figure 4. There are several strong *cohesive subgroups* in the graph – bottom (pharmaceuticals), middle (oil & gas), and top (industrial). It might be obvious that people have a strong tendency to have relations and ask for advice with those in the same practice.

The Exponential Family Random Graph model (ERGM) (Robins et al. 2007) is used to analyze the data. The distribution of Y can be parameterized in the form:

$$P_{\theta,Y}(Y = y) = \exp\{\theta^{T} g(y)\} / k(\theta, Y), y \in Y,$$

Where Y: a random adjacency matrix an unvalued network
Y: a set of all obtainable networks
y: a particular given network
θ: a vector of model coefficients
g(y): the q-vector of statistics based on the adjacency matrix y

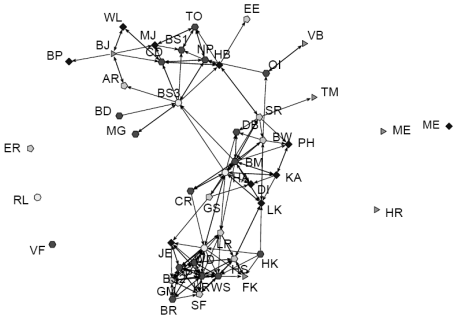


Figure 3: Sociogram against Position

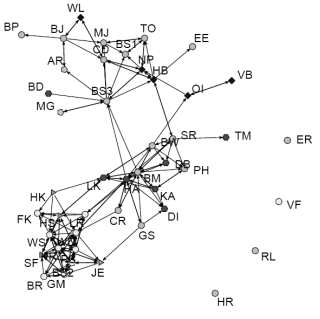


Figure 4: Sociogram against Practice

To fit the model, we made use of the Statnet package (Handcock et al. 2003) in R interface (R Development Core Team 2008). First, we fitted the model using *edges* term to identify a general propensity that people have relation with others. We then tried several different attributes using the *nodematch* term to identify homophily. As a result, the model was better fitted when using all attributes, but position. The selected model was simulated using Makov Chain Monte Carlo (MCMC) method to compare the observed network and the fitted model. Then, the term *gwesp* (Geometrically Weighted Edgewise Shared Partner distribution), which adds a statistic equal to the geometrically weighted shared partner distribution with weight parameter α, is added to the model. Different α values were tested and a value of 0.6 was chosen. As a result, the model was fitted with homophily terms of gender, practice, region, and location, and shared vertices term. The equation for the fitted model is:

$$\text{Logit}[P(Y_{ij} = 1 \mid x, \beta) = -5.9885X_1 + 0.5218X_2 + 1.02X_3 + 2.0257X_4 + 0.1551X_5 + 0.942X_6$$

Where: X1: the number of edges in the network
X2: the number of edges (i,j) for which gender(i)= gender(j)
X3: the number of edges (i,j) for which practice(i)= practice(j)
X4: the number of edges (i,j) for which region(i)= region(j)
X5: the number of edges (i,j) for which location(i)= location(j)
X6: the geometrically weighted shared partner distribution with weight parameter alpha

The coefficients can be interpreted in terms of the log-odds of different types of ties. For example, the log-odds of a tie between two completely heterogeneous individuals is -5.9885. The log-odds of a tie between two individuals who are homogeneous by practice is -4.9685. The log-odds of a tie between two individuals who are completely homogeneous by all attributes is -1.3239. The probability that corresponds to each log-odds is 0.0025, 0.0069, and 0.2102 respectively.

DYNAMIC NETWORK AND ADVANCED CONSTRUCTION PLANNING

Table 1 shows studies that identified valid relationships between the properties of networks and their performances. Even if there is little research on temporary project teams in construction from a network perspective, drawing an analogy from studies in similar realms, a hypothesis stating that the patterns of communication in temporary project teams in construction may affect performance seems plausible. Indeed, there is no evidence to indicate that network properties of temporary project teams in construction projects would be independent from their performance. Therefore, such a potential relationship deserves further scrutiny. Still, social network analysis (SNA) emphasizes the static analysis of relationships. Thus, SNA is very useful in capturing snapshots of temporary project teams at a point of time. However, it cannot account for time-varying relations of the underlying networks of temporary project teams that are dynamic in nature. Knowledge creation of temporary project teams needs to be understood from a dynamic viewpoint, where the attributes of actors and the network co-evolve as the teams proceed from one phase of the project to the next.

Table 1: Network Properties and their Effect on Performance

Source	Properties
O'Reilly and Roberts	Task group structure,
Davidet al. (1989)	Technology, group structure
Lucius and Kuhnert	Density of networks
Flap et al. (1998)	Intra-organizational networks
Cummings and Cross	Structural properties of work
Leenders et al. (2003)	Virtuality and communication
Rodan and Calunic	Knowledge heterogeneity
Sammarra and Biggiero	Heterogeneity and specificity of

Dynamic network analysis (DNA) is an emerging field centered on the dynamic relations and the impact of such social network dynamics on individual and group behavior (Carley 2003). Carley (2003) recently expanded SNA to the realm of dynamic analysis through the development of a meta-matrix, treating ties in a probabilistic manner, and combining social networks with cognitive science and multi-agent systems. In DNA, the actors (agents) can communicate, store information, and learn; the relations are probabilistically generated; and the networks change as the agents change. With DNA, we can:(1) describe social network dynamics; (2) visually represent it; and (3) develop what-if scenarios of varying organization settings through an analytical method rather than heuristics.

DNA can provide a way to overcome the drawbacks of traditional planning and control methods, which lack the ability to model the organizational and information-handling processes present in large-scale construction projects, by presenting implications of organizational settings in an explicit way. DNA can help investigate and answer questions such as:

- What is the primary driving force behind network dynamics in temporary project teams?
- How do actors' attributes and network dynamics in temporary project teams evolve?
- How can we predict network dynamics and what actions can be taken to lead them into desired directions?
- How do network dynamics affect individual performance and organizational performance throughout the duration of construction projects?

CONCLUSIONS

We have examined current construction planning and control processes and introduced the theoretical foundations and some existing applications of social network analysis (SNA) and dynamic network analysis (DNA) in this paper. Because the data used to illustrate SNA and DNA is borrowed from other domain due to lack of similar data in construction, the findings have limitations and may not be directly applicable to temporary project teams in construction. However, they illustrate the potential of such analysis and establish the rationale for studying the application of SNA and DNA in construction.

REFERENCES

Ballard, G. (2005). "Construction: one type of project production system." *Proceedings of the 13th International Group for Lean Construction (IGLC) Conference, Sydney*.

Borgatti, S. P., and Foster, P. C. (2003). "The Network Paradigm in Organizational Research: A Review and Typology." *Journal of Management*, 29(6), 991-1013.

Carley, K. M. (2003). "Dynamic Network Analysis." Dynamic Social Network Modeling and Analysis: Workshop Summary and Papers, R. Breiger, K. Carley, and P. Pattison, eds., Committee on Human Factors, National Research Council, National Research Council, Washington, DC, 133-145.

Cornick, T. C., and Mather, J. (1999). *Construction project teams : making them work profitably*, Thomas Telford, London.

Cross, R. (2008). "The network roundtable - network analysis tutorials." <https://webapp.comm.virginia.edu/NetworkRoundtable/> (Aug. 12, 2008).

Cummings, J. N., and Cross, R. (2003). "Structural properties of work groups and their consequences for performance." *Social Networks*, 25(3), 197-210.

David, F. R., Pearce Ii, J. A., and Randolph, W. A. (1989). "Linking Technology and Structure to Enhance Group Performance." *Journal of Applied Psychology*, 74(2), 233-241.

El-Bibany, H. (1997). "Parametric Constraint Management in Planning and Scheduling: Computational Basis." *Journal of Construction Engineering and Management*, 123(3), 348-353.

Flap, H., Bulder, B., and Volker, B. (1998). "Intra-organizational Networks and Performance: A Review." *Computational & Mathematical Organization Theory*, 4(2), 109-147.

Flyvbjerg, B. (2004). "Procedures for Dealing with Optimism Bias in Transport Planning." T. B. D. f. Transport, ed.

Flyvbjerg, B., Bruzelius, N., and Rothengatter, W. (2003). *Megaprojects and risk : an anatomy of ambition*, Cambridge University Press, United Kingdom; New York.

Handcock, M. S., Hunter, D. R., Butts, C. T., Goodreau, S. M., and Morris, M. (2003). "statnet: Software tools for the Statistical Modeling of Network Data." Seattle, WA.

Haymaker, J., and Fischer, M. (2001). "Challenges and Benefits of 4D Modeling on the Walt Disney Concert Hall Project." CIFE Working Paper.

Hendrickson, C., and Au, T. (1989). *Project management for construction : fundamental concepts for owners, engineers, architects, and builders*, Prentice Hall, Englewood Cliffs, N.J.

Jin, Y., and Levitt, R. E. (1996). "The virtual design team: A computational model of project organizations." *Computational & Mathematical Organization Theory*, 2(3), 171-195.

Laufer, A., and Tucker, R. L. (1987). "Is construction project planning really doing its job? A critical examination of focus, role and process." *Construction Management and Economics*, 5(3), 243 - 266.

Lee, S., and Pena-Mora, F. (2007). "Understanding and managing iterative error and change cycles in construction." *System Dynamics Review*, 23(1), 35-60.

Leenders, R. T. A. J., van Engelen, J. M. L., and Kratzer, J. (2003). "Virtuality, communication, and new product team creativity: a social network perspective." *Journal of Engineering and Technology Management*, 20(1-2), 69-92.

Levitt, R. E., and Nissen, M. E. (2003). "The virtual design team (VDT): a multi-agent analysis framework for designing project organizations." *Integration of Knowledge Intensive Multi-Agent Systems, 2003. International Conference on*, 115-120.

Levitt, R. E., Thomsen, J., Christiansen, T. R., Kunz, J. C., Jin, Y., and Nass, C. (1999). "Simulating Project Work Processes and Organizations: Toward a Micro-Contingency Theory of Organizational Design." *Management Science*, 45(11), 1479-1495.

Loosemore, M. (1998). "Social network analysis: using a quantitative tool within an interpretative context to explore the management of construction crises." *Engineering Construction & Architectural Management (Blackwell Publishing Limited)*, 5(4), 315.

Lovallo, D., and Kahneman, D. (2003). "Delusions of Success." *Harvard Business Review*, 81(7), 56-63.

Lucius, R. H., and Kuhnert, K. W. (1997). "Using sociometry to predict team performance in the work place." *Journal of Psychology*, 131(1), 21-32.

Macal, C. M., and North, M. J. (2005). "Tutorial on agent-based modeling and simulation." *Winter Simulation Conference, 2005 Proceedings of the*, 2-15.

Majid, M. Z. A., and McCaffer, R. (1998). "Factors of Non-Excusable Delays That Influence Contractors' Performance." *Journal of Management in Engineering*, 14(3), 42-49.

Mead, S. P. (2001). "Using Social Network Analysis to Visualize Project Teams." *Project Management Journal*, 32(4), 32-38.

Morris, P. W. G., and Hough, G. H. (1987). *The anatomy of major projects : a study of the reality of project management*, Wiley, Chichester; New York.

Nonaka, I. (1994). "A Dynamic Theory of Organizational Knowledge Creation." *Organization Science*, 5(1), 14-37.

O'Reilly, C. A., and Roberts, K. H. (1977). "Task group structure, communication, and effectiveness in three organizations." *Journal of Applied Psychology*, 62(6), 674-681.

Pryke, S., and Pearson, S. (2006). "Project governance: case studies on financial incentives." *Building Research and Information*, 34(6), 534-545.

Pryke, S. D. (2004). "Analysing construction project coalitions: exploring the application of social network analysis." *Construction Management & Economics*, 22(8), 787-797.

Pryke, S. D. (2005). "Towards a social network theory of project governance." *Construction Management & Economics*, 23(9), 927-939.

Robins, G., Pattison, P., Kalish, Y., and Lusher, D. (2007). "An introduction to exponential random graph (p*) models for social networks." *Social Networks*, 29(2), 173-191.

Rodan, S., and Galunic, D. C. (2004). "More than Network Structure: How Knowledge Heterogeneity Influences Managerial Performance and

Innovativeness." *Strategic Management Journal*, 25, 541-556.
Sammarra, A., and Biggiero, L. (2008). "Heterogeneity and Specificity of Inter-Firm Knowledge Flows in Innovation Networks." *Journal of Management Studies*, 45(4), 800-829.
Swan, W., McDermott, P., and Khalfan, M. (2007). "The application of social network analysis to identify trust-based networks in construction." *International Journal of Networking and Virtual Organisations*, 4(4), 369-382.
Team, R. D. C. (2008). "R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing." R Foundation for Statistical Computing, Vienna, Austria.
Thorpe, T., and Mead, S. (2001). "Project-Specific Web Sites: Friend or Foe?" *Journal of Construction Engineering and Management*, 127(5), 406-413.
van Duijn, M. A. J., and Vermunt, J. K. (2006). "What Is Special About Social Network Analysis?" *Methodology: European Journal of Research Methods for the Behavioral and Social Sciences*, 2(1), 2-6.
Wegner, D. M. (1987). "Transactive memory: A contemporary analysis of the group mind." *Theories of group behavior*, 185-208.

MODELING THE EFFECT OF AN ALTERNATIVE REVIEW PROCESS: CASE STUDY OF A STATE PERMITTING AGENCY

Peter P. Feng[1], Iris D. Tommelein[2], and Glenn Ballard[3]

[1]PhD Candidate, Department of Civil and Environmental Engineering, University of California, Berkeley, CA 94720-1712, PH (510) 292-9786, peterfeng@comcast.net
[2]Director, Project Production Systems Laboratory and Professor, Civil and Environmental Engineering Department, 215-A McLaughlin Hall, University of California, Berkeley, CA 94720-1712, Phone (510) 643-8678, FAX (510) 643-8919, tommelein@ce.berkeley.edu
[3]Research Director, Project Production Systems Laboratory and Professor, Civil and Environmental Engineering Department, 215-A McLaughlin Hall, University of California, Berkeley, CA 94720-1712, Phone (510) 643-8678, FAX (510) 643-8919, ballard@ce.berkeley.edu

ABSTRACT

The purpose of the research presented here is to describe workflow through an organization that reviews submissions for building permit approval and understand the effect of an alternative review process on the time to permit assuming a certain level of staffing conducting the review. The alternative review process engages the state review agency early in reviewing the design with the owner, architect, engineer, and contractor. Data was obtained from a state permitting agency to develop a simulation model of an alternative review process and the disruption rework causes on the permitting approval process. This simulation model shows that incorporating an alternative review process can shorten the overall time to permit a hospital. It also shows that the alternative review process shifted the design and permitting curve, reducing the time to permit, while increasing the workload up-front. This research recognizes that the alternative review process does not suit all projects, and that permitting agencies who adopt it must judiciously decide how to staff their organization to support process implementation.

INTRODUCTION

In the state of California, hospital construction undergoes a review process that includes governmental oversight. This oversight is accomplished by many organizations, including local government, Department of Health Services, Department of Geologic Services, and the Office of Statewide Health Planning and Development (OSHPD). This paper focuses on the workflow of the design and permitting phase, specifically through

one of six OSHPD divisions, namely the Facilities Development Division (FDD). FDD is tasked with ascertaining that hospital designs will be such that constructed facilities will remain standing after a disaster. Design drawings must meet California building codes and when completed, are delivered to FDD for review. This review can take up to two years because of the time for FDD to review, for designers to correct errors, resolve ambiguities, etc., and then for FDD to re-review the drawings. Without an alternative review process, FDD often takes the longest time to review submissions, relative to other oversight agencies.

Hospital design drawings are reviewed in three ways. The first is the traditional '100% contract drawings' where the design team completes the entire design package (which on a large project could be thousands of drawings) and then delivers it to OSHPD/FDD for review. FDD plan reviewers make comments and then send the set back for correction by the design team. This cycle continues many times until the drawings are deemed code compliant, whereupon FDD approves them. If the drawings contain no errors, this is the most efficient way for the drawings to be permitted through the agency. However, this situation rarely occurs.

The second and most often used way to review and approve drawings is to break the project down into phases. A 'phased project' divides the project into major systems, to include underlying utilities, foundation, structure, mechanical systems and roof systems. This way differs from the '100% contract drawings' in that the design team can submit the different phases as soon as they are complete. This process decreases the batch size of the design drawings but increases the number of project reviews FDD has to perform.

The third way is to request 'partial permits'. This differs from the phased approach in that each phase separately can be approved and permitted to construct. This allows the construction process to begin earlier by reducing batch sizes, but it also increases the number of reviews. The downside is the difficulty of determining which parts of the drawings are approved with permits and which are not. An example of this is: Where do underground utilities start and stop in relation to the foundation?

All of these processes create substantial rework pushing back construction schedules and leading to significant cost escalation (e.g., Morris (2007) estimates escalation at about 12% per year).

REWORK

Rework in the design and construction of facilities can be defined in many ways. It is the process by which an item is made to conform to the original requirement by re-completion or correcting (Ashford 1992) and "doing something at least one extra time due to non-conformance to requirements (Construction Industry Development Agency 1995). Rework can also be defined as the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time (Love et al. 1999). Rework can be defined specifically for field operations as activities that have to be executed more than once in the field or activities that remove work previously installed as part of the project (Rogge et al. 2001), or as the total cost of redoing work in the field regardless of initiating cause (Construction Owners Association of Alberta 2001).

Such definitions are focused on negative iteration—rework that is wasteful to the final product—yet rework can also be positive. Ballard (1999) defined 'negative rework' as that which can be eliminated without loss of value or causing failure to complete the project. An example of negative rework occurs when a plumbing system fails pressure testing and has to be removed and replaced. He defined 'positive rework' as value-adding, as exemplified by instances when participants in the design process leave with a better understanding of customer requirements.

Negative rework is costly and wastes time. Informal surveys of design teams have revealed estimates as high as 50% of design time spent on such needless rework (Ballard 1999). During the construction phase, studies have found rework in design and construction to range in amount from 2% to 12% of the contract cost (Burati et al. 1992, Josephson and Hammarlund 1999, Love and Heng 2000). The need for rework is partly due to the variability in the execution of work. One way to reduce the occurrences of rework is to support the development of designs that are of higher initial quality upon first submittal, and this higher initial quality can be achieved by implementing an alternative review process.

WHAT IS AN ALTERNATIVE REVIEW PROCESS?

An alternative form of review is to involve major stakeholders in facility procurement as early as possible to avoid non-code-compliant designs. A critical piece to accomplishing this process is for the team to acquire common understanding of the project scope, objectives, value proposition, etc. Common understanding consists of shared meanings created through communication or collective experiences and is composed of five elements: (1) shared ways of thinking, (2) shared ways of operating, (3) shared knowledge, (4) shared goals, and (5) trust (Makela 2002).

On projects, common understanding occurs in two ways. Figure 1 represents traditional project delivery. Here the owner selects the architect early; they produce a concept design for the facility that is approved by the owner. Engineers are then hired to design the foundation, structural system, mechanical-, electrical- and fire, life, safety systems. During this time, the common understanding of the facility increases among those involved thus far. Then, in the instance of hospitals, once the design drawings are completed, they are submitted to FDD for review. During this time, major trade contractors may be hired to contribute to the creation of the contract documents. As this occurs the common understanding of the facility approaches 100%.

In contrast, Figure 2 represents the integrated project delivery approach. Here the common understanding of the project increases dramatically early on because the architect and construction manager or general contractor are hired onto the project early. In addition, engineers, major trade contractors and government agencies are brought in early as well. This project delivery system has many benefits; however, one major drawback is the level of effort is realized earlier in the system by many stakeholders and puts additional cost pressures on the owner.

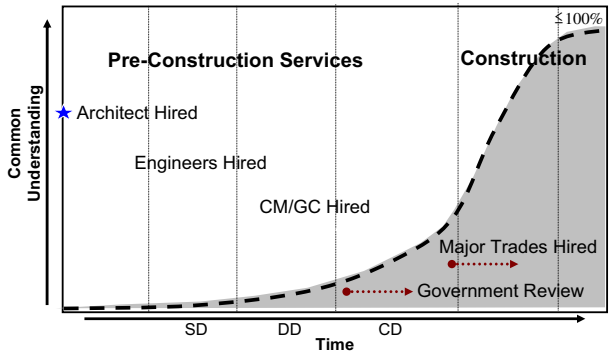


FIGURE 1. Traditional project delivery level of common understanding (modified from Lichtig 2008)

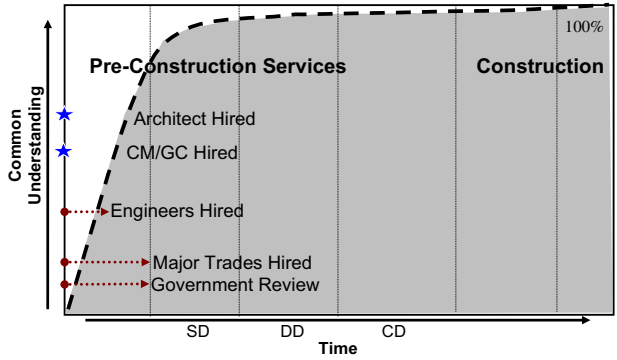


FIGURE 2. Integrated project delivery level of common understanding (modified from Lichtig 2008)

SHIFTING THE DESIGN CURVE "LEFT"

Figure 3 shows the design and construction industry trying to shift the design process to the left (curve no. 4) of traditional project delivery (curve no. 3). To accomplish this shift, an integrated team must be put into place. Accordingly, the American Institute of Architects' (AIA) guideline breaks the design process into six project delivery stages that differ from the traditional stages, as shown on the x-axis of figure 3. The integrated delivery model, shown by curve no. 4 and the light grey text, on the x-axis shifts the effort to the left of the traditional curve. It also shows the government review process taking place much earlier in time.

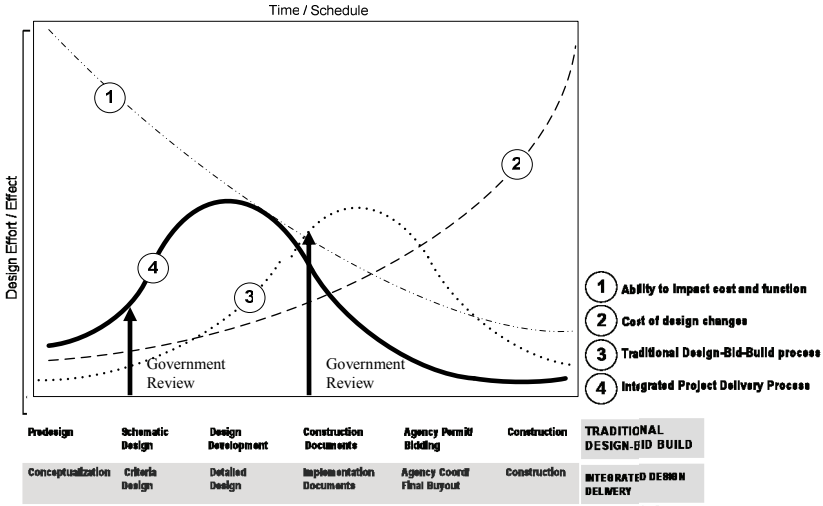


FIGURE 3. MacLeamy Curve - shifting the design curve (modified from AIA 2007)

This shift left is accomplished through a different paradigm. According to the AIA (2007), the integrated project delivery approach "integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction." However, AIA integrated project delivery does not offer many tools to shift the design curve to the left. It highlights the need for collaboration, concurrent and multi-level designs, but falls short in suggesting specifics. In contrast, this research, inline with the integrated form of agreement (IFOA), promotes the need for the Last Planner System™, target value design, built in quality, and work structuring.

DISCRETE EVENT SIMULATION (DES)

Forecasting effects of organizational process change is difficult. The FDD consists of 235 personnel and reviews over $14B in construction every year (OSHPD 2008). Making a change in this organization takes time and more time to understand the results. Computer simulation is inexpensive and provides insight on the effect of organizational process change before any changes physically get implemented.

Discrete event simulation (DES) models are used to study alternative production system configurations. These models, using for example the STROBOSCOPE (Martinez 1996) simulation engine, are made up of activities or processing steps (called 'Combis' = rectangles with cut-offs in the top-left corner, or Normals = rectangles), holding places for resources while they are not in use and thus accumulate (Queues), symbols to model

flow (arrows) and stochastic or deterministic branching (Forks). STROBOSCOPE (1) allows the state of the simulation to control the sequence of tasks and their relative priorities, (2) models resource selection schemes so that they resemble the way resources are selected for tasks in actual operations, and (3) models probabilistic material utilization, consumption and production.

STROBOSCOPE has been used to model 'lean' applications such as 'pull' in pipe-spool supply and installation (Tommelein 1998), multi-tasking and batching in the delivery of pipe supports (Arbulu et al. 2002), feedback in planning, fabrication, shipping, and installation of duct work (Alves and Tommelein 2006), and various lean production management principles applied to high-rise apartment construction (Sacks et al. 2007). The present work adds to this suite of educational models.

ALTERNATIVE REVIEW PROCESS DES MODEL

In consultation with senior members of the FDD, it was determined that a discrete event simulation model be developed to show how different review processes can affect the time to permit hospital designs. The model describes the current state process and data is used to validate system behavior. It simulates the effect early involvement has on the time to permit. Early involvement of the FDD plan reviewers (i.e., architect, electrical, mechanical, structural, and fire, life, safety engineers) with the owner, architect and design engineers reduces the time to permit.

Figure 4 shows a discrete event simulation model that illustrates in a simplified way the review process for hospital design in California. One part of the model, highlighted and noted with a 'one' shows the first review process. Drawings are located in the DrawingTable queue. Review personnel are categorized into five disciplines representing the 1) Architect, 2) Structural Engineer, 3) Mechanical Engineer, 4) Electrical Engineer, and 5) Fire, Life, and Safety Engineer. Each personnel queue contains one individual. The personnel queues are associated with discipline review activities. The review activity times, determined from organizational data, are normally distributed and depend on project size; larger projects have larger combined review times. Projects enter the system in random order and are reviewed following a first in first out (FIFO) scheme. Each project must be reviewed five times, one for each review discipline and once completed, the project flows into the second part of the simulation model.

The second part of the model, highlighted and noted with a 'two' shows a dynamic rework cycle. The first part of the rework cycle is to determine if rework is required. Each project size has a different chance of rework. The probability of rework was determined from organizational data. If the project does require rework it will be placed in the rework queue; otherwise it will be placed into the complete queue.

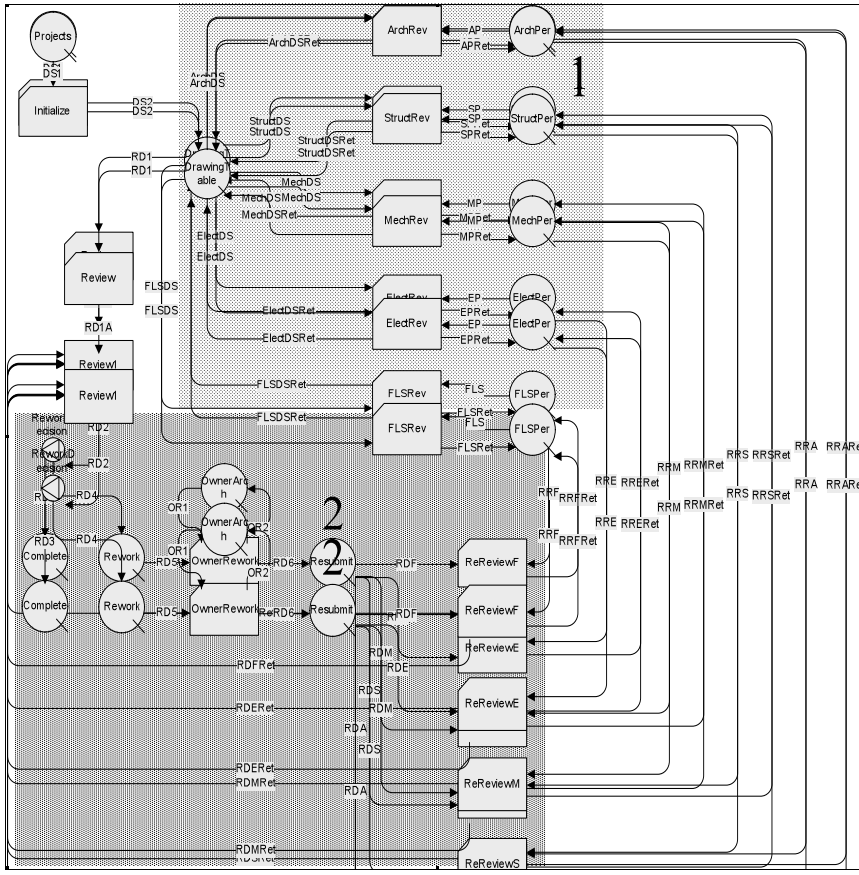


FIGURE 4. Discrete event simulation (DES) of current and alternative review process

Upon entering the rework queue , the simulation engine rando mly determines which discipline will require re -review. This information is tracked for each individual project. The project then goes into the owner rework activity. This simulates the drawings going back to the design team to correct errors. The owner re work time is category specific. Larger projects require more owner rework time while smaller projects require less.

Upon owner rework completion , the projects flow into the resubmit queue awaiting re-review. The simulation matches the assigned error with the correct discipline and then draws the appropriate reviewer into the re -review activity and upon re -review completion the project re -enters the rework decision fork. A project requiring re -review has a higher

priority than a first review continuing first in first out, which allows projects that have been in the system longer to be completed earlier.

The rework cycle continues until the project is determined to not require rework, and thus gets approved. The chance of rework decreases with each rework cycle simulating the improvement of design drawings. This has been modeled by dividing the rework percentage by two after the first rework cycle, and then by three after the second rework cycle. The rework cycle can recur indefinitely, however, it is rare that a project is reworked more than four or five times.

Three scenarios were conducted to determine the impact of an alternative review process. Projects are placed into four categories and entered into the simulation model. The four categories are based on project cost and are divided into 1) less than $50K, 2) between $50K and $1M, 3) between $1M and $10M, and 4) greater than $10M. The original model represents the current organizational process receiving approximately 50 category 1, 100 category 2, 35 category 3, and 20 category 4 projects in a six month time frame. The second and third scenarios show a dedicated team performing alternative review only. Developing this model was requested by the FDD as they intend to put this team into practice and wanted to know the impact to the mean time to permit for the largest projects that the organization encounters. These two scenarios of a dedicated alternative review process were loaded with 40 and 50 category 4 projects and are referred to as DA40 and DA50 respectively.

SIMULATION RESULTS

Figure 5 shows normal distributions for three simulation scenarios, each one based on a sample size of 1,000 iterations. From left to right, the first two curves represent a dedicated review team that only performs an alternative review process (40 and 50 projects respectively). The third curve represents the time to permit for the original organizational structure (20 projects).

The decreased mean time to permit represents only a portion of the benefits of an alternative review process that engages major stakeholders early. Additional benefits of the alternative review process include: 1) reduced probability of rework, 2) if rework does occur, reduced time to correct, resubmit and re-review, and 3) increased job satisfaction for the plan reviewers. The latter occurs because the plan reviewers are now integral members of a design team, involved in a proactive process to design a hospital, rather than being part of a reactive process where they constantly catch design errors.

A statistical analysis was performed to compare DA40 and DA50 with the original mean time to permit. DA40 (mean 450 days, SD 13.8) and DA50 (mean 530 days, SD 14.3) were compared to the original model (mean 650 days, SD 17.6) resulting in a p-value of 0.0001 for both scenarios.

CONCLUSIONS

This research and supporting simulation results recommends utilizing a separate review team to handle alternative review projects resulting in an overall mean time to permit savings of approximately six months. However, this dedicated review team should

maintain a threshold of 40 to 50 projects in its queue, otherwise, diminishing returns on the mean time to permit occurs.

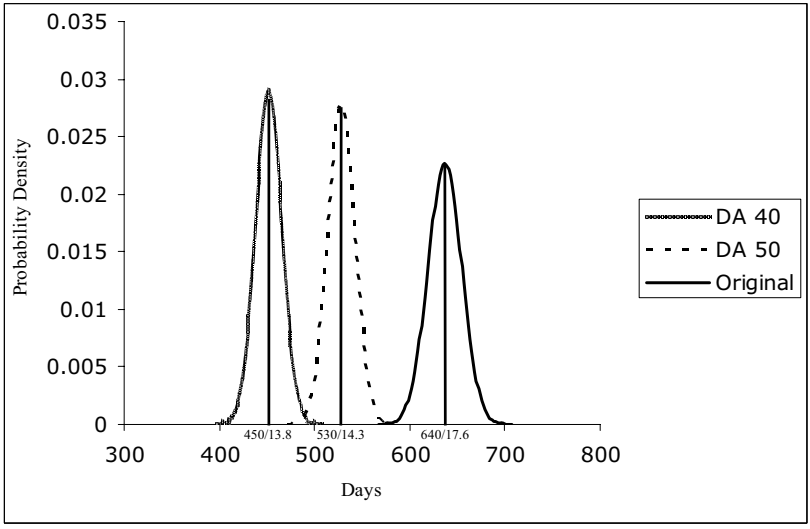


FIGURE 5. Mean time to permit for three scenarios (N = 1,000)

ACKNOWLEDGMENTS

Research for this paper was in part supported by gifts made to the Project Production Systems Laboratory (http://p2sl.berkeley.edu/). All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the author and do not necessarily reflect the views of members of the Project Production Systems Laboratory.

REFERENCES

AIA (2007). "Integrated Project Delivery: A Guide." *Rep. No. 1,* American Institute of Architects.

Alves, T.D.C.L. and Tommelein, I.D. (2006). "Simulation as a tool for production system design in construction." *Proc. 14th Conference of the International Group for Lean Construction* (IGLC14), 25-27 July 2006, Santiago, Chile, 10 pp., 341-353.

Arbulu, R. J. (2002). "Contributors to lead time in construction supply chains: Case of pipe supports used in power plants." *Winter Simul Conf Proc,* 1745-1751.

Ashford, J. L. (1992). "The management of quality in construction." *E & F Spon*.

Ballard, G. (1999). "Positive vs negative iteration in design." *Proc. 8th Conference of the International Group for Lean Construction* (IGLC8), 17-19 July 2000, Brighton, United Kingdom, 10 pages.

Burati, J. J. (1992). "Causes of quality deviations in design and construction." *Journal of Construction Engineering and Management,* 118(1), 34-49.

Construction Industry Development Agency. (1995). "Measuring up or muddling through: best practice in the Australian non-residential construction industry." *Construction Industry Development Agency and Master Builders Australia,* 59-63.

Construction Owners Association of Alberta. (September 28, 2001). "Meeting Minutes."

Josephson, P.-E., and Hammarlund, Y. (1999). "Causes and costs of defects in construction a study of seven building projects." *Automation in Construction,* 8(6), 681-687.

Lichtig, W. (2008). "Common Understanding vs. Time." McDonough Holland & Allen Attorneys at Law, Powerpoint presentation slides.

Love, P. E. D., Mandal, P., and Li, H. (1999). "Determining the causal structure of rework influences in construction." *Construction Management and Economics,* 17(4), 505.

Love, P. E. D., and Heng, L. (2000). "Quantifying the causes and costs of rework in construction." *Construction Management and Economics,* 18(4), 479-490.

Makela, K. (2002). "Construction of common understanding. Interplay of organizational culture, communication and knowledge in inter-company R&D-projects, Master's thesis, Department of Communication, University of Helsinki."

Martinez, J.C. (1996). "STROBOSCOPE State and Resource Based Simulation of Construction Processes." PhD Diss., University of Michigan, Ann Arbor, Mich.

Morris, P. (2007). "Construction Cost Escalation." Davis Langdon, Technical Report, Sacramento, Ca.

Office of Statewide Planning and Development. (2008). "Facilities Development Division." http://www.oshpd.ca.gov/FDD/Plan_Review/Hosp_Insp.html (August 15, 2008).

Rogge, D. F., Cogliser, C., Alaman, H., and McCormack, S. (2001). "An investigation of field rework in industrial construction." *Rep. No. RR153-11,* Construction Industry Institute.

Sacks, R. (2007). "LEAPCON: Simulation of lean construction of high-rise apartment buildings." *Journal of Construction Engineering and Management,* 133(7), 529.

Tommelein, I. D. (1998). "Pull-driven scheduling for pipe-spool installation: simulation of lean construction technique." *ASCE, J. of Constr. Engrg. and Mgmt,* 124(4), 279-288.

AN APPROACH TO CLASSIFYING UNCERTAINTIES IN CONSTRUCTION SCHEDULES

H. Clay Phillips[1], Susan M. Bogus[2], Timothy J. Ross[3]

[1] PhD candidate, University of New Mexico and Project Manager, Applied Research Associates, P.O. Box 5388, Albuquerque, NM 87185; PH (505) 846-0487; FAX (505) 846-6430; email: hphillips@ara.com
[2] Assistant Professor, Department of Civil Engineering, University of New Mexico, MSC01 1070, Albuquerque, NM 87131; PH (505) 277-1395; FAX (505) 277-1988; email: sbogus@unm.edu
[3] Professor, Department of Civil Engineering, University of New Mexico, MSC01 1070, Albuquerque, NM 87131; PH (505) 277-3459; FAX (505) 277-1988; email: ross@unm.edu

ABSTRACT

Planning is arguably the most difficult, and important, phase of the construction process. One must have a very intimate grasp of what tasks are needed to complete a job, how they might be interdependent and therefore sequenced, and the construction methods, equipment, and skill sets required to execute them. At this step there is already a tremendous amount of uncertainty injected into the schedule, which only increases when site conditions and human interaction are added. The result is the existence of uncertainty in several forms in construction schedules, including probability, possibility, belief/plausibility, and fuzzy. There are different methods for uncertainty quantification based on the type of uncertainty. When applied appropriately, these methods can lead to an overall level of uncertainty (or total uncertainty) in a schedule. The first step to quantifying the total uncertainty in a schedule is to define and classify the types of uncertainties that may occur. Through a series of thought experiments a flow chart has been developed and examples provided to illustrate a classification process.

INTRODUCTION

Professionals have used probability theory for years to deal with uncertainty, since it has broad application and has been very well developed. What many people do not realize, however, is that probability theory is only one of several tools available for

dealing with uncertainty. Probability only accommodates one type of uncertainty – aleatoric or natural variability. Upon observation of a system, there are two possible extremes; total ignorance, meaning nothing is known about the system, to complete certainty where everything is known. If knowledge of the system is entirely complete then one can make decisions with total confidence. Uncertainty exists whenever there is an information deficiency. Probability theory is intended to deal with randomness or natural variability. One may have all the information available about a given system, but if it is inherently random there is still uncertainty, but it can be completely characterized by a probability density function. But what if the uncertainty stems from information that is incomplete, imprecise, fragmentary, unreliable, vague, ambiguous, or contradictory? Intuitively one can see that each of these describes a type of uncertainty, generally called epistemic, that is different than that produced by natural variability, and thus, requires an approach different from probability. In general, the four most common theories used to describe and quantify uncertainties are as follows (Klir 2006, Ross 2004):

- *Probability Theory:* covers aleatoric or natural variability, such as inclement weather or variable traffic conditions that might prevent workers from arriving on time.
- *Possibility Theory:* covers non-specificity such as poor directions to the job site or imprecise information about the location of buried utilities (e.g. the underground power line is on the east side of the project site; good luck finding it!).
- *Belief/Plausibility Theory:* covers uncertainties which might be characterized in intervals, or where significant ignorance plagues the information (e.g., educated guesses). Examples might be the existence of unexploded ordinance or historical artifacts that might be uncovered when conducting site work.
- *Fuzzy Set Theory:* deals with vagueness as a result of linguistic descriptors, for example the design strength of the concrete is *about* 3000 psi, or the subcontractor will deliver the reinforcing steel for the footer *in approximately a week*.

Classifying the uncertainties in even a simple schedule can be extremely difficult. The tools that are becoming ubiquitous for quantifying uncertainties other than aleatory are only part of the solution to understanding the total uncertainty in a system. So far, there seems to be a lack of information in the literature regarding rules or processes one can use to differentiate one type of uncertainty from another within a system. When presented with a system, a process begins to unfold in one's mind as to the nature of the uncertainties, but it is exceedingly difficult to articulate, especially in a step-wise manner, what the thought process was that led to the conclusion that one or more distinct types of uncertainty exists. Simply put, how does one move from observing a system to articulating what uncertainties exist, and therefore which uncertainty theories apply, and secondly, how can one determine the proportion of each contributing uncertainty to the total uncertainty in a system? It is important to realize that each uncertainty within a system contributes to the total

perceived uncertainty. Due to the lack of research in this area, quantifying the individual uncertainties and aggregating them into a single total uncertainty are concepts that are still very much in their infancy. Given the lack of research, it is appropriate that the first step would be to identify uncertainties in a system, like a construction schedule, and to develop an approach for classifying each uncertainty by type.

QUANTIFYING UNCERTAINTY IN CONSTRUCTION SCHEDULES

Construction schedules are by their very nature amorphous even though they present precise starting and ending dates. That the human element is integral to their being inevitably leads to uncertainty. Human communication and idea transfer is not precise but still suits most needs quite well in most circumstances; less so for something like a construction schedule, but more so for example when telling your spouse that you will meet her or him around noon for lunch. This is sufficiently accurate for the purpose of a social encounter and a meal but not for managing the schedule for large or even small construction projects. Everyone knows that poor weather, equipment failures, material shortages, traffic congestion, and countless other unknowns can and will affect the schedule. Owners will generally include penalties for finishing late, and incentives for finishing early just to keep the contractor mindful of maintaining the schedule. Most contractors will build extra time into their schedule because they explicitly understand there are uncertainties that are directly proportional to the complexity and duration of a project. Generally the more complex and lengthy a project the less certain you can be that the construction schedule is accurate because there are simply too many things that could happen, both predictable and not, that would affect the duration of one or more construction activities.

In presenting the critical path method (CPM) for scheduling Clough et al (2000) make the assumption that each construction activity's duration is deterministic. In other words, it is assumed that a construction activity that has been executed a number of times in the past is understood well enough that experience and historical information can be used to assign an accurate duration. However in their discussion of the Program Evaluation and Review Technique (PERT), Clough et al (2000) acknowledge that even with experienced schedulers the nature of construction is such that CPM may not realistically estimate the project duration. PERT is industry's acknowledgement that uncertainty exists in construction, that each activity is assumed as highly variable, and therefore a technique was needed to help deal with the expected uncertainty. In PERT all the uncertainty in the schedule, whether it is from an inaccurate estimation of activity duration or other reasons, is assumed to be entirely based on variability and that probability theory can be used to fully capture the uncertainty in a schedule. One may concede that a particular construction activity that has been executed a number of times in the past and that will be executed again in the future may, if plotted, show a scatter of durations that would lead you to believe variability is in fact the source of uncertainty. A closer examination however would lead one to understand that the underlying causes of the uncertainty lie not

only in variability, but also in other sources such as vague, incomplete, or contradictory information that one must rely on for the duration estimate.

A review of literature in the last 25 years indicates that more and more researchers are beginning to embrace the idea that there is more to uncertainty than simply natural variability, and that the scheduling techniques, primarily CPM, used by most engineers are not designed with such concepts in mind. Recently researchers and engineers have realized the need to understand other types of uncertainty and have taken the first steps in applying new tools to quantify more than just variability in a construction schedule. Chantaravarapan et al (2004) study Monte Carlo simulations with an eye toward improving a schedule so as to generate cost savings and improve productivity. Of note here is that even though there is clearly an attempt to confront "numerous uncertainties", the assumption is that they are all entirely aleatory or stochastic in nature. Bonnal et al (2004) make the effort to reduce fuzzy techniques to the point where they are pragmatic enough that without too much effort it is possible to move from the academic sphere to real project-scheduling practitioners for real-world implementation. Koll, et al (1999) demonstrate fuzzy modeling in a number of applications, but more relevant to this study, they demonstrate a partnership between fuzzy methods for estimating durations of construction activities in a tunneling project and then use possibility theoretic interpretation by assigning degrees of possibility as a replacement for probability for the total duration based on subjective expert opinion. Lei, Sou-Sen, et al (1999) explicitly recognize uncertainty in scheduling by using fuzzy set theory to estimate activity durations.

During the literature review it was quickly revealed that fuzzy sets and fuzzy logic are becoming more mainstream as can be seen by more and more applications of the technique in recent years, but they are still significantly less than probability theory. This is a clear indicator that engineers are increasingly becoming uncomfortable with current model outputs being taken as approximate predictions of reality with probability theory used alone to account for fluctuations. The belief is that predictions obtained in this way may be so far from reality as to render them useless, or even worse, misleading, Fetz, et al (1999). Therefore, a more comprehensive approach is necessary to quantifying uncertainty in a schedule.

CLASSIFICATION APPROACH

The first step in quantifying uncertainty in a schedule is to develop a technique for determining if probability, possibility, belief/plausibility, or fuzzy set uncertainties exist in a system like a construction schedule. One way to start the "sorting process" is by using exclusion from aleatory uncertainty. In other words, it is sometimes easier to say what something is not before you can determine in fact what it is. It is a reasonable expectation that most people have at least some familiarity with probability and statistics. Without taking a course in Generalized Information Theory most people can quickly grasp, especially in an intuitive, not computational sense, phenomena that are inherently random or variable provided they have a short primer or a few examples to use as guides. Examples include the likelihood that it will rain

on the jobsite today, or whether workers will be late arriving because of traffic, or whether a worker will be absent because of a death in the family.

Aleatory, or inherent variability is generally one of the easier uncertainties to identify. Any time an outcome is different than what is expected, and due to forces beyond anyone's control, or due to an unknown number of influences of varying degrees, and there is nothing one can do to reduce the uncertainty, that is natural or inherent variability, which can be characterized by probability theory. It is worth noting that this is not necessarily a trivial observation. On the surface a system may appear to be behaving in a purely random manner, but closer scrutiny may reveal that there are other uncertainties besides variability underlying and driving the observed behavior of a system. For example, a particular construction activity such as placing concrete for a footer might be something where a contractor has a great deal of experience. He may have determined over many years how many man-hours of labor are required to place and finish a certain quantity of concrete. Yet even after years of historical data and experience the outcome is never exactly the same each time. In one case the concrete from one of the transit mixers might have too high a slump and must be rejected, thereby slowing the project. The high slump might be the result of a batch plant operator receiving instructions that the required slump should be about 4 inches. This introduces a (fuzzy) uncertainty due to the nature of our day-to-day linguistic communication. Or perhaps the transit mixer operator arrived late because the directions he received to the job site only included the street and not the address requiring him to search to find the job site. That would be a case of non-specificity, or possibility uncertainty. In aggregate, the outcome in this very simple example would be a deviation from the expected number of labor hours to complete the job, which might look like random variability, but the root cause actually is a result of other types of uncertainties.

Recognizing when uncertainty is a result of the vagueness inherent to language is fairly straight forward. Descriptors such as close, warm, high, low, tight, about, near, around, on top, below, etc. are classic examples of fuzzy set uncertainty that we use every day. "We will complete the framing in about 1 ½ weeks" is adequate for communicating a sense of the magnitude of the job and scheduling other construction activities, however when additional attention is paid it becomes clear there is uncertainty in the duration of this activity because there is no precise definition of what is "about 1 ½ weeks". Or, "if we use three grounding rods instead of two we should get a sufficiently low resistance reading." What is sufficiently low? 100Ω? 3Ω?

In addition to recognizing vague language, one can also use a mental exercise to understand very basic fuzzy set uncertainty. In classical, or crisp sets, an object or element either belongs to a set or it doesn't. There is no in between; it is either white or black, on or off. Fuzzy sets, on the other hand, allow for a "grey area". There is a point at which an object or element definitely and without question is not a member of the set, and at the other extreme there is a point at which the same object or element is definitely and without question a member of the set. But here there is something in-between too. An object or element can be mostly outside the set, but

still at least partly in the set too. A good visual is to think of the difference between a thick, fuzzy line and a crisp thin one, and what is happening as you move from one side of the line to the other. A good example here is to describe someone as being "tall". If one were to poll 100,000 Americans with a single question, "At what height would you define someone as being tall?" the outcome would almost certainly be a range of values, with the lower boundary say at 5 ½ feet. Through the polling data the upper boundary might be say 7 feet. In this case a membership function can easily be created that describes the degree of membership within the set of "tall people" with zero membership for anyone shorter than 5 ½ feet, and full membership for anyone 7 feet tall and taller. Clearly, in-between 5 ½ feet and 7 feet there is some question or vagueness, (fuzziness) as to whether a person is tall. Once someone is aware of this very simple concept it is quite easy to spot fuzzy set uncertainty. Vague or imprecise linguistic descriptors are an immediate clue.

If one can recognize an uncertainty, and then determine that it is not aleatory in nature, nor is it due to imprecise language, then probability and fuzzy sets can be eliminated as the types of uncertainty in question. Next, consider the indicators for possibility theory. The best way to begin understanding the concept of possibility is to approach a system with the same mindset that Sherlock Holmes brought to his investigations. In other words, the famous logic of this fictitious sleuth was based on what is possible and impossible. After eliminating what was impossible necessarily led to what was possible, no matter how improbable it might seem. The theory requires that the set of possible alternatives must be mutually exclusive, or stated another way, only one alternative in the set of possible alternatives can be true. In probability theory, there is a degree of evidence assigned for each random variable x in the Universal set X, the sum of which must be 1. Or in other words, the unit interval [0,1] is distributed over all the elements in the universal set to create a probability distribution function. Possibility does not distribute a fixed unit. Each element within the set of possible alternatives is assigned the value 1, and all other elements, those that are not possible, are assigned the value 0 (Klir, 2006). A state of complete ignorance exists when all elements within the power set equal 1, (1, 1, 1, … 1). In other words, if anything is possible then you have no idea what the outcome will be; a state of complete ignorance. At the other extreme, no uncertainty exists when there is only one possible alternative (1, 0, 0, … 0).

Possibilistic uncertainty is best described linguistically as imprecision or nonspecificity. There are many construction-related examples of possibilistic uncertainty; as mentioned earlier, a worker given incomplete directions such as "3rd street", but not having the exact address, or the location of buried utilities might be described on the drawings as "east of monument A-3". There is nothing vague in either of these examples, but there is a lack of precision or specificity. For the sake of argument, what if instead the driver was given the wrong address, or the drawings had an error and should have read "east of monument B-3" instead? Based on the discussion so far it is possible to rule out fuzzy uncertainty because the linguistic descriptors are not vague. There also is no lack of precision or specificity, so this is not possibilistic uncertainty. There clearly is a mistake, or error in both examples

which could be interpreted as differing from the expected value, therefore the uncertainty here appears to be aleatory.

The last type of uncertainty to be discussed is that associated with evidence, or the lack thereof. Evidence theory is also referred to as Belief/Plausibility, which is how it will be referred to here. A belief measure is associated with a preconceived notion, and a plausibility measure is associated with the notion of information that is possible. Belief/Plausibility uncertainties are far more ubiquitous than one might realize. It is a somewhat amorphous concept that can be conceptualized in several ways. One way is to think in terms of intervals. If Belief and Plausibility are at the two ends of the "spectrum" regarding the likelihood of an event occurring, then it is easy to visualize it as an interval. Another way of gaining a sense of the character of Belief/Plausibility is to think in terms of qualitative judgment. For example, consider a construction engineer who has a great deal of experience creating CPM schedules. There are certain construction activities he has performed many times in the past, and given his current crew's numbers and skill levels he has a very good sense for how long a particular activity should take. No work-studies, time/motion analysis, or references to Means is required. This is experience and professional judgment at work. It is safe to say that this type of uncertainty may be injected into a system whenever professional judgment or experience is used to assess the outcome of a particular event. Clearly, using an educated guess or professional judgment regarding an assignment of a particular duration to a construction activity falls squarely within this uncertainty category.

Having described the characteristics of four different types of uncertainty, the next step is to develop a process to classify specific uncertain events in terms of the type of uncertainty. The need for classification arises from the fact that quantification methods are dependent on the type of uncertainty. Starting with the more easily recognizable indicators and progressing to the more difficult, Figure 1 illustrates a decision process that can be used to determine the type of uncertainty observed. The process in Figure 1 starts by asking if an event meets certain characteristics for a particular type of uncertainty. If the event does not meet these characteristics for the first type of uncertainty, then the process asks if the event meets the characteristics for the next type of uncertainty. The process continues until the event can be classified. Because the flow chart in Figure 1 only contains characteristics for four types of uncertainty, there is the chance that an event may not meet any of the criteria. However, the four types of uncertainty were selected based on the fact that they would cover the vast majority of uncertain events in a construction schedule.

CONCLUSIONS

Construction schedules are rife with uncertainty and early attempts to recognize and deal with it were based entirely on probability theory. In recent years there have been attempts by researchers and engineers to take the standard of practice to a new level by recognizing that schedules contain uncertainties for reasons beyond natural variability including incomplete, imprecise, fragmentary, unreliable, vague, or

contradictory information. Tools such as fuzzy set theory, possibility theory, and probability theory have been used individually and in combinations all in an attempt to make construction schedules as accurate as they can be. The research described here is part of a larger project intended to assign a hard number that describes the confidence one can have in a schedule. The tool that might make this possible is a Total Uncertainty algorithm that is designed to capture and combine into a single quantity all the uncertainties in a particular system; in this case a construction schedule. The first step in this process is to develop a process through which one can classify the types of uncertainties present in a construction schedule. Once uncertainties are classified, the impact of the uncertainty on the overall schedule can then be quantified using appropriate methods. From a practical viewpoint, understanding the total uncertainty associated with a schedule and the source of the uncertainty can be valuable information for a project manager. This information can be used for budgeting, planning, and schedule control purposes.

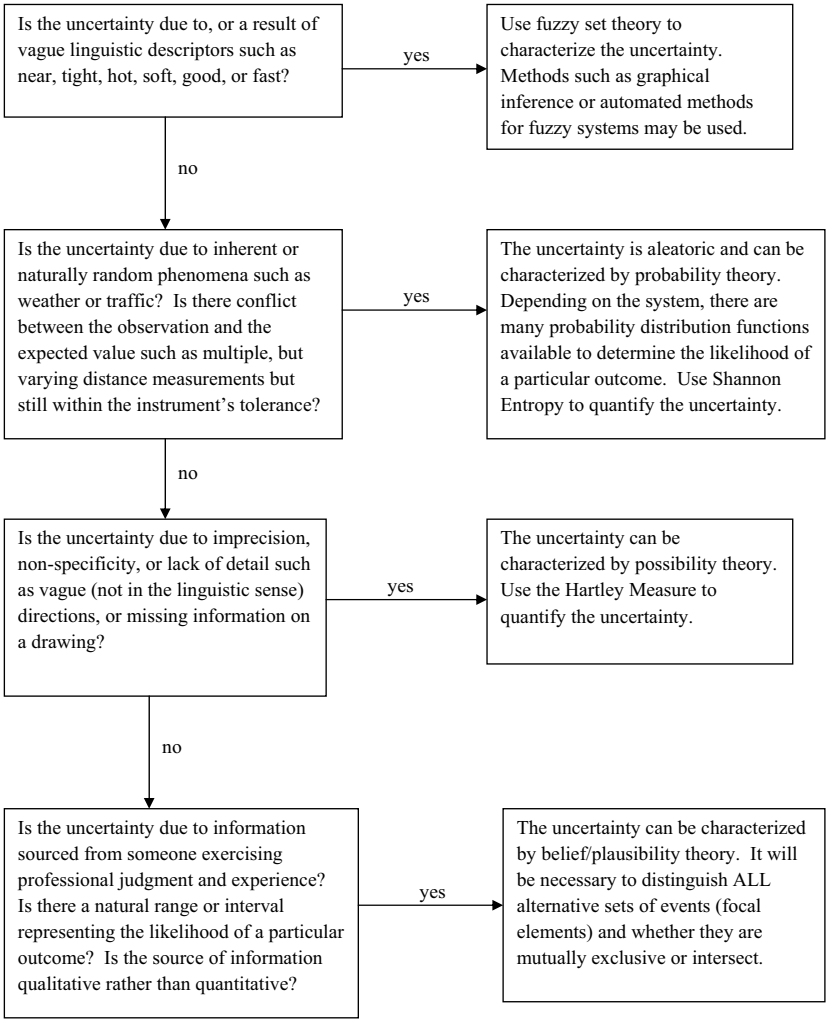


Figure 1. Flow Chart for Classifying Uncertainties

REFERENCES

Bonnal, Pierre, et al (2004). "Where do we stand with fuzzy project scheduling?" Journal of Construction Engineering and Management, v130, n1, 114-123.

Chantaravarapan, Samarn, et al (2004). "On using Monte Carlo methods for scheduling." Proceedings-Winter Simulation Conference, v2, 1870-1874.

Clough, Richard H. et.al. (2000). Construction Project Management. John Wiley & Sons, Inc. USA.

Fetz, Thomas, et al (1999). "Fuzzy models in geotechnical engineering and construction management." Computer-Aided Civil and Infrastructure Engineering, v14, n2, 93-106.

Klir, George J. (2006). Uncertainty and Information. John Wiley & Sons, Hoboken, New Jersey.

Koll, David, et all (1999). "Fuzzy models in geotechnical engineering and construction management." Computer-Aided Civil and Infrastructure Engineering, n14, 93-106.

Lei, Sou-Sen, et al (1999). "Fuzzy optimal model for construction resource leveling scheduling." Canadian Journal of Civil Engineering, v26, n6, 673-684.

Ross, Timothy (2004). Fuzzy Logic with Engineering Applications. John Wiley & Sons Ltd, England.

ASSESSMENT OF METHODS FOR ADJUSTING CONSTRUCTION COST ESTIMATES BY GEOGRAPHICAL LOCATION

Giovanni C. Migliaccio[1], Paul Zandbergen[2], Adam A. Martinez[3]

ABSTRACT

Conceptual cost estimates are fundamental to the success of construction projects. These early estimates are commonly prepared through the aid of historical data and later adjusted to take into account specific project characteristics such as location. The common practice for adjusting estimates for location is to use sets of location cost factors. When a location is not represented in the chosen data set, the nearest location factor is usually selected. The validity of this interpolation method has not been substantiated.

Geographical Information System (GIS) techniques are used to conduct spatial analysis of the RSMeans' City Cost Index (CCI) national reference data. Spatial auto-correlation of these CCI values is tested to determine the validity of the nearest neighbor interpolation method at both the national and state level. In addition, an alternative analysis between nearest neighbor and the state average CCI value methods has been performed. Findings reveal positive, nationwide correlation between proximity and CCI values. In addition, 19 individual states showed highly significant results of positive correlation between proximity and CCI value and no state showed significant negative correlation. The alternative analysis between nearest neighbor and state average was not conclusive. Half the time the nearest neighbor measure provided a better estimate, and half the time the state average proved a better measure.

Keywords: Construction Cost Estimation, Location Adjustments, City Cost Indexes, Geographic Information Systems

[1] Assistant Professor, The University of New Mexico, Department of Civil Engineering, MSC01 1070, Albuquerque, NM 87131-0001, gcm@unm.edu

[2] Associate Professor, The University of New Mexico, Department of Geography, MSC01 1110, Albuquerque, NM 87131-0001, zandberg@unm.edu

[3] Graduate Research Assistant, , The University of New Mexico, Department of Civil Engineering, MSC01 1070, Albuquerque, NM 87131-0001, tater@unm.edu

Introduction

Construction project entities, most notably owners and constructors, engage in complex and sometimes overwhelming processes in each phase of a project lifecycle. Estimating costs is a prime example of this course of action. At any stage of this progressive project lifecycle, accuracy of cost estimates contributes to the overall success or failure of a construction project. In beginning stages of a project, such as the conceptual and planning phases, estimates help owners determine financially feasibility. They rely on preliminary cost estimates for budgeting and programming purposes. While preliminary estimates are expected to have a certain degree of inaccuracy, as the project lifecycle progresses estimate accuracy is expected to improve. If these sequential estimates suggest need for additional funds, the project would go under a financial distress phase with the owner battled by the decision of securing these funds to the project or terminating the project in its current stage. Although these stages have independent factors that contribute to their degree of success or failure, a major determinant can still be attributed to cost estimation and cost estimation methods.

A generic methodology for the classification of project cost estimates is provided by the cost estimate classification system published by the Association for the Advancement of Cost Engineering (AACE International). The AACE system reinforces the concept of estimating as a continuing process by recognizing and distinguishing estimates at various phases of the project lifecycle. Table 1 summarizes this guideline as a generic cost estimate classification matrix. The most significant characteristic used to categorize cost estimate type is the degree of project definition; however, other characteristics include end usage, methodology, expected accuracy, and the time and effort needed to prepare the estimate. The system identifies five cost estimate classes during the entire project life cycle (Christensen & Dysert, 2003).

Cost estimation is an experience-driven profession that relies on both knowledge of the construction industry and historical cost information sources. Preliminary cost estimates are fundamental to the success of construction projects. AACE class 3, 4 and 5 estimates can be considered as preliminary estimates and are used for programming, feasibility and budgeting purposes. These early estimates are commonly prepared through the aid of historical data and later adjusted to take into account specific project characteristics such as location and size among others. However, "the maturity of the input information […] is a highly-important determinant of accuracy" (Christensen & Dysert, 2003; p.4). While project scope and percentage of completion are definite factors affecting accuracy, there are other considerations that should be given, especially to the quality of reference cost estimating data and the validity of estimation methods.

The method adopted to adjust cost estimates by location is a determining factor in the preliminary estimation process. The common practice for adjusting estimates by location is to use sets of location cost factors. These location factors are developed using concepts similar to the AACE-suggested factoring method (Pietlock, 2006). These factors are primarily used in preliminary stages of projects to produce conceptual estimates. According to Gould (2002), conceptual estimates are also referred to as rough order of magnitude (ROM) estimates. These estimates are

typically developed on a national average basis and must be adjusted using a corresponding location factor. Previous project cost information must also be adjusted to current or future dollars if pertinent to the current project estimate. Similarly, size of project is a factor that must be adjusted. Gould concludes his description of the ROM process by stating, "Lastly, an appropriate contingency should be applied to allow for scope adjustments as well as economic or market conditions" (p.103). All of these are factors of the estimation process and part of cost estimation methods.

This paper focuses on the validity of methods for location adjustments. Area Cost Factor (ACF) Indexes and City Cost Indexes (CCI) are examples of location factors. While the ACF indexes are useful for military projects, the CCI offer the most adopted and complete set of location factors for estimating costs of building projects. The purpose of CCI is to aid the cost estimator in adjusting for specified categories of project requirements such as general labor, equipment rental, and material costs as the geographic locations of individual construction projects vary. RSMeans includes an updated CCI set in their annual publications. This set has proven to be a very useful tool by providing cost values associated with individual city locations. While these cost index values are available for many cities throughout the United States and Canada, they do not provide values for all municipal locations within these territories. When a location is not represented in the chosen data set, the nearest state neighbor location factor is usually selected. Although this interpolation method has proven to be functional, the validity of this approach has not been substantiated. This paper uses Geographical Information System (GIS) techniques to conduct spatial analysis of the RSMeans' City Cost Index (CCI) national reference data. Spatial auto-correlation of these CCI values is tested to determine the validity of the nearest neighbor interpolation method at both the national and state level. In addition, an alternative analysis between nearest neighbor and state average CCI value methods has been performed.

Table 1: AACE Cost Estimate Classification System (adapted from AACE, 2003)

ESTIMATE CLASS	LEVEL OF PROJECT DEFINITION *Expressed as % of complete definition*	END USAGE *Typical purpose of estimate*	METHODOLOGY *Typical estimating method*	EXPECTED ACCURACY RANGE *Typical +/- range as percentage of estimated cost*	PREPARATION EFFORT *Typical degree of effort as percentage of total project cost*
CLASS 5	0% to 2%	Screening or Feasibility	Stochastic or Judgment	[+40% to +200%] [-20% to -100%]	0.005
CLASS 4	1% to 15%	Concept Study or Feasibility	Primarily Stochastic	[+30% to +120%] [-15% to -60%]	0.01-0.02
CLASS 3	10% to 40%	Budget, Authorization, or Control	Mixed, but Primarily Stochastic	[+20% to +60%] [-10% to -30%]	0.015-0.05
CLASS 2	30% to 70%	Control or Bid/Tender	Primarily Deterministic	[+10% to +30%] [-5% to -15%]	0.025-0.1
CLASS 1	50% to 100%	Check Estimate or Bid/Tender	Deterministic	[+10%] [-5%]	0.05-0.5

Research Methodology

To test the validity of the interpolation method used by RSMeans, spatial analysis was conducted through the use of Geographic Information System (GIS) technology. GIS is a tool used to conduct spatial analysis as well as statistical analysis of all cities throughout the United States with a CCI value. The results of the spatial-statistical

analysis are used to describe spatial patterns in the CCI data and the defensibility of the interpolation of CCI values. In this study, GIS technology plays an important role in analyzing cost estimation.

This study includes a threefold research methodology. First and foremost, we want to determine if autocorrelation between proximity and CCI value exists on a national level. Secondly, we want to answer this same question but at the individual state level. Lastly, we want to compare the state average CCI value with that of the closest city to determine if state average is acceptable alternative to the common practice.

The first step of the research methodology was to plot every geographic location with an RSMeans CCI value within the United States. Hawaii and Alaska were excluded from the study. From these points a graduated color scheme was created to determine if a visual relationship existed between proximity and CCI values. To examine this relationship more closely a spatial autocorrelation test was conducted. The Moran's I statistic was determined as the best testing technique for the project criteria due to the fact that it is an established measure of spatial autocorrelation. CCI data points for each state was separated into sections by state boundaries and individually tested to produce a Moran's I value for every state.

Testing was also done to produce a Moran's I value for the entire United States. In addition, state average CCI values were calculated and compared to each CCI city within the state to determine the difference, which constitutes an error factor. Similarly, an error factor was created for the difference between each CCI value and its nearest CCI value. These two errors were compared to determine if the average or the closest distance was a better method of correlation.

Data Collection and Analysis

The preliminary GIS data used in this research consists of two basic data files, (1) a vector shape file of the continental United States and (2) a point file containing more than 40,000 geocoded US cities. Within the research study area there are 649 geographical locations with a CCI value provided by *RSMeans*. These values were added to the attributes of the corresponding geocoded points. The 649 cities were then exported and made into a new data frame showing all the locations with an *RSMeans* CCI value. These points were then symbolized with a graduated color scheme as shown in figure 1.

Looking at figure 1 we can see a general visual pattern of similar CCI values in close proximities. This pattern is especially apparent in the east and west coast areas. To test the spatial correlation between proximity and CCI value, the local Moran's I tool was used on every state in the study area as a whole and individually. Delaware, Washington D.C., and Rhode Island did not contain enough data points to run the test statistic. According to Bolstad (2005):

Moran's I values approach a value of +1 in areas of positive spatial correlation, meaning large values tend to be clumped together, and small values clumped together. Values near zero occur in areas of low spatial correlation (p.412).

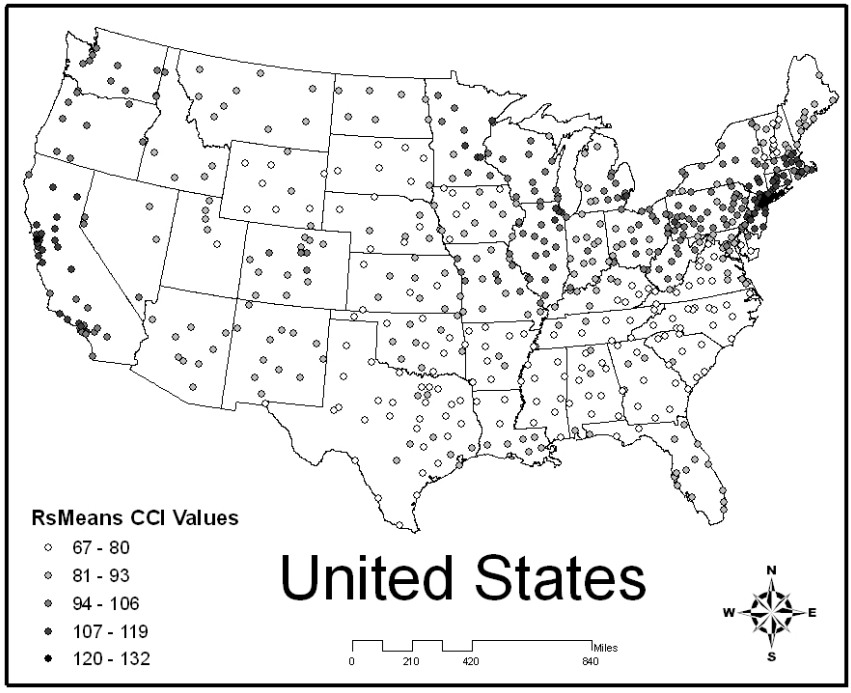


Figure 1: CCI Locations by Value

Similarly, as the Moran's I values approach a value of -1, this indicates a negative correlation, or autocorrelation. While no states had a significant negative correlation value, 24 showed a positive relation between proximity and CCI value. As part of the Moran's I test, a statistical Z value was produced. Z-values below -2 show significant evidence against the null hypothesis (proximity and CCI value is correlated), and Z-values above +2 show significant evidence supporting the null hypothesis. Table 2 shows the results of the individual Moran's I test statistic.

These results show that 25 states reported a positive, individual Moran's I value, but only 19 of them showed a Z-score value equal to or greater than 2. This means that 19 states show highly significant results of clusters of cities with closely related CCI values. In addition, the results from the Moran's I test for the entire nation showed a positive index value of 0.49 and a significance of 90.93. This indicates a very highly significant value that is between low and high spatial clustering of CCI values throughout the nation. Both testing results at the state and national levels are internal validations supporting the interpolation method used by *RSMeans.*

Table 2: Moran's I Tests Results

State/District	Moran's Index	Clustered	Z Score	Significant
ALABAMA	-0.106245		-0.476793	
ARIZONA	-0.178088		-0.473334	
ARKANSAS	-0.115634		-0.426931	
CALIFORNIA	0.820966	YES	14.042334	YES
COLORADO	-0.115919		-0.560558	
CONNECTICUT	0.041086	YES	1.825827	NO
DELAWARE	TOO FEW RECORDS			
DISTRICT OF COLUMBIA	TOO FEW RECORDS			
FLORIDA	0.101853	YES	2.225169	YES
GEORGIA	-0.048505		0.773887	
IDAHO	-0.026602		0.861344	
ILLINOIS	0.498979	YES	8.72939	YES
INDIANA	-0.028556		0.875952	
IOWA	0.050944	YES	2.459729	YES
KANSAS	-0.047728		0.669308	
KENTUCKY	0.14384	YES	3.418235	YES
LOUISIANA	0.028915	YES	1.928826	NO
MAINE	-0.14854		-0.491829	
MARYLAND	0.057158	YES	1.255529	NO
MASSACHUSETTS	0.135946	YES	2.897366	YES
MICHIGAN	0.563173	YES	5.419719	YES
MINNESOTA	0.323685	YES	2.518224	YES
MISSISSIPPI	-0.054603		0.828869	
MISSOURI	-0.019038		0.754391	
MONTANA	-0.076468		0.53581	
NEBRASKA	0.016878	YES	1.21904	NO
NEVADA	0.031196	YES	0.658152	NO
NEW HAMPSHIRE	0.313499	YES	3.296673	YES
NEW JERSEY	0.093083	YES	2.015206	YES
NEW MEXICO	0.022073	YES	2.035047	YES
NEW YORK	0.625865	YES	8.04446	YES
NORTH CAROLINA	0.130211	YES	1.702305	NO
NORTH DAKOTA	-0.233536		-0.65595	
OHIO	0.14973	YES	3.909278	YES
OKLAHOMA	-0.030998		0.940727	
OREGON	0.061146	YES	2.3324	YES
PENNSYLVANIA	0.144825	YES	5.507111	YES
RHODE ISLAND	TOO FEW RECORDS			
SOUTH CAROLINA	-0.128443		0.157375	
SOUTH DAKOTA	-0.320901		-1.823682	
TENNESSEE	-0.201274		-0.784914	
TEXAS	-0.012473		0.489588	
UTAH	-0.080554		1.387565	
VERMONT	-0.028159		1.033033	
VIRGINIA	0.5849	YES	5.595534	YES
WASHINGTON	0.326007	YES	3.852031	YES
WEST VIRGINIA	0.085484	YES	2.788805	YES
WISCONSIN	0.323674	YES	4.112459	YES
WYOMING	-0.089586		0.353008	

As an alternative to the proximity based default algorithm used by *RSMeans,* research was conducted on the state average CCI value. In figure 2 we see a graduated color map layout of the US demonstrating this substitute.

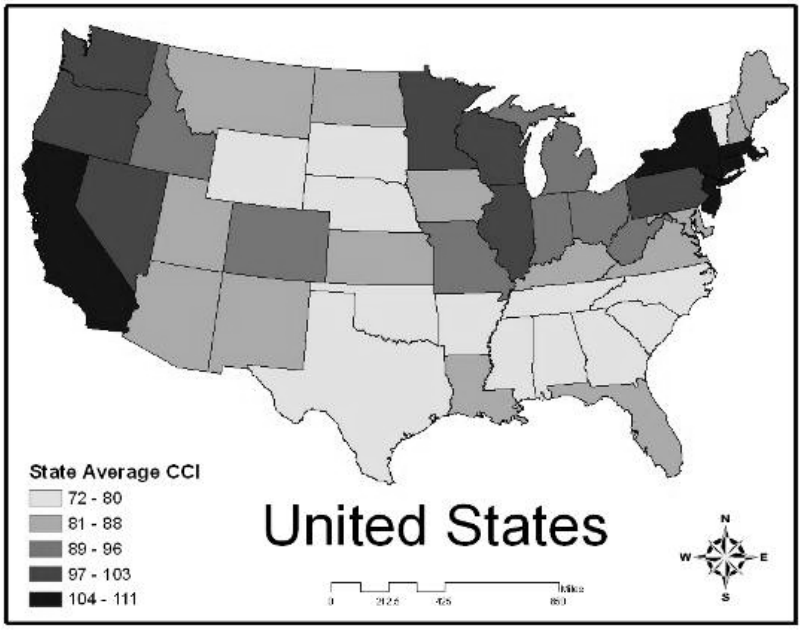


Figure 2: State Average CCI Values

Looking at figure 2, we see a similar pattern of clusters of states that have the same degree of color, meaning they have similar averages. This suggests that state average may be a likely candidate for unknown CCI locations especially those near state borders. To test this theory, an experiment was conducted on the known CCI locations. Using GIS, each CCI value was removed and compared to the individual state average and the nearest CCI value. Both of these values were subtracted from the actual value of each location creating positive and negative difference. This result is also known as the error, meaning overestimates or underestimates. To confirm that all possible combinations occur, the two variables were measured directly against each other as shown in Figure 3.

In some cases, selecting either the nearest city value or the state average value produces an overestimate (or underestimate). In other cases, one measure produces an overestimate, while the other an underestimate. The absolute values of the errors were summarized to quantify performance of the two variables. A chart was developed to determine if the values of proximity or state average was closer to the actual value of each of the 649 municipalities. In 319 cases, proximity proved to be a better method. Similarly, in 320 cases state average was a better method, and 10 cases returned inconclusive results due to equality between the two methods. Results

basically show there is a 50/50 split: half the time the nearest city measure is better, half the time the state average is better. This suggests that the use of the state average CCI value may be an alternative to the currently-used nearest neighbor interpolation method.

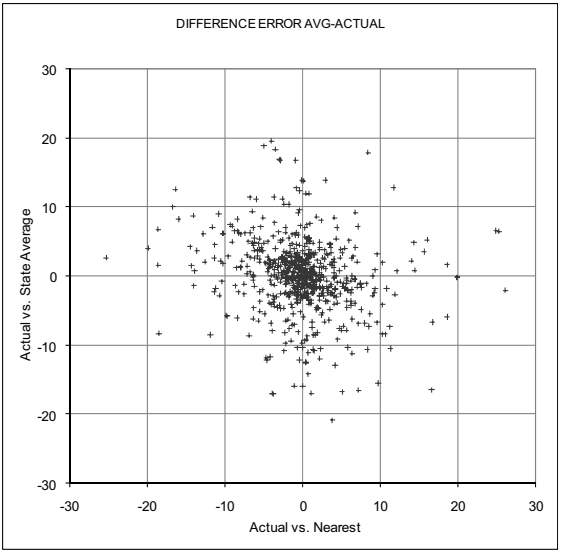


Figure 3: Comparative Analysis Results (nearest neighbor vs. state avg)

To test which variable had a higher degree of accuracy, the median absolute error was summarized. The median value for the nearest city approach is 2.30, while for the state average this is 2.56. The lower value proves a higher degree of accuracy. This is the first indication that nearest city method is slightly better. In addition, a comparison of distributions was plotted which is shown in Figure 4.

Figure 4 shows that the distributions are nearly identical, but the curve for nearest city values reflects slightly lower values, confirming this method as slightly advantageous over state average. To test the hypothesis that the nearest city measure becomes less reliable with increasing distance between CCI locations, the degree of error was measured for small and large distances. The results are shown in Figure 5, which does not support the hypothesis. Many large errors occur at small distances and many small errors occur at greater distances suggesting that the nearest city method does not become more reliable when proximity between known and unknown CCI values becomes smaller. Some unexpected patterns were found, such as the occurrence of some very large errors (> 10%), including at very short distances.

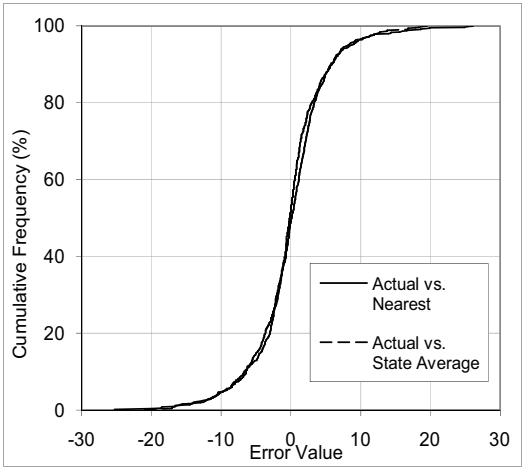


Figure 4: Comparative Analysis Results (plotted error)

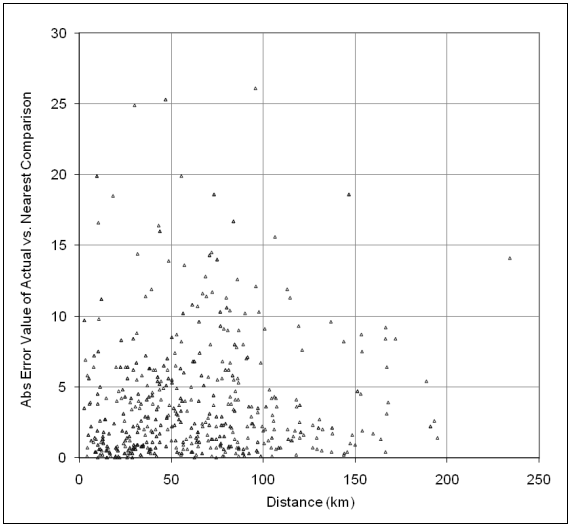


Figure 5: Proximity-Accuracy Test

Conclusions

In answering the question if RSMeans interpolation method is defensible, research conducted in this study does provide evidence that supports the use of proximity-based autocorrelation between distance and CCI value. Patterns in Moran's I values reveals strong spatial autocorrelation at both national level and state level for many states. Location adjustment methodology for both nearest city and state average perform almost equally well, with a slight advantage to nearest city. Future studies involving spatial analysis may provide for a better understanding of the relationship between state average CCI values and location adjustment methodology. A possible continuation of this study involving spatial analysis should include the variability of CCI values between states and within states to determine if state boundaries play a considerable role, as expected in construction cost estimation. Similarly, testing alternative interpolation methods, such as nearest city within state boundaries and determining patterns in outliers based on city-specific factors (e.g. population size) may prove useful. Other useful studies may test the use of other city-specific correction factors and alternative geostatistical interpolation methods.

References

Bolstad, P. (2005). *GIS Fundamentals* (2nd Ed.). White Bear Lake, MN: Eider Press.

Christensen, P., & Dysert, L.R. (2003). *AACE International Recommended Practice No. 17R-97 Cost Estimate Classisfication System.* Retrieved March 22, 2008, from http://www.aacei.org/technical/rps/17r-97.pdf

Gould, F. E. (2002). *Managing the Construction Process* (2nd ed.). Columbus, OH: Prentice Hall.

McCabe, B., O'Grady, J., & Walker, F. (2002, June). *A study of construction cost sources.* Paper presented at the Canadian Society for Civil Engineering Annual Conference. Montreal, Canada.

Pietlock, B.A. (2006). *AACE International Recommended Practice No. 28R-03 Developing Location Factors by Factoring – as Applied in Architecture & Engineering, Procurement & Construction.* Retrieved March 22, 2008, from http://www.aacei.org/technical/rps/28r-03.pdf

RSMeans. (2006). *Building Construction Cost Data* (64th Annual Ed.). Kingston, Mass: Reed Construction Data.

Walsh, E. (2008). The Estimator Shortage ~ Is There One? If There Is, What Do You Do? Retrieved March 22, 2008, from http://www.aspenational.org/PDFs/ EstimatorShortage.pdf

TIME PREDICTION FOR HIGHWAY PAVEMENT PROJECTS USING REGRESSION ANALYSIS

Ahmed M. Abdel Aziz[1]

Abstract

In the planning stages of highway projects sufficient information may not be available to apply a full scale critical path method (CPM) analysis to predict the duration and the use of approximate methods would be required. Highway agencies usually record representative information about the projects, e.g. planned and actual duration, quantities of work, project cost, and project miles. By applying a set of statistical methods to these historical records, a prediction of the duration of a project could be obtained. This paper describes the development of time prediction models through the application of general multiple regression analysis, ridge regression analysis, and nonlinear partial least-square regression analysis to project data from Washington State Department of Transportation. The models were developed using representative variables including the hot mix asphalt (HMA) quantity, grading quantities, and surfacing quantity, the number of project miles, and the contract value. Cluster analysis was used to further improve the prediction ability of the models. Through an example, the developed models were validated against an actual project data. The prediction of project duration is an important objective of highway agencies and the developed models would be helpful tools to achieve this objective.

INTRODUCTION

The aim of time prediction is to forecast the most likely number of working days required to complete a project. The accurate method for predicting project duration is to develop a *critical path method* (CPM) network, which defines all project activities, establishes the sequence/logic between the activities, and determines the duration of the activities on the basis of the quantities of work and the production rates of the work crews. However, in the planning stages, sufficient information may not be available to apply a full scale CPM analysis. Highway agencies usually record information about the planned and actual duration of a project, the quantities of work, the costs, the weather conditions during construction, and the number of miles. Applying statistical methods to these and other historical data can help predict an approximate duration of a project, where the quality of the prediction will depend on the quality of the data.

[1] Assistant Professor, the University of Washington, Box 351610, Seattle, WA, 98195; PH (206) 616-3618; FAX (206) 685 1976; amaziz@u.washington.edu

In 1995, the National Cooperative Highway Research Program (NCHRP) endorsed a study to identify the methods used by state DOTs to determine contract time for highway construction (Herbsman and Ellis 1995). Through interviews and a survey of practitioners it was found that manual methods involving the use of spreadsheets were used to determine project duration using a predefined set of controlling activities with a predefined logic and production rates. The research recommended development of historical data to support production rate determination and suggested the development of a statistical database for determining contract time.

In 2000, Hancher and Werkmeister (2000) developed a system for determining contract time for the Kentucky Transportation Cabinet (KyTC). The system determines the time for a new project based on a predefined project template comprising a set of controlling activities linked via a specific logic/sequence. Six project templates were defined to reflect the work type of six project classifications. The system runs on the software package MS Project.

In 2002, the Federal Highway Administration produced a brief guide on procedures for determining contract times (FHWA 2002). In this guide, FHWA mentioned a number of methods, including CPM calculation, bar charts, and an "estimated cost method." The estimated cost methods rely on historical information gathered in tables to illustrate project cost versus project time for different project types, traffic volumes, and geographic locations.

In 2006, Stoll et al. (2006) conducted research for the South Carolina Department of Transportation (SCDOT) to identify the best practices for predicting duration estimates, evaluate current methods, and suggest improvements to SCDOT's current methods for time prediction. Similar to the project template system developed for Kentucky, five project templates were defined to reflect work types in five project categories. For each template, critical activities and CPM logic were defined and combined with SCDOT's recorded production rates.

As with other State DOTs, Washington State Department of Transportation (WSDOT) continuously considers all possible means to increase the accuracy of the time and cost predictions of projects. This article is part of a research that addresses this effort. The objective of the article is to describe the development of regression models to predict the time of highway projects based on historical records of projects.

DATA COLLECTION AND ANALYSIS

The current work utilized data for projects awarded between 1990 and 2004, and completed in early 2006. Out of 2700 projects, 964 were selected as several records had insufficient data - for example some projects had no duration and estimates with working days more than one calendar month could have. A number of representative cost, length, and time variables were collected including contract value, asphalt concrete pavement (ACP)/hot mix asphalt (HMA) quantity (ton), pavement surfacing (ton), grading (ton, cy), and project centerline miles. Contract values were normalized to the year 2005 using the WSDOT cost index.

TIME PERFORMANCE of WSDOT PROJECTS

In an initial step toward development of prediction models, time performance of WSDOT projects and the relationships between project duration and the

representative variables were studied. Figure 1 shows the change of the average time growth percentage in relation to brackets of prime bid amounts. Time growth is measured as the percentage difference between the workable charged days for a project and the original contract days. Along with the average time growth for each bid bracket, the figure shows also the maximum value, the 95th percentile, the 5th percentile, and the minimum time growth percentage. The figure clearly establishes the substantial difference between the actual and planned project duration.

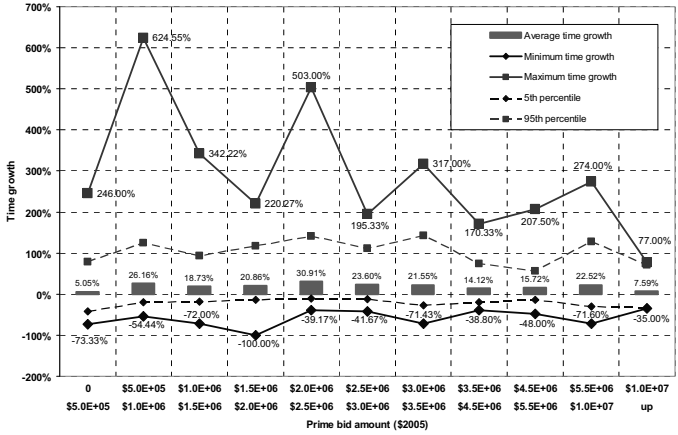


Figure 1: Time growth percentages for specified prime bid amount

Figure 2 illustrates how the workable charged days (WCD) of projects varied in relation to the prime bid amounts (PBA). A slight and steady increasing trend can be noted between the WCDs and the PBAs. This trend however was not strong with the project length and the ACP/HMA quantities where the relationship tended to be leveled or flat for the different brackets.

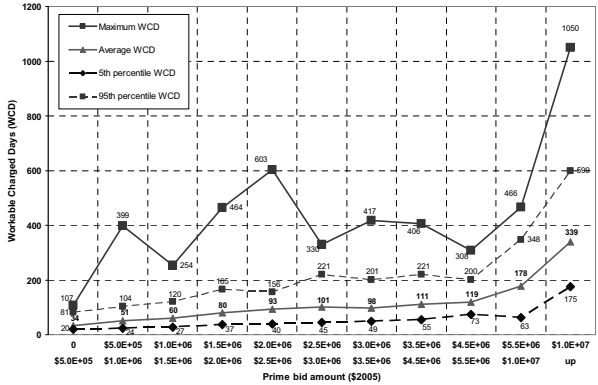


Figure 2: Variation of workable charged days against the prime bid amounts

THREE-DIMENSIONAL TIME TABLES

The work started by developing three-dimensional matrixes, characteristic tables, that give the duration when two variables change at a time. A sample of ACP/Miles table is in Table 1. For example, an average of 84 working days is obtained when 15,000 to 20,000 tons of ACP/HMA are planned for project length 2.5 to 5 miles. Similar tables were developed to give the duration for a combination of project cost and ACP/HMA, and for project cost and project miles. The tables have: the average (first line), minimum and maximum values (second line), standard deviation and the number of contracts (third line).

Table 1: Working days information for specific ACP/HMA tons and specific miles

Miles \ ACP		0 5,000	5,000 10,000	10,000 15,000	15,000 20,000	20,000 25,000	25,000 30,000	 >40,000	WCD for Miles
0	2.5	59, 15, 148, 58 , 231	83, 24, 230, 66 , 74	103, 37, 192, 52 , 27	128, 37, 337, 101 , 20	168, 52, 290, 92 , 7	149, 60, 203, 91 , 3	95, 64, 126, 48 , 2	74, 16, 202, 67 , 366
2.5	5	66, 24, 125, 59 , 50	66, 24, 168, 47 , 45	70, 29, 147, 46 , 44	84, 37, 155, 47 , 17	90, 47, 163, 43 , 15	95, 45, 174, 49 , 11	296, 79, 479, 161 , 8	83, 26, 214, 74 , 197

TIME PREDICTION MODELS

The following sections explain the development of the time prediction models. In phase one, the statistical characteristics of the variables were investigated and a preliminary regression analysis was performed. In the subsequent phases, regression analysis techniques were used to develop prediction models that would attain reasonable *mean absolute percentage error* (MAPE) values. MAPE compares the predicted duration to actual duration.

Phase I Development

The relationship between project completion time and project variables can be explained through graphical representation and through a study of the correlation between variables. Figures 3 and 4 illustrate the relationship between the WCD and project miles and ACP/HMA quantities with correlation coefficients 0.08 and 0.38. The graphs clearly establish that the relationship with both variables is not strong.

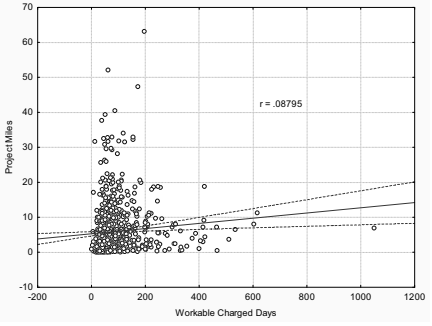


Figure 3: WCD v.s. project miles

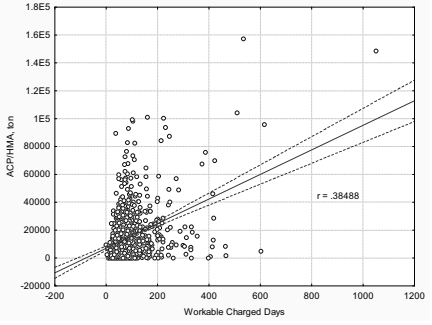


Figure 4: WCD v.s. ACP/HMA

However, an important finding from these graphs is that the relationship between WCD and the other variables may be better explained if the variables are transformed with the natural logarithms. For example, figures 5 and 6 illustrate a better linear relationship between ln(WCD) and ln(ACP) and between ln(WCD) and ln(Miles). This means that transformed variables should be considered in the models.

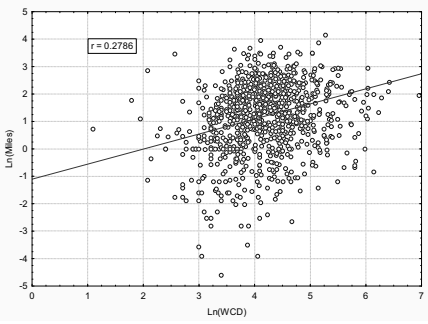


Figure 5: ln(WCD) v.s. ln(Miles)

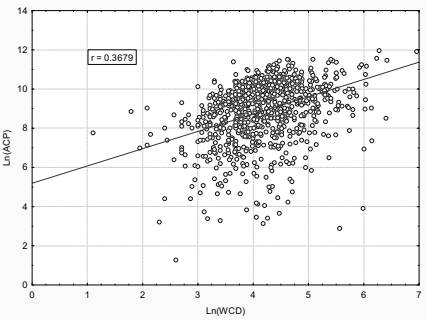


Figure 6: ln(WCD) v.s. ln(ACP)

Similar analysis was done for the WCD and the other variables - the contract value (paid-to-contractor PTC), grading and surfacing quantities. WCD had strong relationship with the PTC dollars which attained a correlation of 0.69 and 0.72 before and after transformation. Strong relationship between the dependent variable (WCD) and the independent variables is generally needed for good prediction model design.

In a first attempt at designing the prediction models, a general multiple regression model (GRM) (Dielman 2005; Makridakis et. al 1998) was applied to the original raw variables with workable charged days as the dependent variable and ACP/HMA quantity, grading (cy and ton), surfacing (ton), project miles, and contract value (paid-to-contractors PTC) as the independent variables. A best subsets regression analysis was performed using GRM. The best subset regression runs all possible regressions between the dependent variable and all possible subsets of the independent variables. Subset models are then ranked in terms of the best fit by using the coefficient of determination, R^2, an adjusted R^2, or *Mallows* C_p statistic. Table 2 illustrates a sample of the best models in the first attempt. The table shows that a number of models had negative coefficients, particularly for grading (ton and cy), which would be rejected as it convey a contradicting belief that the increase in the work quantities would reduce the duration. Multicolinearity was suspected.

Table 2: Std. coefficients using best subset regression (raw variables, no intercept)

Adj. R2	Effects	Miles	PTC	ACP	grading ton	grading cy	surfacing
0.67008	5	0.13431	0.62267	0.08968		-0.06532	0.12767
0.66974	6	0.13360	0.62416	0.09035	0.00834	-0.07230	0.12610
0.66939	5	0.13892	0.61297	0.09039	-0.04552		0.11360
0.66891	4	0.13596	0.61895	0.10023			0.07338
0.66728	4	0.17195	0.66228			-0.08125	0.14239

Figure 7 shows the normal probability plot of the six-variable model; the plot shows a violation of the normality assumption in regression analysis. In addition, Figure 8 shows a cone-shaped standardized residual plot, suggesting another violation of the constant variance assumption. This suggested the preliminary model was not appropriate for time prediction.

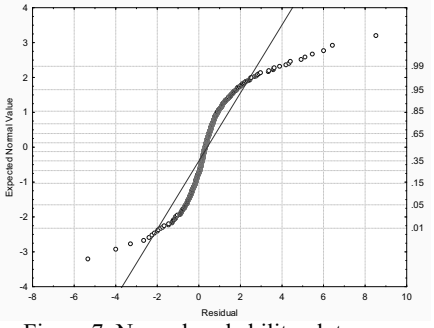


Figure 7: Normal probability plot

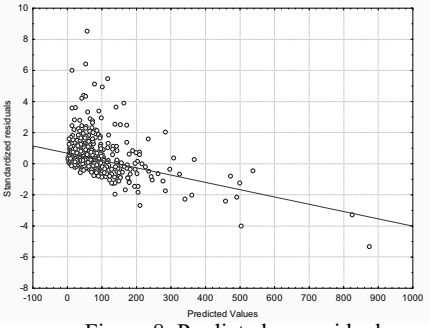


Figure 8: Predicted vs. residuals

Phase II Development

In Phase II, the dependent and independent variables were transformed using the natural logarithms. Table 3 shows a sample of the first best subset no-intercept models. In Figures 9 and 10, the probability plot and the residuals show significant improvement. Equivalent models were produced with intercept; their Adjusted R2 values were below those in Table 3.

Table 3: Std. coefficients of best subsets and transformed variables (no intercept).

Adj R2	Effects	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (grad. ton)	Ln (grad. cy)	Ln (surfacing)
0.98794	5	0.0128	0.8295	-0.0641	0.1751		0.0493
0.98793	4	0.0132	0.8518	-0.0565	0.1941		
0.98792	3	0.0090	0.7983		0.1943		
0.98791	4	0.0082	0.7746		0.1791		0.0395
0.98790	6	0.0126	0.8308	-0.0652	0.1838	-0.0125	0.0528

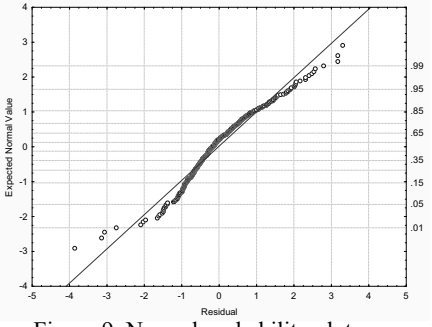


Figure 9: Normal probability plot

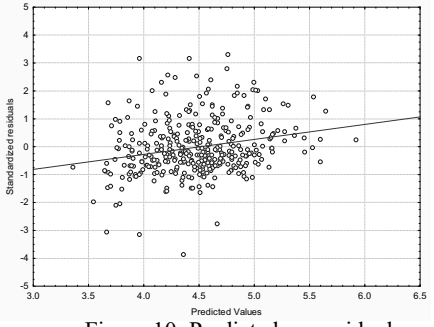


Figure 10: Predicted vs. residuals

As shown in Table 3, the ACP/HMA, grading (cy), and miles had negative coefficients, suggesting multicolinearity. The six-variable model had tolerance values approaching zero and large variance-inflation-factor (VIF) values, see Table 4.

Table 4: Multicolinearity in six-variables GRM model (no intercept)

Adj R2	Tolerance	VIF
Ln(Mileage)	0.502419	1.99037
Ln(PTC05)	0.010447	95.72163
Ln(ACP)	0.014435	69.27436
Ln(Grading ton)	0.012782	78.23704
Ln(Grading cy)	0.010106	98.94826
Ln(Surfacing ton)	0.013255	75.44112

One of the common methods for dealing with the multicolinearity effects is "Ridge" regression analysis (Dielman 2005; Kutner et al. 2005). Ridge regression uses a procedure to artificially decrease the correlations between the variables so that more stable beta coefficients can be obtained. A constant (lambda) is added to the diagonal of the correlation matrix, which is then re-standardized, and the off-diagonal elements are divided by the constant. Therefore, the values of lambda are increased to the point at which multicolinearity is reduced. For example, Table 5 shows the results for the no-intercept six-variable model, which, when compared to Table 4, shows improvement when Ridge regression is applied.

Table 5: Six-variables Ridge model (no intercept; 0.15 lambda)

Adj R2	Tolerance	VIF	Coefficient
Ln(Mileage)	0.770404	1.29802082	0.064900
Ln(PTC05)	0.202697	4.93346962	0.073366
Ln(ACP)	0.209983	4.76228266	0.098155
Ln(Grading ton)	0.211642	4.72495776	0.083372
Ln(Grading cy)	0.207070	4.8292918	0.083268
Ln(Surfacing ton)	0.199047	5.02394257	0.099831

General nonlinear partial least square regression (PLS) is another regression analysis method (Rannar et. al 1994; de Jong, 1993; Geladi and Kowalsky 1986). PLS transforms the original predictor variables into factor scores by using linear combinations of the original predictors. The objective is to have no correlation between the factor score variables, which are then used in the predictive model. In this sense, multicolinearity is dealt with.

The development of models for the research started with the regression models (GRM) in Phase 1, and if negative parameters or multicollinearity was found, then Ridge regression was used. Then PLS was used to compare results with those of the Ridge regression. The best model was selected based on MAPE. For example, Table 6 shows the results for the six-variable model. The last two "GRM" models were rejected because of their negative coefficients. The same process was repeated for model combinations of two to five variables. Table 7 shows the best models without the contract value (PTC) variable (Table 8 has contract value). The models were numbered, e.g. 4.3, 4 refers to four-variable models and 3 to the model number in this category), and a suffix P means a model with PTC contract value.

Table 6: Regression results for the six-variable time prediction model

Regression	Adj R2	MAPE	Intercept	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (Grad. Ton)	Ln (Grad. Cy)	Ln (Grad. Cy)
Ridge	0.4807	**0.3405**	0.1576	0.0146	0.2058	0.0306	0.0370	0.0316	0.0483
PLS	0.9906	**0.3642**	0.0126	0.0126	0.1647	0.0904	0.0382	0.0389	0.0605
Ridge	0.9540	**0.4016**		0.0649	0.0734	0.0982	0.0834	0.0833	0.0998
GRM	0.9879	**0.3980**		0.0344	0.2586	-0.032	0.0902	-0.006	0.0285
GRM	0.5987	**0.3472**	-3.66	-0.074	0.5522	-0.045	0.0893	-0.041	0.0194

Table 7: Subset of the best time prediction models without contract value

Model	Reg.	Adj R2	MAPE	Intercept	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (Grad. Ton)	Ln (Grad. Cy)	Ln (Grad. Cy)
4.3	GRM	0.46399	**0.37709**	2.09200	0.06149		0.06855	0.10264		0.09002
5.1	GRM	0.45602	**0.38111**	2.06996	0.06165		0.07143	0.07527	0.03186	0.08547
3.1	Rdg.	0.43001	**0.38122**	1.92910			0.10522	0.08838		0.09362
4.1	GRM	0.45456	**0.38691**	1.72118			0.12223	0.07597	0.02500	0.08696
2.2	GRM	0.45011	**0.38704**	1.98808			0.13220	0.13893		

Table 8: Subset of the best time prediction models with contract value

Model	Reg.	Adj R2	MAPE	Intercept	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (Grad. Ton)	Ln (Grad. Cy)	Ln (Grad. Cy)
P5.2	Rdg.	0.49931	**0.30707**	0.39454	0.03301	0.20628		0.03501	0.02802	0.04935
P4.2	Rdg.	0.44748	**0.33015**	0.22879		0.20399	0.04015		0.04309	0.05204
P5.3	Rdg.	0.47518	**0.33897**	0.06827	0.01128	0.21762	0.02922	0.04933		0.06072
P5.1	Rdg.	0.48088	**0.33955**	0.06851		0.21102	0.03394	0.03682	0.03104	0.04903
P6.1	Rdg.	0.48067	**0.34052**	0.15763	0.01464	0.20585	0.03064	0.03704	0.03164	0.04829

Phase III Development

It was decided to seek enhancing the prediction ability of the models using cluster analysis. Cluster analysis allows using a number of classification algorithms to organize observed data into meaningful structures; the *k-means* clustering algorithm was used, Tables 9 and 10. Tables 11 to 14 show the models for cluster #1 (26k tons to 160k tons) and for cluster #2 (0 to 26k tons). Clustering slightly improved the MAPE values.

Table 9: Clustering based on ACP variance

ACP Clusters	Between SS	Within SS	# in C1	# in C2	# in C3	# in C4	# in C5	# in C6
2	1.893448E+11	1.151274E+11	173	789				
3	2.528505E+11	5.162170E+10	43	258	661			
4	2.729557E+11	3.151647E+10	24	124	267	547		
5	2.832719E+11	2.120033E+10	20	61	157	229	495	
6	2.898917E+11	1.458051E+10	14	33	103	162	230	420

Table 10: Characteristics of ACP/HMA clusters

Clusters	Min	Max	Mean	SD	#
1	26,226.4	157,293.43	44,342.67	20,375.36	173
2	0	26,001.64	7,812.42	7,448.69	789

Table 11: Cluster #1 of 2 – Subset of the best time models "without" contract value

Model	Reg.	Adj R2	MAPE	Inter-cept	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (Grad. Ton)	Ln (Grad. Cy)	Ln (Grad. Cy)
3.1	Rdg	0.93701	**0.35754**				0.16323	0.13981		0.16192
2.1	Rdg	0.89629	**0.37680**				0.20377			0.23134
4.1	Rdg	0.93311	**0.37765**				0.13227	0.10279	0.10249	0.12746
3.2	Rdg	0.92152	**0.37823**				0.15482		0.14009	0.16033

Table 12: Cluster #1 of 2 – Subset of the best time models "with" contract value

Model	Reg.	Adj R2	MAPE	Inter-cept	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (Grad. Ton)	Ln (Grad. Cy)	Ln (Grad. Cy)
P3.2	Rdg	0.94113	**0.30233**			0.10392	0.14543	0.14541		
P4.1	Rdg	0.95165	**0.32405**			0.08265	0.11555	0.10641		0.12013
P3.3	Rdg	0.94084	**0.33054**			0.10441	0.14566		0.14176	
P3.1	Rdg	0.94180	**0.33119**			0.10001	0.13775			0.16178

Table 13: Cluster #2 of 2 – Subset of the best time models "without" contract value

Model	Reg.	Adj R2	MAPE	Inter-cept	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (Grad. Ton)	Ln (Grad. Cy)	Ln (Grad. Cy)
5.1	Rdg.	0.47248	**0.34230**	2.18549	0.07907		0.07153	0.08476	0.01657	0.06971
4.3	GRM	0.48445	**0.34342**	2.14943	0.07957		0.07328	0.10105		0.07247
3.1	GRM	0.46089	**0.35032**	1.85084			0.11236	0.09519		0.08102
4.1	Rdg.	0.42638	**0.35185**	2.00006			0.10105	0.06771	0.02541	0.07695

Table 14: Cluster #2 of 2 – Subset of the best time models "with" contract value

Model	Reg.	Adj R2	MAPE	Inter-cept	Ln (Miles)	Ln (PTC)	Ln (ACP)	Ln (Grad. Ton)	Ln (Grad. Cy)	Ln (Grad. Cy)
P5.2	Rdg	0.44442	**0.31228**	0.61920	0.02945	0.19465		0.03681	0.02645	0.04280
P6.1	Rdg	0.42859	**0.32225**	0.46193	0.01544	0.18574	0.03272	0.03766	0.02604	0.04604
P5.3	Rdg	0.42300	**0.34998**	0.16399	0.02067	0.21438	0.02676	0.04634		0.05957
P3.2	Rdg	0.38932	**0.35209**	0.24315		0.22503	0.04737	0.05213		

Example for Using Time Prediction Models

Contract WSDOT # 6708 (2004) at 110 actual days is shown in Table 15.

Table 15: Contract #6708 in 2004

year	Contract #	Miles	PTC 05	ACP/HMA	Grad. ton	Grad. cy	Surfacing Ton	WCD
2004	6708	15.92	3382380.43	37618.30	91823.00	91823.00	1031.30	110

Using a miles/ACP characteristic table, it was obtained: 87 days average, 65 minimum, 108 a maximum, and **97** days by interpolation; which compared well with the actual days.

Using the models developed herein, the predicted time was obtained, as shown in Table 16. The average was **114** working days and **100** working days with and without the contract value. Both represented good prediction in comparison to the original contract value.

Table 16: Predicted completion time for contract #6708 (2004)

Model #	Predicted WCD	MAPE	Model #	Predicted WCD	MAPE
4.3	**119**	8.49%	P5.2	**105**	4.93%
5.1	**123**	11.61%	P4.2	**97**	12.04%
3.1	**110**	0.33%	P5.3	**106**	3.57%
4.1	**117**	6.78%	P5.1	**112**	1.37%
2.2	**144**	30.73%	P6.1	**114**	3.57%
…	**…**	…	…	**…**	…
Average	**114**	4.06%		**100**	9.41%

SUMMARY AND CONCLUSIONS

Through statistical analysis of WSDOT historical projects, time prediction tables were developed in which project duration can be obtained for two variables at time. To improve the prediction ability, models were developed to predict completion time (working days) using general multiple regression models, Ridge regression models, and nonlinear partial least-square regression models. Models were also developed using cluster analysis, and a slight improvement were obtained over those of the full sample models. The models developed in this research could be used to select a model that match the available information.

Given that only six variables were used, the MAPE values obtained would be considered reasonable for predicting completion time. Better models would be obtained to address some shortcomings, e.g. by addressing the weather conditions for the project, addressing the seasons in which the project will be built, and developing a lane-mile equivalent for projects.

REFERENCES

De Jong, S (1993) "SIMPLS: An Alternative Approach to Partial Least Squares Regression.", *Chemometrics and Intelligent Laboratory Systems*, 18, 251-263.

Dielman, T. (2005). "Applied Regression Analysis: A Second Course in Business and Economic Statistics." Brooks/Cole.

Federal Highway Administration (FHWA) (2002). "FHWA guide for construction contract time determination procedures." http://www.fhwa.dot.gov/legsregs/directives/techadvs/t508015.htm

Geladi, P., & Kowalski, B. R. (1986). "Partial Least Squares Regression: A Tutorial/", *Analytica Chimica Acta*, 185, 1-17.

Hancher, D. E., and Werkmeistr, R.F. (2000). "Kentucky contract time determination system." Kentucky Transportation Center, Lexington, KY.

Herbsman, Z. J., and Ellis, R. (1995). "Determination of Contract Time for Highway Construction Projects." NCHRP Synthesis Report 215, Transportation Research Board, Washington, D.C.

Kutner, M., Nachtsheim, C., Neter, J., and Li, W. (2005). "Applied linear statistical models – fifths edition." McGraw-Hill, New York.

Makridakis, S., Wheelwright, S., and Hyndman, R. (1998). "Forecasting methods and applications – third edition." John Wiley & Sons, NJ.

Rannar, S., Lindgren, F., Geladi, P, and Wold, S. (1994). "A PLS Kernel Algorithm for Data Sets with Many Variables and Fewer Objects. Part 1: Theory and Algorithm.", *J. of Chemometrics*, 8.

Stoll, B., O'Reilly, J., and Bell, L. (2006). "Methodologies for determining construction contract time and evaluating contract time extension." South Carolina DOT, Rep 652, SC.

DEVELOPMENT OF PEOPLE-BASED MAPS EXPERIENCE MANAGEMENT SYSTEM FOR CONSTRUCTION PROJECTS

Yu-Cheng Lin[1]

ABSTRACT

Experience management refers to the processes governing the creation, storage, reuse, maintenance, dissemination and evaluation of experience relevant to a particular situation or problem-solving context. In the construction industry, experience can be reused and shared among the involved engineers and experts to enhance construction processes and minimize costs and problem solving time. This study proposes a novel and practical People-Based Maps (PBM) approach to capture and represent engineer experience and project knowledge This approach enables users to survey and access the experience of previous engineers and experts in similar projects and to appropriately assess their tacit and explicit experience. This study applies Experience Management principles to the construction phase of construction projects and develops a Construction Assistant People-based Map Experience Management (APMEM) system for contractors. The APMEM system is then applied in a Taiwan high-tech science park construction project to verify the proposed methodology and demonstrate the effectiveness of sharing previous experience in the construction phase. Experience can be captured and reused to benefit future projects by effectively utilizing people-based maps and web technology during the construction phase of a project. The combined results of this study indicate that an APMEM system can provide an effective experience management platform for other construction projects by adopting a people-based maps approach.

.

INTRODUCTION

Construction experience transfer is the application of knowledge gained in previous projects to maximize current project objectives (Reuss and Tatum, 1993). Acquired knowledge and skills can be called “experience” (Manavazhi, 1995). Experience is what individuals have done and thoughts that have occurred to them previously (Davenport and Prusak., 1998). Although knowledge management (KM) is well established in the construction industry, experience management (EM) is a new concept in information systems. Knowledge management is a collection of processes governing creation, storage, reuse, maintenance, dissemination and utilization of knowledge. Two broad categories of experience are tacit and explicit experience.

[1] Assistant Professor, Department of Civil Engineering, National Taipei University of Technology, No.1.Chung-Hsiao E. Rd., Sec.3, Taipei, Taiwan, E-Mail: yclinntut@gmail.com

Tacit experience is personal, context-specific experience that is difficult to formalize, record or articulate, and is stored in the minds of people (Malhotra, 2000). Explicit experience can be codified and transmitted in a systematic and formal language and can be acquired from documents, including reports, articles, manuals, patents, pictures, images and video (Malhotra, 2000; Tiwana, 2000). Useful experience can be recorded in different forms and media, such as in the minds of experts, in operating procedures or documents, databases and intranets. Effective experience management in the construction industry effectively and systematically transfers experience among engineers.

This study is concerned with experience as it relates to knowledge acquired via pervious construction projects. To enhance the quality of experience management gained by engineers involved in construction projects, this study presents a novel People-based Maps (PBMs) approach that generates experience management solutions in the construction industry. Combined with web-based technology and PBMs, this study presents a novel Construction Assistant People-based Map Experience Management (APMEM) system that enables engineers to reuse domain knowledge (knowledge is acquired from humans in a special area) and experience by dynamically exchanging and managing experience during the construction phase of a project. In the proposed APMEM system, the map-based experience exchange environment enables engineers to manage and dynamically share their experience with other engineers. Engineers are thus invited to exchange and share their experience, and construct valued content through their own experience. In this study of a Taiwanese construction building project, survey (questionnaire) results indicate that the APMEM system integrated with the PBMs approach is effective in construction experience exchange and management.

PROBLEM STATEMENT

In the context of construction management, problems encountered in projects can serve as references for working on similar projects. When completing projects, engineers and experts usually accumulate domain knowledge and valuable experience and do not share this experience with others. Experience management is an experience-intensive task in which available and reusable experience is extremely useful to engineers. Moreover, senior engineers participating in projects and acting as knowledge workers may facilitate collection and management of experience. To be competitive, a contractor must accumulate experience through previous projects and apply it to relevant projects. However, no appropriate platforms exist to assist engineers or experts in exchanging and sharing their know-how and experiences during construction projects. Additionally, few suitable platforms have been developed to assist engineers in sharing their experiences when needed. Although enterprises in the A/E/C industry have begun collecting and storing explicit information in enterprise databases, they have not always been successful at retrieving and sharing tacit experience (Woo et al., 2004). Therefore, sharing and using tacit experience in construction projects is the primary objective of this study.

RESEARCH OBJECTIVES

This study presents novel approaches for managing and reusing specific experience during construction projects. The PBMs methodology captures and represents

engineer experience and project knowledge. The APMEM system facilitates dynamic experience exchange and management services in the construction phase of a project for reuse of domain knowledge and experience. By integrating the PBMs and web-based technology, engineers can acquire problem solutions and experience directly from senior engineers, which decreases time and cost associated with on-the-job training. The APMEM system serves users by requesting assistance from selected engineers or all engineers in an enterprise who have relevant experience via submission of a problem description via PBMs. Furthermore, senior and junior engineers can effectively and easily exchange knowledge and experience through PBMs that is related to a specific aspect of a construction project.

To apply experience management to new or existing construction projects, the process and content of experience acquired from projects must be collected, recorded and saved in a system. To assist participating engineers in recording and managing their experience, PBMs help engineers explore their experiences acquired from projects. The primary objectives of this study are as follows: (1) enhance the experience sharing from engineers and experts related to construction projects using the PBMs approach; (2) efficiently communicate tacit experience among engineers in various construction environments and, (3) provide a web-based platform and maps for users to acquire the required experience from engineers. The APMEM system is then applied to a selected case of a Taiwan high-tech construction project to verify the efficacy of the proposed approach and the value of sharing experience during construction projects.

BACKGROUND RESEARCH

Experience management is the process of collecting, modeling, storing, reusing, evaluating and maintaining experience (Bergmann, 2002). Experience management in construction projects promotes an integrated approach for the creation, capture, sharing and reuse of profession-based domain knowledge obtained from previous projects. Numerous research efforts have focused on knowledge management applications in the construction industry. A Hong Kong study examined the main barriers to effective knowledge sharing and the critical factors and benefits associated with construction companies in Hong Kong and the United Kingdom (Fong and Chu, 2006). Intelligent representation structures store and access construction domain knowledge, and combines the knowledge types with advanced planning tools to facilitate rapid formulation and assessment of initial construction project plans (Udaipurwala and Russell, 2002). The activity-based knowledge concept and system for contractors enhance construction knowledge management work (Tserng and Lin, 2004). Moreover, a construction web-service knowledge management environment was proposed to improve informed sustainable practices (Wetherill et al., 2007).

Knowledge maps are knowledge management tools (Van den Berg and Popescu, 2005). A knowledge map includes sources, flows, points of knowledge within an organization (Liebowitz, 2005). All captured knowledge can be summarized and abstracted through a knowledge map (Lin et al., 2006). A knowledge map also provides a blueprint for implementing a knowledge management system. Numerous studies have focused on use of knowledge maps to support various knowledge management tasks (Woo et al., 2004; McAleese, 1998). Davenport and Prusak (1998) observed that development of a knowledge map involves locating significant

knowledge in an organization and publishing a list or picture that indicates where the knowledge is located. A Mind Map (Buzan and Buzan, 1993) diagram presents the structure of ideas in an associative manner, resembling how ideas are stored in the brain.

BACKGROUND RESEARCH

The proposed PBMs are specific approaches to construction experience management. Although knowledge and concept maps are not new to knowledge management, the proposed PBM approach is a novel concept and specific to construction experience management. People-based maps can be diagrammatic and graphic presentations of experience linking relationships between experience and people attributes. The PBMs primarily assist in the acquisition of necessary experience easily and effectively. The primary advantages of using PBMs are as follows: (1) engineers can easily understand and determine which engineers and experts have special experience related to a problem; (2) the maps enhance visual experience illustration between construction projects and participants; (3) users can edit their experience based on PBMs; and, (4) PBMs methodology helps users identify the experience most relevant to a project.

Framework of People-based Maps

People-based maps have multiple levels, and are constructed from variables that can be broken down by decomposing experience units into relatively smaller map units into which acquired experience is saved. PBMs can have several layers. The first layer generally models an enterprise or departmental/organizational unit. This layer presents an overview of available knowledge in the context of enterprise departments. The project unit is modelled in the second layer. This project layer mainly is an overview of available knowledge in the context of all enterprise projects. The third level layers model activity units (network illustration) or groups of activities. This activity layer primarily presents an overview of available activity-related knowledge associated with a particular project. The low layers are then modelled in people units (people illustration). This people unit is an overview of available special domain people linkages. Similarly, any map unit in this low layer can be broken down to incorporate other components in the low layers. Map contents can be viewed as a single point or as ranges. The structure of PBMs enables users to access experience through layers based on attributes and types of acquired experience. Experience saved in map units of a project map includes both tacit and explicit experience. Explicit experience can comprise an experience topic, experience description and experience attachments (documents, reports, drawings and other explicit sources). Tacit experience may include problem descriptions, explanations of problem solutions, suggestions, and know-how explanations. Furthermore, PBMs provide users with an overview of available and unavailable experience in core project areas, enabling appropriate management of tacit and explicit experience. This tacit and explicit experience in map-based experience management is the same as the duration and relationship of project-based project management. Identifying the relationship between current and previous map units is significant for users seeking to link related experiences. Current project experience can be utilized and the same or similar map units from previous projects can be accessed when recording experiences. Of course, the proposed system is designed to automatically or manually link

activities that are extremely similar.

PBMs have components and procedures based on construction project management and, thus, differ from existing knowledge maps. The proposed PBMs consist of ten components. These ten components are number of experiences, number of people, experience topics, experience layers, experience relationships, experience owners, experience diagrams, experience packages, experience attributes, and similar experiences. Procedures are presented for constructing PBMs based on an experience management framework. The procedure consists of the following six primary phases: experience determination; experience extraction; experience attribute; experience linking; experience validation; and, experience sharing.

DEVELOPMENT OF THE APMEM SYSTEM

The APMEM system is run on Microsoft Windows 2003 with an Internet Information Server (IIS) as the web server. The prototype is developed using Java Server Pages (JSPs), which are easily incorporated with HTML and JavaScript technologies to transform an Internet browser into a user-friendly interface. Figure 1 show the system concept and framework.

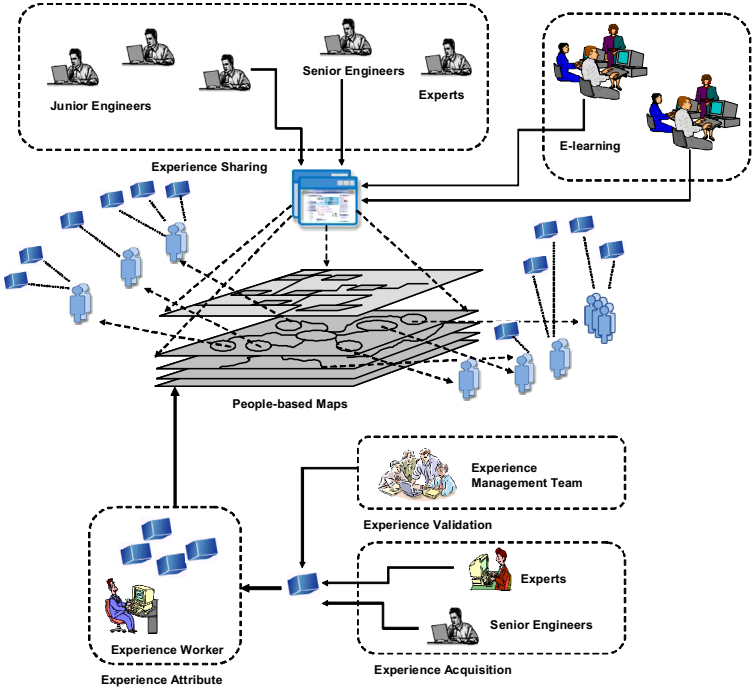


Fig. 1. System concept and framework

The APMEM system server supports four distinct layers: interface, access, application and database layers. Each layer has its own responsibilities. The interface

layer defines administrative and end-user interfaces. Users can access information via web browsers such as Microsoft Internet Explorer or FireFox. Administrators control and manage information via the web browser or using a separate server interface. The access layer provides system security and restricted access, firewall services and system administration functions. The application layer defines various applications for collecting and managing information. These applications offer indexing, experience maps, digital photo/video management functions, full text searching, collaborative work and document management functions. The database layer consists of a primary Microsoft SQL Server 2003 database. The web and database servers are on different computers. A firewall and virus scanning can used to protect the system database against intrusion.

The APMEM system allows project category searches, keyword searches and expert category searches. The keyword search and project category functions enable users to access the needed knowledge directly from activities of selected projects. The system also provides another service for users to find related knowledge according to related experts. Those related particular experts can contribute their knowledge to users seeking knowledge thought the APMEM system. One main feature of the APMEM system is that is enables users to request assistance in experience sharing and exchange from specific engineers or all engineers in an enterprise by submitting a request or problem description through the PBMs. Users can select experienced engineers from the PBMs to request assistance or send the problem directly to the APMEN system to request further assistance.

CASE STUDY AND SYSTEM EVALUATION

The APMEM system was utilized in the Taiwan high-tech construction project to verify the efficacy of the proposed methodology and demonstrate the effectiveness of sharing experience during construction. This case study was undertaken for a 13-month construction project with a schedule that had approximately 5337 activities. Moreover, all engineers were encouraged to explore and edit their own experience in the APMEM system. Figure 1 presents the experience-sharing interface in the APMEM system.

During the experience acquisition phase in the case study, tacit experience can be transferred into explicit experience by senior engineers and knowledge workers. The knowledge workers and senior engineer initially generated a main experience map based on the original project plan. After the main map was generated, experienced senior engineers were invited to edit their experiences in the map. All engineers had to record their own experience relative to the tasks for which they were responsible. Each engineer created an experience map and summarized their experience and domain knowledge in the map to enable solution reuse in future projects. When the submitted experience was approved, the system showed the process for submission automatically, and an assistant in the EM team classified the experience by placing it in an appropriate position (map units in the experience map) in the system. That is, users can directly access related experience by clicking on map units in the multilevel experience maps. In the experience storage phase, all experience was centralized and stored in the central database to avoid adding redundant data. The performance of all experience maps was validated before the experience maps were published. The junior engineers utilized Assistant Services to

request the assistance and find two engineers who generated similar project reports. The two junior engineers found experts and retrieved, referred to and studied the experience (including descriptions, digital video and documentation) provided by these senior engineers. The two junior engineers began applying this knowledge to their own project. Furthermore, the two junior engineers provided experience-based feedback and offered their own experience after completing their project. Moreover, this experience is then updated when feedback and another solution to the same problem are added. The updated experience set was republished in map units of the experience map after completing the approval process, and a notice was transmitted to authorized members.

During field trials, verification and validation tests were performed to evaluate the proposed system. The verification test assessed whether the APMEM system performed the tasks specified in system analysis and design. The validation test selected case participants to use the system, who then provided feedback via a questionnaire. The APMEM system was installed on a general contractor's main server during field trials. A user guide and two APMEM system workshops were provided to teach users about the APMEM system. Use of the APMEM system was demonstrated for respondents, who were then requested to express their opinions of the system via the questionnaire. Figure 2 presents the experience-sharing interface in the APMEM system.

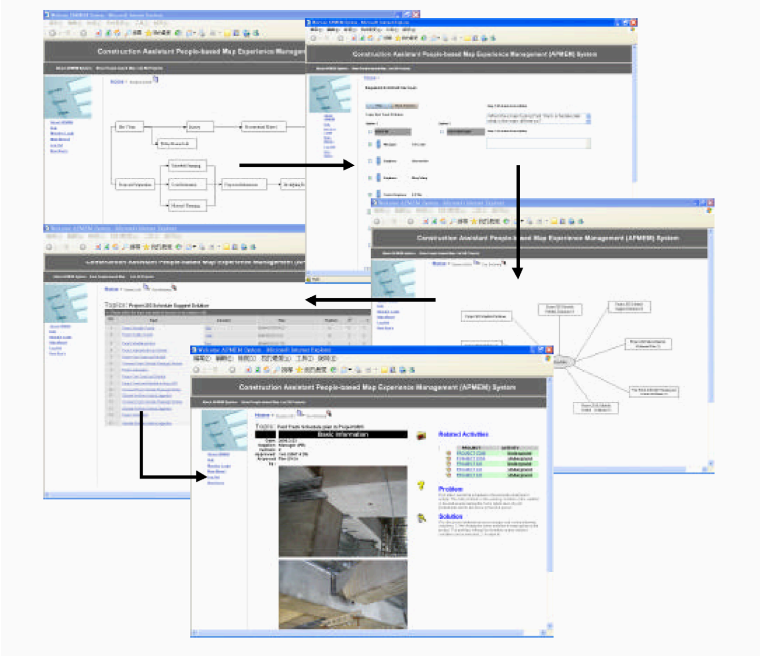


Fig. 2. Experience Sharing Interface of the APMEN System

To evaluate system functions and user satisfaction with system capabilities, questionnaires were distributed. System users were asked to grade system conditions, system function and system capability on a five-point Likert scale, ranging from 1 for "not useful" to 5 for "very useful." The next section presents the detailed results of the performance evaluation and the general contractor satisfaction survey conducted during field trials (Table 1). Based on the user-satisfaction survey, participants gave an average of 91% on their satisfaction in experience sharing that the APMEM system enabled engineers to exchange and share their experience using PBMs to express their ideas and thoughts. Furthermore, the user-satisfaction rate of 88 %, indicating that the PBMs provided clear and dynamic representations of experience and effectively identified engineers with experience and knowledge related to the project. Participants gave an average score of 89% for the easiness and convenience in requesting assistance.

Table 1. System Evaluation Result

The functionality and usage of system	**Mean Score**
Ease of Exchanging Experience	4.8
Reliability	4.4
Applicable to A/E/C Industry	4.7
User Interface	4.6
Over Information Sufficiency	4.7
Over System Usefulness	4.5

The capability of system	**Mean Score**
Reduce Communication Problems	4.8
Reduce Unnecessary time	4.5
Reduce Rework Percentage	4.5
Reduce Lost of Experience Problems	4.3
Ease of Finding Experienced Engineers or Experts	4.6
Ease of Finding Related Experience	4.7
Enhance Experience Updating Problems	4.4
Improve Experience Sharing Problems	4.5

Note: the mean score is calculated from respondents' feedback on fivescale questionnaire: 1(Strongly Disagree), 2, 3, 4 and 5 (Strongly Agree)

Use of the APMEM system assists engineers in communicating their ideas and sharing their experiences. The primary advantages of the APMEM system, based on questionnaire results, are as follows. (1) the APMEM system enables users to survey and access the tacit and explicit experience of engineers and experts who have worked on similar projects. (2) the APMEM system enables users to request experience support and exchange experience with selected engineers or all enterprise engineers by submitting problem descriptions through PBMs. (3) the APMEM system enables users to find the needed knowledge and experience from experienced participants. (4) the APMEM system enables users to exchange explicit/tacit experience with engineers.

The use of PBMs mainly helps engineers communicate their knowledge easily and effectively. Questionnaire results indicate that the primary advantages of PBMs in the system are as follows: (1) PBMs provide clear and dynamic representations, thus identifying the experience and knowledge of engineers relevant to a project; (2) the PBMs clearly identify available engineers or experience when requesting special experience and knowledge for a current project; and, (3) users can find needed experience easily and effectively.

The suggestions are made based on received feedback as follows: (1) The policy and strategy must be reworded to encourage and enrich experience content; (2) Further effort is needed to update explicit/tacit experience related to various projects in the system; (3) Knowledge workers (senior engineers and experts) require substantial time and assistance to edit and record their experience; (4) The willingness of participant to share experiences should be improved.

CONCLUSIONS

This study presented a novel and practical methodology for capturing and representing the experience and knowledge of engineers using the PBMs approach. Moreover, this study developed an APMEM system that provides dynamic experience exchange and management services for reuse of domain knowledge and experience. The PBMs divide experience into map units, thus forming an effective experience management tool for construction projects. The APMEM system enables engineers to exchange and share their experience using PBMs. The integration of experience management and PBMs is a promising means of enhancing construction experience management during construction. Effective integration of web technology in the APMEM system has been demonstrated by the case study of a Taiwan high-tech construction project. Overall, field test results indicate that the APMEM system is an effective and simple platform for construction experience management. Furthermore, observation results result show that the APMEM system significantly enhanced progress in the process and management of construction experience. The APMEM system minimizes communication of ineffective experience sharing among engineers in a collaborative environment. Further work on construction experience management will involve the further system development using advanced experience maps and automated capture functions for engineers working on construction projects.

ACKNOWLEDGMENTS

The authors would like to thank the National Science Council, Taiwan, for financially supporting this research under contract number NSC 95-2221-E-027-143-.

REFERENCES

Bergmann, Ralph (2002), Experience Management: Foundations, Development Methodology, and Internet-Based Applications, Springer, Berlin.

Buzan, T. and Buzan, B., (1996), The Mind Map Book: How to Use Radiant Thinking to Maximize Your Brain's Untapped Potential, Penguin Group, USA.

Davenport, T.H. and Prusak, L. (1998), Working Knowledge: How Organizations Manage What They Know, Harvard Business School Press, Boston.

Fong, P. S. W. and Chu, L. (2006), Exploratory Study of Knowledge Sharing in Contracting Companies: A Sociotechnical Perspective. Journal of Construction Engineering and Management, 132(9), 928-939.

Liebowitz, J. (2005), Linking Social Network Analysis with the Analytic Hierarchy Process for Knowledge Mapping in Organizations, Journal of Knowledge Management, Vol. 9 No.1, 76-86.

Lin, Y. C., Wang, L. C. and Tserng, H. P. (2006). "Enhancing Knowledge Exchange through Web Map-based Knowledge Management System in Construction: Lessons Learned in Taiwan." Journal of Automation in Construction, Vol. 15 (6), pp.693-705.

Malhotra, Y. (2000), Knowledge Management and Virtual Organizations. Idea Group Publishing, Hershey, PA.

Manavazhi, M. R. (1995). "Case-based Reasoning and Hypermedia: Enabling Technologies for Construction Experience Transfer." Technical Report # 102, Center for Integrated Facility Engineering, Stanford University, CA, August 1995.

McAleese, R. (1998), The Knowledge Arena as an Extension the Concept Map: Reflection in Action, Interactive Learning Environments, Vol. 6 No. 1, 1-22.

Reuss, Mark C. and Tatum, C. B. (1993). "Requirements and Tools for Transferring Construction Experience between Projects." Technical Report # 78, Center for Integrated Facility Engineering, Stanford University, CA, Feb 1993.

Tiwana, A. (2000), The Knowledge Management Toolkit – Practical Techniques for Building a Knowledge Management System. Prentice-Hall, New Jersey.

Tserng, H. P. and Lin, Y. C. (2004). "Developing an Activity-based Knowledge Management System for Contraction Projects." Journal of Automation in Construction, Vol. 13 (6), pp.781-802.

Udaipurwala, A. and Russell, A.D. (2002), Computer-assisted Construction Methods Knowledge Management and Selection. Canadian Journal of Civil Engineering, 29(3), 499-516.

Wetherill, M., Rezgui, Y., Boddy, S., and Cooper, G. S. (2007). Intra- and Interorganizational Knowledge Services to Promote Informed Sustainability Practices. Journal of Computing in Civil Engineering, 21(2), 78-89.

Woo, Jeong-Han, Clayton, Mark J, Johnson, Robert E., Flores, Benito E., and Ellis, Christopher (2004), Dynamic Knowledge Map: Reusing Experts' Tacit Knowledge in the AEC Industry. Journal of Automation in Construction, 13(2), 203-207.

APPLICATION OF THE RESOURCE-CONSTRAINED CRITICAL PATH METHOD TO MULTIPLE CALENDARS AND PROGRESSED SCHEDULES

Jesús M. de la Garza[1] and Kyunghwan Kim[2]

[1]Vecellio Professor, Charles E. Via, Jr. Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24061-0105, chema@vt.edu

[2]Assistant Professor, Department of Architectural Engineering, Konkuk University, 1 Hwayang-dong, Gwangjin-gu, Seoul 143-701, Korea, kykim@konkuk.ac.kr

Abstract

This paper presents an application case study of the Resource-constrained Critical Path Method (RCPM). RCPM is a heuristic algorithm to identify resource-dependent activity relationships (resource links) during resource-constrained scheduling. Through resource links, the schedule provides reliable activity floats and the critical path, which traditional resource-constrained scheduling techniques hardly provide. A prototype RCPM system is developed based on the algorithm. The RCPM system is integrated with Primavera Project Planner (P3), so it imports the project data directly from a P3 project, performs required RCPM procedures, and updates the P3 project to establish an RCPM schedule. The system is also equipped with functions to handle PDM logic relationships, multiple calendars, and progressed schedules. This paper briefly reviews the key elements of the RCPM procedures and demonstrates how it can be applied to a P3 schedule that consists of multiple calendars and a progress stage. The presence of Phantom Float in P6 is also illustrated.

Introduction

The Critical Path Method (CPM) is a popular scheduling and control technique in the construction industry. With the critical path and the float amount of each activity, CPM provides the time-criticality level of each activity to the project completion time. In addition, with technological activity relationships in the network, CPM provides a stable work sequence after rescheduling upon schedule changes such as change orders, delays, or accelerations (Li and Willis 1993). Despite of these benefits, CPM has one significant disadvantage in considering resource availability.

Some resources are highly limited in most construction projects and these limited resources can determine the startability of certain activities. However, CPM itself does not consider resource limits, so the CPM schedule cannot be a realistic schedule unless all resource limit conditions are resolved (Clough et al. 2000). For this reason, US courts expects a resource-loaded schedule in delay impact analysis (Wickwire et al. 2001). In order to reflect these limited resources, a number of resource constrained

scheduling (RCS) techniques have been developed (Ahuja 1976; Kelley 1963). In general, when activities are competing for limited resources, the RCS technique delays the start times of some activities, based on a certain priority rule, to reflect current resource availability. Thus, there is no resource limit violation in the schedule after RCS. However, the RCS technique has two significant disadvantages compared to the CPM technique.

First, activity float data in RCS, unlike in CPM, is no longer trustworthy (Fondahl 1991, Bowers 1995; Kim 2003; Kim and de la Garza 2003; Lu and Li 2003; Wiest 1964; Woodworth and Shanahan1988). In CPM, the start time of an activity is decided by the activity relationships in the CPM network. In RCS, however, the start time is decided not only by the activity relationships in the CPM network, but also by the resource constraints. Thus, activities delayed by resource constraints during RCS contain resource dependent relationships with other activities. The traditional RCS technique does not recognize these resource dependent activity relationships, creating incorrect late times and floats. Non-existing float in the schedule of RCS is referred to as Phantom Float in Kim and de la Garza (2003). Leading project management software such as Primavera Project Planner (P3) or MS-Project creates phantom float in a resource-constrained schedule because no practical way to identify the resource dependencies is currently available. Since real floats are unknown in a resource-constrained schedule, every activity has to be treated as a critical activity, resulting in a serious burden for the project manger.

Second, the work sequence in RCS, unlike in CPM, may not be stable after rescheduling upon schedule changes (Li and Willis 1993). This problem results from the activity priority orders in the traditional RCS technologies. The activity order can be changed anytime with schedule changes, resulting in a different work sequence. Additional time and cost will be necessary to reorganize the changed work sequence.

In order to overcome the problems in CPM and RCS, the Resource-constrained Critical Path Method (RCPM) is proposed by Kim and de la Garza (2003). RCPM identifies resource-dependent activity relationships (resource links) during resource-constrained scheduling. Through resource links, the schedule provides reliable activity floats, the critical path, and stable work sequence with schedule changes, which traditional resource-constrained scheduling techniques hardly provide. This paper briefly reviews the key elements of the RCPM procedures and demonstrates how it can be applied to a P3 schedule that consists of multiple calendars and a progress stage. Since multiple calendars also have the ability to break up the critical path, readers are referred to (Kim and de la Garza 2005, Lu and Lam 2008) for an in-depth discussion of the issues brought up my multiple calendars.

RCPM Review

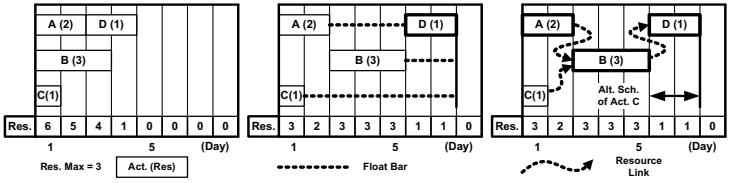
RCPM is a 5-step heuristic algorithm, which establishes a CPM-like resource-constrained schedule by the technological relationships in the original CPM schedule and by the resource links identified from the RCPM processes. Table 1 shows the overview of the RCPM processes. Step 1 performs traditional CPM calculations. Based on the CPM data, step 2 performs serial resource constrained scheduling, during which resource links are created if an activity is delayed due to resource constraints. One or more relationships to the delayed activity are created from certain

activities that have caused the activity delay and that have released the delay-caused resources with completion. Step 3 calculates late start and finish times through a backward pass considering both technological and resource links. In step 4, every activity that has non-zero total float is checked if the total float is available for the whole period. Resource links are created if the total float is not available due to resource constraints. The output of step 4 becomes the final schedule of RCPM, but one more step is performed to provide more flexibility to the schedule. Step 5 identifies alternative schedules for some activities that can be scheduled beyond late finish times determined by the resource links.

Table 1. RCPM Algorithm Process Overview

Step	Function
1	CPM forward and backward passes
2	Serial resource constrained scheduling, making resource links
3	Backward pass with technological and resource links
4	Finding unidentified resource links
5	Finding alternative schedules

Fig. 1 demonstrates the outputs of CPM, RCS, and RCPM on the same schedule. With maximum availability of three resource units, the CPM schedule is not realistic because the first three days are over the resource limit. With RCS, the resource condition is satisfied, but only one activity (*Activity D*) is critical, the critical path is broken, and the float of *Activities A, B,* and *C* cannot be trusted because of the existence of Phantom Float (Kim and de la Garza 2003). With RCPM, the resource dependent activity relationships are identified, the float of each activity is reliable, and the critical path is continuous. Here, the resource links *A – B* and *B – D* are created in the RCPM step 2 and the resource link *C – B* is created in step 4. As an alternative schedule, *Activity C* can be scheduled for day 6 and 7, which are beyond its late finish time determined by the resource link.



(a) CPM **(b) RCS** **(c) RCPM**

Fig. 1 CPM, RCS, and RCPM Comparison

A prototype system has been developed based on the algorithm. In order to make the system practical for real construction projects, the RCPM system is equipped with functions to handle PDM logic relationships, multiple calendars, and progressed schedules.

Case Study: Initial Schedule

The case study schedule includes two calendars and all four PDM relationships. As shown in Table 2, each activity contains an ID, a calendar ID, duration, resource

requirements, and successors. Each successor is represented by an activity ID and a PDM relationship type with a lag.

A P3 project can contain up to 31 different calendars, and each calendar can have a unique pattern of standard workdays per week, holidays, and exceptions. P3 also provides a *Global Calendar* of which holidays and exceptions are applied to all other calendars. An exception date is a working day that is initially a holiday or a standard non-workday of the week. In this case study schedule, *Calendar 1* has 5 standard workdays per week, and *Calendar 2* has 3 workdays per week. Table 3 shows holidays and exceptions in the *Global Calendar* and individual calendars, and Fig. 2 illustrates the two calendars including all the time information.

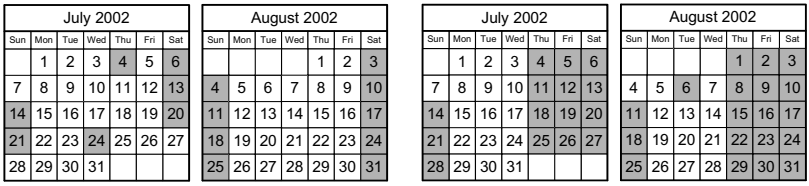
Fig. 3 shows the PDM network of the schedule, and Fig. 4 is the P3 CPM output. Fig. 5 is the RCS output, in which the critical path is broken and most activities contain large amount of floats due to the existence of Phantom Float.

Fig. 6 is an RCPM system output that shows identified resource links from the initial schedule. Fig. 7 is a modified PDM network after the resource links are inserted into the initial network. In this Figure, a curved line represents a resource link. The resource links can be inserted to the original P3 network upon user's request within the RCPM system. Once all resource links are inserted to the original P3 schedule, then the P3 schedule, shown in Fig. 8, becomes an RCPM schedule.

With these inserted resource links, running CPM in P3 now considers resource constraints and provides reliable floats and the continuous critical path. In addition, *Activity 15*, as shown in Fig. 9, can be scheduled any time between 27 and 29 July, which are beyond its LFT as marked in Fig. 8.

Case Study: Progress Update

At the end of the first week after the project has started, the schedule has been updated based on the actual progress as shown in Table 4. Activity 1, 2, and 5 are on schedule, but Activity 7 requires four more days with the same daily resource requirement to finish. Fig. 10 shows the updated RCPM schedule in P3. The finish time delay of Activity 7 has delayed Activity 9 and its subsequent activities based on the technological and resource links.



(a) Calendar 1: 5 days/week **(b) Calendar 2: 3 days/week**

Fig. 2 Calendars in Case-II Schedule

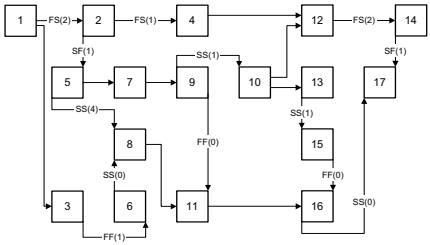


Fig. 3 PDM Network of the Case Schedule

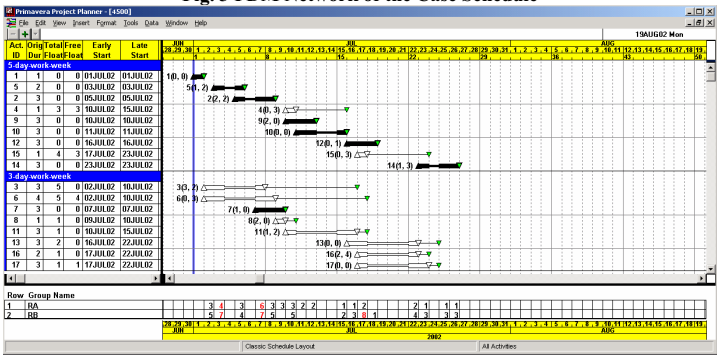


Fig. 4 CPM Output of the Case Schedule in P3

Table 2. Case Schedule Activity Data

ID	Cal.	Dur.	Resources		Successors
			A	B	
1	1	1	0	0	2: FS(2) 3: FS(0)
2	1	3	2	2	4: FS(1) 5: SF(1)
3	2	3	3	2	6: FF(1)
4	1	1	0	3	12: FS(0)
5	1	2	1	2	7: FS(0) 8: SS(4)
6	2	4	0	3	8: SS(0)
7	2	3	1	0	9: FS(0)
8	2	1	2	0	11: FS(0)
9	1	3	2	0	10: SS(1) 11: FF(0)
10	1	3	0	0	12: FS(0) 13: FS(0)
11	2	3	1	2	16: FS(0)
12	1	3	0	1	14: FS(2)
13	2	3	0	0	15: SS(1)
14	1	2	1	3	17: SF(1)
15	1	1	0	3	16: FF(0)
16	2	2	2	4	17: SS(0)
17	2	3	0	0	
Max. Resource			3	6	

Table 3. Holidays and Exceptions

	Global Calendar	Calendar 1	Calendar 2
Holidays	July 4	July 24	August 6
Exception	July 7	July 27 ~ July 28	August 4

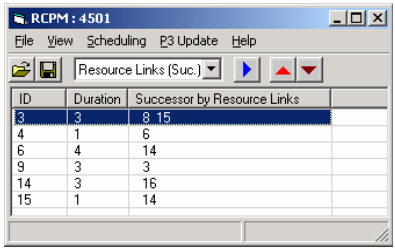


Fig. 6 Resource Links from the RCPM System

Once a schedule is updated, it is necessary to re-apply RCPM. Huge computation time is required in order to find all resource dependencies between parallel activities in a real construction project with thousand activities and with dozens of resources. Thus, RCPM employs a heuristic approach to save time, checking the resource dependency between activities only for the range of each activity's total float. Any changes in the base schedule could invalidate the initial conditions, so re-applying RCPM is required.

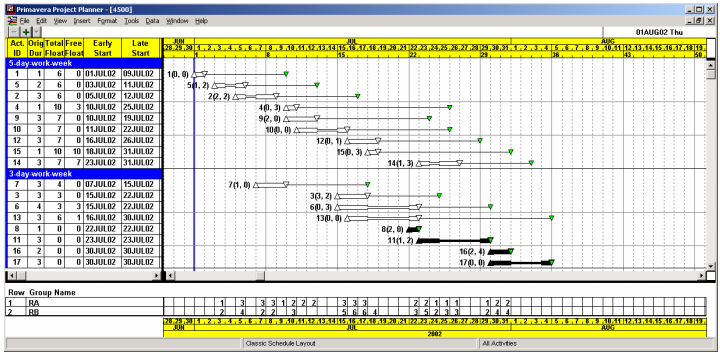


Fig. 5 RCS Output of the Case Schedule in P3

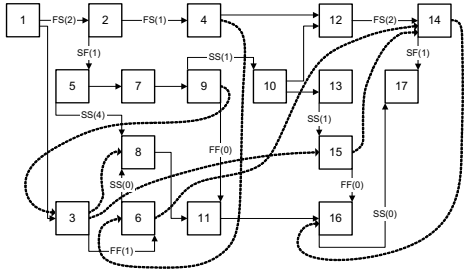


Fig. 7 RCPM Network of the Case Schedule

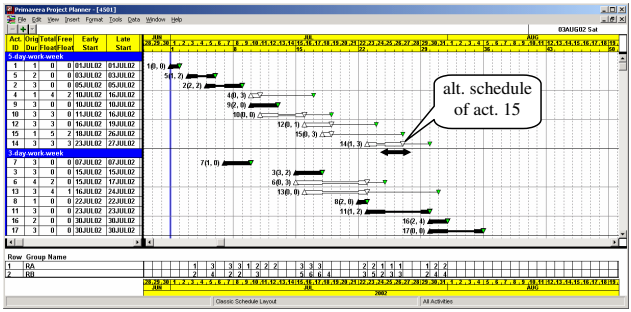


Fig. 8 RCPM Output of the Case Schedule in P3

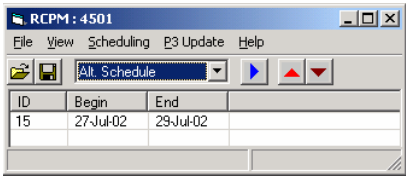


Fig. 9 Alterative Schedules from the RCPM System

Table 4. Progresses as of July 7

Act. ID	Actual Start Time	Actual Finish Time	Remaining Duration
1	July 1	July 1	0
2	July 5	-	1
5	July 3	July 5	0
7	July 7	-	6

After applying RCPM again, a new resource link between *Activity 2* and 9 is identified. *Activity 2* had a zero total float due to the SF (1) relationship to *Activity 5* in the initial schedule (see Fig. 8). Now in the progressed schedule, this relationship is no longer required since *Activity 5* was started and thus a 9-day total float is available for *Activity 2* (see Fig. 10). This 9-day total float of *Activity 2* is not totally available because of *Resource A* and *Activity 9*. Both *Activities 2* and *9* require four units of *Resource A* (two units for each) for July 18~19, but the limit of it is three. Fig. 11 shows the RCPM schedule with the additional resource link between *Activity 2* and *9*, which produces a 7-day total float for *Activity 2* showing that 2 out of the 9 days of total float in Fig. 10 is Phantom Float.

Without the use of RCPM, P3 generates Fig. 12, which shows the rescheduled RCS output after the update from the initial RCS schedule (Fig. 5). In this chart, each activity has an early bar on the top and a target bar (the initial RCS output in Fig. 5) on the bottom. It has one-day earlier completion date compared to the progressed RCPM schedule (Fig. 11). However, in addition to present Phantom Float in this RCS schedule, the activity sequence has significantly changed compared to the target schedule. For example, *Activity 9* and *10* precede *Activity 3* and *6* in the target schedule, but their order is now reversed in the updated schedule. Additional cost and time may be required to accommodate this change.

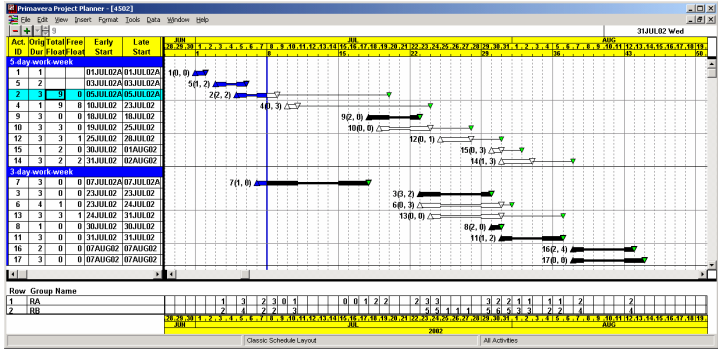


Fig. 10 Progressed RCPM Schedule

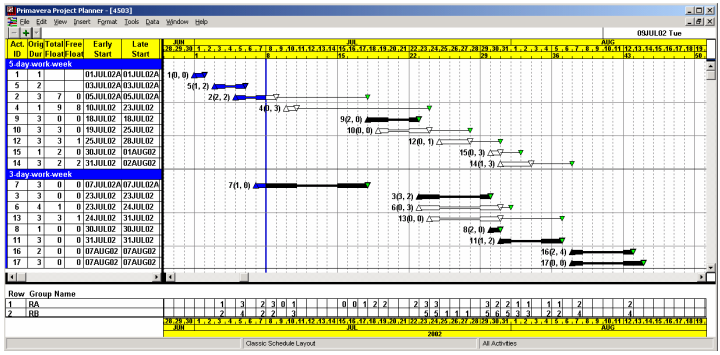


Fig. 11 Progressed RCPM Schedule with Additional Resource Link

RCPM is applied to the Fig. 12 schedule to test if the RCPM system works with this progressed schedule (no resource link identified or included in this schedule) and to compare the result with the progressed RCPM schedule shown in Fig. 11. RCPM performs well with this schedule, creating a different set of resource links compared to the progressed RCPM schedule (Fig. 11). Fig. 13 shows the result after all resource links are incorporated. In this schedule, *Activity 4* can be scheduled for 30 ~31 July, which is beyond its LFT, as marked in Fig. 13. If *Activity 4* is scheduled on 30 July, *Activity 15* should be one day delayed to avoid resource overuse on that date.

Phantom Float in P6

P6 considers resource dependency for activities that are delayed due to resource limit. However, it does not clearly identify resource dependency for activities that are not delayed by resource limit. An example CPM schedule is shown in Fig. 14 and its RCS output with P6 is shown in Fig. 15. Due to resource limit, activities B and D are delayed and the late times of them are updated according to resource dependency between activities A and B and activities B and D. Although P6 does not explicitly create those resource relationships between delayed activities, it can be assumed that P6 reflects the resource dependencies and appropriately update late times of the activities. In this way, it generates a continuous critical path as shown in Fig. 15. Up to now, P6's performance is better than P3's performance because activity D is the only critical activity in P3. However, there is still a question on activity C, which has 6-day total float. Since activity C requires one resource and the maximum availability of the resource is three, it cannot be concurrently executed with activity B. If resource dependency between activities C and B is considered, the total float of activity C should be 1-day, hence P6 is reporting 5 days of Phantom Float. Based on this result, it can be concluded that although P6's output looks better than P3's result, we still should not trust the output after RCS with P6.

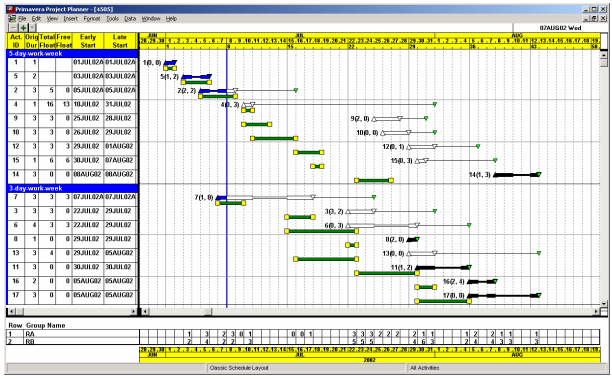


Fig. 12 Progressed P3 RCS Schedule

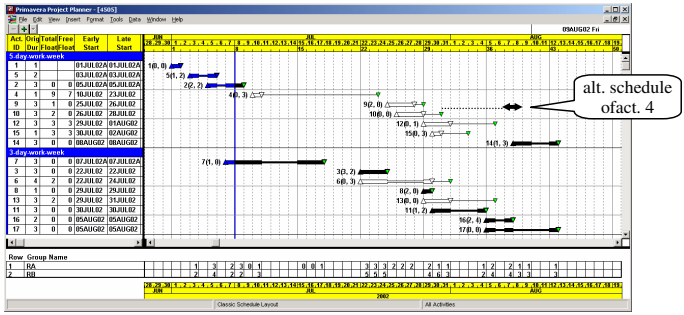


Fig. 13 RCPM Schedule with Progressed Schedule

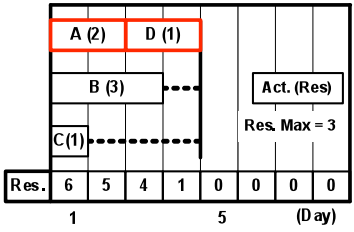


Fig. 14 CPM Schedule

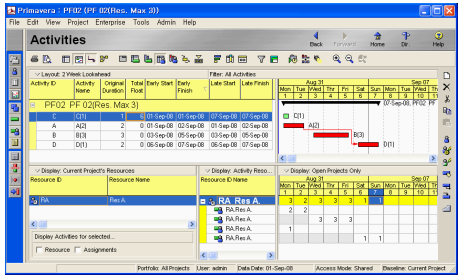


Fig. 15 RCS result in P6

Summary and Conclusions

A construction schedule should consider resource availability; otherwise, the schedule does not correctly represent the project condition. However, current resource constrained scheduling techniques produce Phantom Float and a broken critical path, which could trigger severe disputes among project participants (Fondahl 1991). This paper demonstrates how the Resource-constrained Critical Path Method

(RCPM) can be adapted for scheduling and control phases in real construction projects that normally contains multiple calendars and a number of progress stages. With identified resource links, the RCPM schedule provides reliable float data, the critical path, and stable work sequence with schedule updates. With these features, RCPM also can be adopted for delay impact analyses in a resource-loaded schedule. Further studies such as activity split option, resource links with PDM relationships, and variable resource availability, will be necessary to further enhance the capability of the RCPM.

References

Ahuja, H. N. (1976). *Construction Performance Control by Networks*, John Wiley & Sons, New York, NY.

Bowers, J. A. (1995). "Criticality in Resource-constrained Networks." *Journal of the Operational Research Society*, 46(1), 80-91.

Clough, R. H., Sears, G. A. and Sears S. K., (2000). *Construction Project Management, 4th Ed*, John Wiley & Sons, New York, NY.

Fondahl, J. W. (1991). "The development of the construction engineer: Past progress and future problems." *Journal of Construction Engineering and Management*, ASCE, 117(3), 380-392.

Kelley, J. E. Jr. (1963). "The Critical-Path Method: Resource Planning and Scheduling." *Industrial Scheduling*, Prentice Hall, Englewood Cliffs, NJ, 347-365.

Kim, K. (2003). "A Resource-constrained CPM (RCPM) Scheduling and Control Technique with Multiple Calendars" PhD Dissertation, Virginia Tech, Blacksburg, VA.

Kim, K. and de la Garza, J. M. (2003). "Phantom Float." *Journal of Construction Engineering and Management*, ASCE, 129(5), 507-517.

Kim, K. and de la Garza, J. M. (2005). "Critical Path Method with Multiple Calendars." *Journal of Construction Engineering and Management*, ASCE, 131(3), 330-342.

Li, R. K, and Willis, R. J. (1993). "Resource Constrained Scheduling Within Fixed Project Durations." *Journal of the Operational Research Society*, 44(1), 71-80.

Lu, M. and Li, H. (2003). "Resource-Activity Critical-Path Method for Construction Planning." *Journal of Construction Engineering and Management*, ASCE, 129(4), 412-420.

Lu, M. and Lam H. (2008). "Critical Path Scheduling under Resource Calendar Constraints." *Journal of Construction Engineering and Management*, ASCE, 134(1), 25-31.

Wickwire, J. M., Driscoll, T. J., and Hurlbut, S. B (2001). *Construction Scheduling: Preparation, Liability, and Claims, 2001 Cumulative Supplement*, Aspen Law & Business, New York, NY.

Wiest, J. D. (1964). "Some Properties of Schedules for Large Projects with Limited Resources." *Operations Research*, 12, 395-418.

Woodworth, B. M., and Shanahan, S. (1988). "Identifying the Critical Sequence in a Resource Constrained Project." *International Journal of Project Management*, 6(2), 89-96.

VALIDATING RENOVATION PHASING SCHEDULES USING 4D MODEL BASED METHODS

Peggy Ho[1] and Martin Fischer[2]

ABSTRACT
Scheduling major renovation work in an occupied building represents a major challenge to project managers. Multiple stakeholder requirements from the owner, building occupants, and renovation crews must all be satisfied within a tightly constrained physical environment. This paper describes a renovation planning framework and prototype system that enables project managers to explicitly define and automatically check renovation requirements. The framework is based on and extends 4D model based methods. A case study is presented to show how the framework was used to analyze and compare renovation phasing schedules on a building renovation project. The results indicate that the framework enables better identification of scheduling issues and alternatives.

KEYWORDS: renovation, 4D, scheduling, requirements, occupant

INTRODUCTION

As the need to manage and maintain the existing building stock increases, the efficient renovation of capital facilities becomes increasingly important. Failure to adequately plan phased renovations can lead to increased schedule duration, costs, and increased stakeholder tension. Renovation projects, however, differ from new construction projects such that traditional project management methods (e.g., CPM schedules, spreadsheets) do not accommodate the unique characteristics of renovation projects. First, there are many more constraints on the renovation method and schedule due to the design of the existing building and the scope of the renovation work. Second, in phased renovations, where occupants remain in the building during construction, there are additional constraints on the renovation schedule because the occupants' business operations must continue.

[1] PhD Candidate, Civil and Environmental Engineering, Stanford, CA 94305

[2] Professor, Civil and Environmental Engineering and (by courtesy) Computer Science, Stanford, CA, 94305

Our literature review of renovation planning found that the current research on renovation planning and renovation project management methods was mainly anecdotal and did not provide any explicit methods to aid project managers. In order to address this gap, the authors have developed a framework and ontology to document stakeholder requirements and automatically analyze an existing renovation phasing schedule against those requirements. The authors have developed a prototype 4D-analysis tool to test this framework. We will present a case study on the use of our prototype tool to analyze and communicate stakeholder requirements with respect to a phasing schedule.

RELATED RESEARCH

Prior research in renovation planning has focused on dealing with uncertainty and determining the scope and cost of the renovation (Marir and Watson 1995; Caccavelli and Genre 2000; Jaggs and Palmer 2000; Kaklauskas, Zavadskas et al. 2005). Little research has been conducted on how to manage the renovation process and schedule. Of the research that has been conducted, the results mostly recognize the need for effective communication between project teams and occupants (Egbu 1995; Krizek, Lo et al. 1996; Egbu 1999), without identifying specific methods to accomplish this.

4D modeling has been established as an effective tool for construction schedule visualization and coordination in both new construction (Aalami 1998; Koo and Fischer 2000; Heesom and Mahdjoubi 2004; Jongeling and Olofsson 2006) and renovation projects (Collier and Fischer 1996; Messner and Lynch 2002) alike. 4D-model based analysis goes beyond visualization to enable project managers to analyze schedules for a variety of design and construction challenges including: workspace requirements, construction specifications, and many other areas (Akinci, Fischer et al. 2000; Heesom and Mahdjoubi 2004; Boukamp and Akinci 2007). However, the focus of these 4D-based analyses has mostly been for new construction.

Requirements research in the design and construction industry have mainly focused in two areas: design requirements (e.g, program of requirements) and specifications (e.g., design codes, construction specifications). Recently, there has been a focus on model-based requirement and specification checking (Kiviniemi 2005; Boukamp and Akinci 2007; GSA 2007; Solibri Inc 2007; ICC 2008). However, the research has been focused mainly on checking a product model against requirements, not checking a schedule against requirements.

This research builds on these points of departure to formalize a renovation planning framework by building on current requirements research and extending 4D model-based analysis methods.

RENOVATION PLANNING FRAMEWORK

The authors developed the renovation planning framework after both observing and actively creating 4D models for visualization purposes for several renovation planning meetings on various projects. When performing these tasks, the authors identified several limitations to current 4D modeling methods for meeting the needs

of renovation project managers. First, project managers need to know what is happening in the building at any point in the renovation (e.g., what areas are being renovation, who is in a particular space, etc.), which requires additional attributes (e.g., occupant ID, space function, etc.) to be tracked in addition to the product model geometry. Second, the project managers need to know how each activity in the schedule affects the overall building. Finally, project managers need to understand all of the requirements imposed by stakeholders on the project and ensure these requirements are satisfied throughout the renovation schedule.

Our framework addresses these limitations and provides an overall process to automatically check and analyze stakeholder requirements and metrics over time. The framework utilizes a requirement ontology and renovation activity ontology. The requirement ontology provides a structure for project manager to define stakeholder requirements and metrics in a computer-interpretable way. The renovation activity ontology enhances traditional phasing schedule activities to enable an automated method to update the product model in the prototype program.

Figure 1 describes the renovation framework, which consists of two major phases: initialization and simulation. In the initialization phase, the project managers identify the requirements to be checked. These requirements serve as the basis for determining which spatial and activity properties to track in the simulation phase. This is crucial to ensure that only the necessary properties are tracked. While the requirement ontology may be useful in gathering inputs from stakeholders, the intended purpose of the ontology is to provide an explicit structure to represent and automatically validate renovation metrics. User elicitation and requirement gathering methods are not within the scope of this research.

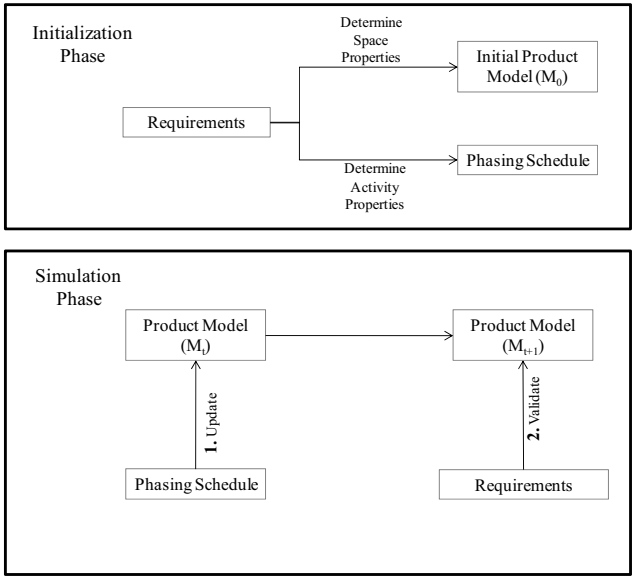


Figure 1. Renovation Planning Framework

In the simulation phase, the product model is automatically updated according to phasing schedule, which is represented with the renovation activity ontology. The renovation activity ontology divides all phasing schedule activities into two categories: occupant move activity or renovation activity. With current 4D modeling tools, an activity is described by a start date, end date, and activity type, as related to a specific component. In the renovation activity ontology, the activity is further defined to include both the occupant ID (i.e., who is moving) and the occupied square footage (i.e., how much of the occupant is moving). This level of detail is necessary in order to identify potential issues in the renovation schedule, as shown in the case study below. A renovation activity is further defined by indicating which product model attributes are changed as a result of the renovation activity (e.g., the function of a space is changed from "Office" to "Kitchen").

After the update, the framework evaluates the schedule by validating the requirements against the current state of the product model. This is necessary because the requirements must check the entire building as a whole, whereas the schedule only indicates changes to specific spaces within the building. For example, a project requirement may indicate that there must be at least four courtroom spaces available at any given time. When a renovation crew begins renovations in a courtroom space, the entire building must be analyzed to ensure there are still at least four courtroom spaces still available. This process is repeated for the remainder of the schedule.

Benefits to the project managers that use this framework include: being able to explicitly define schedule requirements from stakeholders, check these requirements, and identify and visualize any potential issues with the schedule. Project managers will also able to compare schedules explicitly and quantitatively to quickly analyze what-if scenarios for the project.

The authors developed a prototype tool for our proposed framework in Microsoft Access 2007 to implement the framework. The authors manually initialized the system by defining the product model geometry and attributes, in a BIM-authoring software, and the schedule attribute information in a scheduling software. The prototype imports product and schedule attribute information into Microsoft Access and then updates the building and validates the entire renovation schedule. After each time step is evaluated, the prototype program takes a "snapshot" of the building to record the location and occupied square footage of each occupant, as well as the spatial properties of each space (e.g., whether the space has been abated or not). After the entire simulation is run, these snapshots are then exported into a 4D visualization tool to visualize to location of the occupants over time (Figure 3, upper).

The next section explains a case study utilizing the prototype system.

CASE STUDY: FEDERAL BUILDING

The building in this case study is a 419,000 square foot Federal Building constructed in the 1960's. The scope of the renovation includes abatement and renovation of eight floors, and non-structural seismic upgrades to all floors. The building is scheduled to be occupied during renovation, with each of the eight floors moving into swing space on the second floor. The challenges to the project team are to verify and optimize swing space use, track occupant locations over time, and identify shared occupant and construction spaces. An initial phasing schedule was developed by the project manager, which contained 46 activities (23 occupant moves and 23 renovation activities). Based on the results of the analysis of the baseline schedule, the authors created a new schedule alternative to resolve some of the issues found in the baseline schedule. This new alternative involved moving the occupants in the different sequence and accelerating the spandrel work.

ANALYSIS NEEDS

The requirements checked at each simulation period were:

- Renovation activities cannot occur in a space that is already occupied.
- The total occupied square footage cannot exceed the geometric square footage of the space.

The following metrics were automatically analyzed in the program:

- Total area of vacant space over time
- Number of occupant moves per occupant

RESULTS

Table 1 contains the some of the violations in the baseline schedule that were automatically identified from the analysis. There were two main sources of violations. First, renovation activities occurred in the swing space while tenants were scheduled to occupy the space. Second, in some instances where floors had multiple tenants, violations occurred when the schedule did not fully vacate a floor yet new tenants were scheduled to occupy the floor, resulting in future occupants moving into a space that was already occupied. The data shown in Table 1 is exported as a schedule into a 4D visualization tool (Figure 3, lower). The 4D visualization allows the project manager to visualize what activities are occurring in the building, along with potential violations as a result of renovation activities.

Table 1. Major issues found in baseline schedule

Violation ID	Activity Description During Violation	Start Date	End Date	Violation Type	Component	ActivityID
V35-B6AB	35 - Move 8th floor to Swing for Spandrel Work	5/14/09	5/19/09	OccupiedOMEndSpace	B6AB	35
V36-B6AB	36 - Move 7th floor to Swing for Spandrel Work	11/12/09	11/17/09	OccupiedOMEndSpace	B6AB	36
V4-B523	4 - Move 6th floor to 9th	1/28/10	2/3/10	OccupiedOMEndSpace	B523	4
V21-B703	21 - Abate 11th floor	2/12/10	3/25/10	OccupiedDuringConstruction	B703	21
V22-B703	22 - Build-out 11th floor	3/26/10	12/16/10	OccupiedDuringConstruction	B703	22
V23-B703	23 - Move into 11 (CIS from 13)	12/17/10	12/23/10	OccupiedOMEndSpace	B703	23
V24-B4FE	24 - Abate 13th floor	12/24/10	2/3/11	OccupiedDuringConstruction	B4FE	24
V25-B4FE	25 - Build-out 13th floor	2/4/11	10/27/11	OccupiedDuringConstruction	B4FE	25
V26-B4FE	26 - Move into 13 (ICE from 2 & CIS expansion)	10/28/11	11/3/11	OccupiedOMEndSpace	B4FE	26
V14-B895	14 - Abate 14th floor	9/6/12	10/17/12	OccupiedDuringConstruction	B895	14
V17-B6AB	17 - Abate 2nd floor	3/26/09	5/6/09	OccupiedDuringConstruction	B6AB	17
V2-B523	2 - Abate 9th floor	3/26/09	5/6/09	OccupiedDuringConstruction	B523	2
V18-B6AB	18 - Build-out 2nd floor	5/7/09	1/27/10	OccupiedDuringConstruction	B6AB	18
V3-B523	3 - Build-out 9th floor	5/7/09	1/27/10	OccupiedDuringConstruction	B523	3

The baseline vacant space (Figure 2, dotted line) highlighted two issues in the schedule. First, in January 2010, there is a significant increase in vacant space in the building. Further inspection revealed that the 11th floor occupants vacated the space, but the construction crew did not enter the space until several months later, indicating inefficient use of the space. Second, there was approximately 5000 sf of vacant swing space available during the majority of the project. This indicated that more occupants could be moved into the swing space to enable the renovation crews to work faster. Based upon these two insights, the authors developed a new alternative phasing schedule. The new alternative involved moving occupants to a different swing space floor, which allowed renovation crews to work in a more efficient sequence. The spandrel work was also accelerated since a greater number of occupants were able to be moved into swing space. As a result, the space utilization is higher since the amount of vacant space (Figure 2, solid line) is significantly reduced.

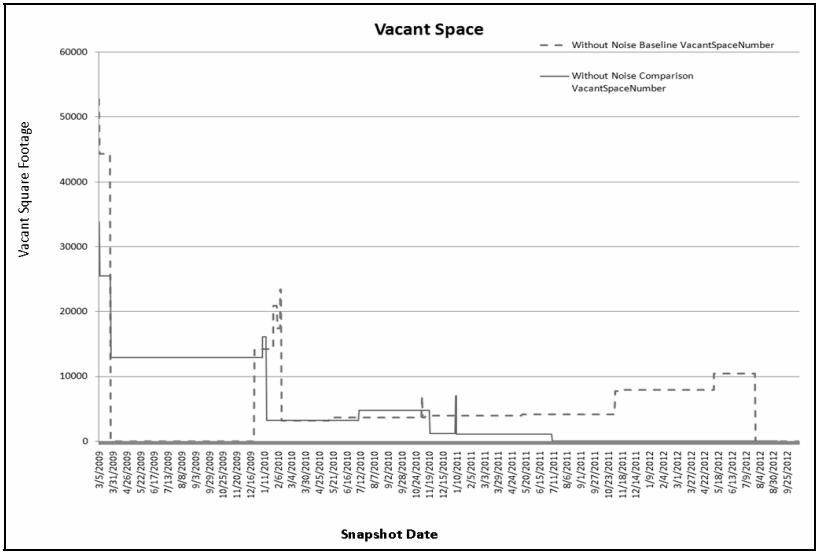
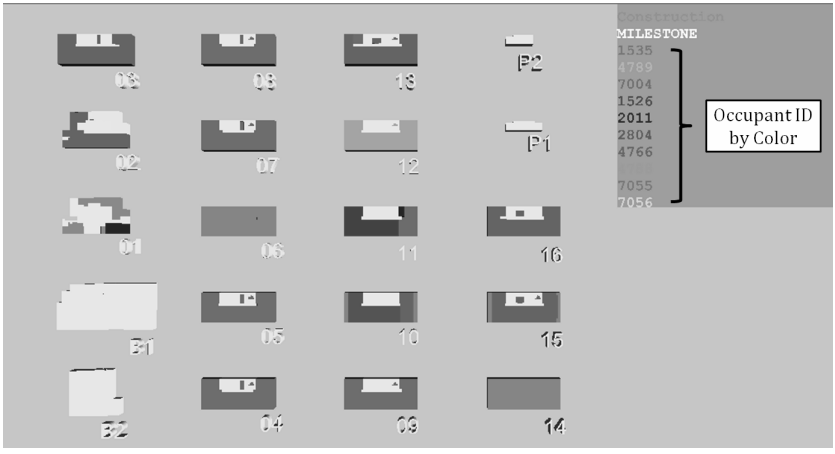


Figure 2. Comparison of Vacant Space Usage in Baseline and Alternative Phasing Schedules

The framework also enables the project manager to visualize both the occupants over time (Figure 3, upper) as well as highlight violations (Figure 3, lower). Feedback from the project manager confirmed that the 4D visualization of these attributes enable better understanding of the issues in the phasing schedule.



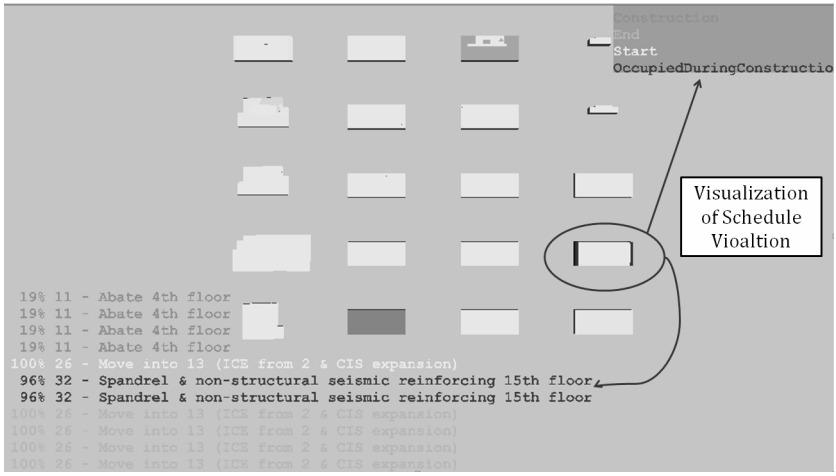


Figure 3. Snapshots of 4D Analysis of Baseline Phasing Schedule

CONCLUSION & FUTURE WORK

To successfully execute a project, designers must meet certain design specifications and program requirements and contractors must adhere to construction specifications. Similarly, renovation planners must meet certain occupant and contractor requirements throughout the renovation process. Although construction contracts typically have few project specific schedule specifications (e.g., the required end date of the project), in reality, the schedule must meet many stakeholder requirements.

Renovation planning is more complex that new construction planning and requires project managers to gather multiple stakeholder requirements, check the renovation schedule for conformance to the requirements, and analyze multiple time-based metrics based. This research formalizes a 4D model based renovation planning framework and ontology that enables project managers to proactively manage the renovation schedule and alternatives in more depth. The framework and ontology have been shown to better analyze phasing schedules by automatically identifying and visualizing problem areas to aid project managers in develop new alternatives.

In on-going research, the framework will be further refined using two additional case studies of a courthouse building and land port of entry renovation. In combination with the above case study, these projects provide generality because they represent a diverse combination of scope, requirements, and issues found in renovating occupied facilities and will enable validation of the entire framework. Future work may include testing on a wider range of renovation project types (e.g., hospitals, heavy civil, etc). Ultimately, this work may lead to automated methods to generate and optimize renovation schedules based upon stakeholder requirements.

REFERENCES

Aalami, F. (1998). Using Method Models to Generate 4D Production Models. Department of Civil and Environmental Engineering. Stanford, Stanford University. **PhD**.

Akinci, B., M. Fischer, et al. (2000). Automated Generation of Work Spaces Required by Construction Activities. Stanford, Center for Integrated Facility Engineering, Stanford University.

Boukamp, F. and B. Akinci (2007). "Automated processing of construction specifications to support inspection and quality control." Automation in Construction **17**(1): 90-106.

Caccavelli, D. and J.-L. Genre (2000). "Diagnosis of the degradation state of building and cost evaluation of induced refurbishment works." Energy and Buildings **31**(2): 159-165.

Collier, E. and M. Fischer (1996). Visual based scheduling: 4D modelling on the San Mateo County Health Centre. 3rd ASCE Congress on Computing in Civil Engineering, Anaheim, CA.

Egbu, C. O. (1995). "Perceived degree of difficulty of management tasks in construction refurbishment work." Building Research & Information **23**(6): 340-344.

Egbu, C. O. (1999). "Skills, knowledge and competencies for managing construction refurbishment works." Construction Management and Economics **17**(1): 29-43.

GSA (2007). GSA BIM Guide Series 02: Spatial Program Validation. O. o. t. C. A. a. C. Programs. Washington DC, U.S. General Services Administration.

Heesom, D. and L. Mahdjoubi (2004). "Trends of 4D CAD applications for construction planning." Construction Management and Economics **22**: 171-182.

ICC. (2008). "SmartCodes." Retrieved October 27, 2008, 2008.

Jaggs, M. and J. Palmer (2000). "Energy performance indoor environemntal quality retrofit - a European diagnosis and decision making method for building refurbishment." Energy and Buildings **31**(2): 97-101.

Jongeling, R. and T. Olofsson (2006). "A method for planning of work-flow by combined use of location-based scheduling and 4D CAD." Automation in Construction **16**(2): 189-198.

Kaklauskas, A., E. K. Zavadskas, et al. (2005). "Multivariant design and multiple criteria analysis of building refurbishments." Energy and Buildings **37**(4): 361-372.

Kiviniemi, A. (2005). Requirements Management Interface to Building Product Models. Civil and Environmental Engineering. Stanford, Stanford University. **PhD**.

Koo, B. and M. Fischer (2000). "Feasibility study of 4D CAD in commercial construction." Journal of Construction Engineering and Management **126**(4): 251-260.

Krizek, R. J., W. Lo, et al. (1996). "Lessons Learned from Multiphase Reconstruction Project." Journal of Construction Engineering and Management: 44-54.

Marir, F. and I. Watson (1995). Representing and indexing building refurbishment cases for multiple retrieval of adaptable pieces of cases. Lecture Notes in Computer Science. Heidelberg, Springer Berlin. **1010:** 55-66.

Messner, J. I. and T. Lynch (2002). A Construction Simulation Model for Production Planning at the Pentagon Renovation Project. International Workshop on Information Technology in Civil Engineering 2002, November 2-3, 2002, Washington, D.C.,USA, ASCE.

Solibri Inc (2007). Solibri Model Checker. Helsinki**:** BIM Analysis Software.

MAPPING ACTORS AND ROLES IN CONSTRUCTION KNOWLEDGE

J. Zhang[1] and T. E. El-Diraby[2]

[1]Ph.D Candidate, Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, ON, Canada, M5S 1A4; PH (416) 623-7956
[2]Associate Professor, Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, ON, Canada, M5S 1A4; PH (416) 978-8653; FAX (416) 946-5054; e-mail: tamer@ecf.utoronto.ca

ABSTRACT
Modelling actors and roles and mapping their relations have great significance in the construction industry for effective communication. However, the attention and effort in this area is far lagged behind the research of construction product modelling and process modeling. After discussing the philosophical root of understanding actors and roles, this paper proposed an ontological model for major entities involved in construction, and then established criteria of identifying actors and roles. Based on the two taxonomies (for actors and roles) developed in this study, an innovative way of mapping an actor to its possible roles was illustrated.

INTRODUCTION
People and organizations are related and interdependent in many ways, both inside the construction industry and across industries, and they need effective communication to obtain useful information at right time. Significant research efforts have been dedicated to construction product modeling and construction process modeling. Little work has been done on modeling actors and roles in construction knowledge. With the evolution of social web and semantic web, it is important to profile actors and roles to support proper flow of information and exchange of knowledge.

The reason to differentiate Actor and Role is that the two concepts represent different information needs. For example, a *Mechanical Engineer* who is not embedded in any context (not participates in any project or process, not relates to any organization, etc.) normally care about general information related to his profession like the new technology in Mechanics or professional events. The role of a *Mechanical Engineer* varies a lot based on different contexts the object may be involved. There could be several *Mechanical Engineers* working in a project with different roles like a

Designer (from a consulting firm), a *Supplier* (from the manufacturing company), an *Inspector* (from government department), or a *Contractor* (from contracting firm). They normally have different perspectives on the project, associated with different interests, responsibilities, rights, and many other attributes; therefore, understanding Actors and Roles as well as their relationships becomes essential to effective communication in construction.

Most past and existing research on actors and roles in construction industry tends to be either very introductory in textbooks for a lot of concepts like (Murdoch and Hughes 2000) or focal on very few important concepts in much more details like (Cherns and Bryant 1984; Hodgson and Jeffry 1999; Price 1994). There has been no systematic modeling effort to expound different roles of industry actors.

A core task of this project is to develop an ontology to encapsulate the industry knowledge about actors and roles in terms of their information and knowledge needs. In the field of engineering informatics, an ontology typically include three major elements: a taxonomy of concepts (a hierarchy of common vocabulary), a set of relationships (to build the taxonomy and to link concepts across taxonomy trees), and a set of axioms (to describe and limit the behaviour of concepts). This paper describes the ontological model of actors and roles, defines taxonomies for actors and roles, and proposes a way to map actors and their possible roles.

THE ROLE-ACTOR DEBATE

Finding a proper way to define roles in our life and model their relationship to actors is a long debate among philosophers and the debate will keep going in the near future. Because of the ever present fuzziness between the two concepts, some researchers have adopted the view that actors and roles can only be modeled as a combined entity "actor-role". This is because it is so hard to find a clear methodology to discern the two concepts from each other. Should we consider a "project manager" to be an actor or should we consider that to be a "role" played by a "civil engineer". Which of a "designer" and an "architect" should we consider as the actor? Is an "owner" an actor or a role? What about a "client"? Can a design firm be the designer in one project and the project manager in another and a client (or client representative) in a third?

From the perspective of a functionalist, a role is a set of expectations of behaviours and acknowledged attributes that a society places on an individual. By unspoken consensus, certain behaviours and attributes are deemed "appropriate" and others "inappropriate". One of the major objectives of modeling roles is to differentiate those appropriate and inappropriate behaviours and attributes. Functionalists believe roles are relatively inflexible and are more-or-less universally agreed upon. Although it is recognized that roles are situated in various settings where their behaviours and attributes could be very different, the functionalist approach has difficulty in accounting for variability and flexibility of roles in different contexts (Michener and DeLamater 1999). Another perspective to observe roles is interactionist. A role, in this conception, is not fixed or prescribed but something that is constantly negotiated between individuals in a tentative, creative way (Goffman 1961). This perspective

emphasizes the interaction between individuals and defines roles in terms of interactions.

The functionalist approach of understanding roles still remains a fundamental concept in many industries including construction, even though it has been criticized for its static perspective. Construction industry is relatively stable in terms of role behaviours and attributes (assigning a role to an object is dynamic though), and can be envisioned as a setting in which objects (modeled by individual actors and organizational actors) participate in various construction projects, occupying distinct positions. Each of these positions entails a role, which is a set of functions performed by the object for the setting.

Steimann (2000) summarized 15 features of being roles in conceptual modeling; among them this proposed Actor-Role model supports the following features:

- An actor cannot be played by any other actors; otherwise, it is a role.
- An object can play one or more roles simultaneously in different contexts.
- An object may play the same role several times, simultaneously.
- A role can be transferred from one object to another.
- Different roles may share structure and behaviour.
- An object and its roles share identity. In the object-oriented world this entails that an object and its roles are the same, a condition that has been paraphrased as "a role is a mask that an object can wear".

PROPOSED ONTOLOGICAL MODEL

In this model an Actor relates to fixed or innate characteristics, while a Role relates to the functional, exterior and dynamic attributes. Additionally, a "role" is a link between an actor and a process. In other words, the actor-role duality is actually a trilogy of actors and their temporal (assigned) roles in certain processes. In a different context, the same actor could assume a different role in the same process or another process (see Figure 1).

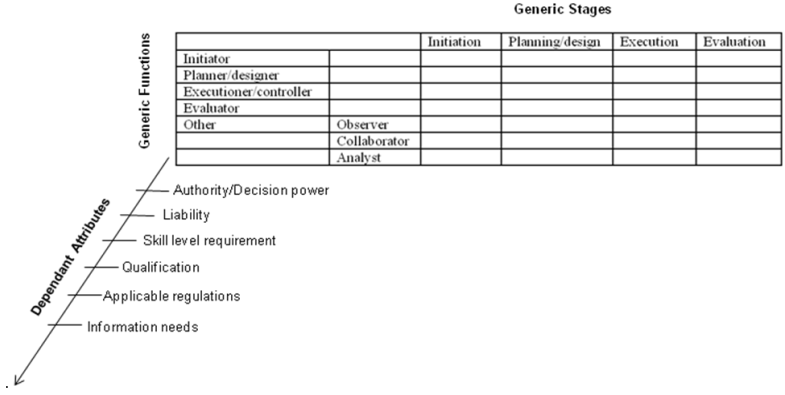


Figure 1: The Ontological Model of Role

The attributes of a process within a certain context drives the definition of roles and the selection of proper actors to perform them. For example, the design process requires a set of attributes to be present in the designer. The minimum includes: design skills, design experience, academic and professional qualifications, etc. If this process is part of a design-build contract in an urban infrastructure project, this context define additional (more dynamic) attributes such as: liability levels, span of authority, and so on. The former attributes define more of innate characteristics that have to be present in an individual (or a firm) to assume the role of a designer (irrespective of the context). They cannot be assigned to the actor by the process or the context. The latter attributes are more of floating characteristics that can be assigned to any actor (as long as they satisfy the minimum requirements of the innate attributes).

Consequently, this ontology defines actors mainly based on the innate attributes. Fundamentally, an Actor is limited to the most basic attribute and legal characteristics of an entity. An *Architect* holds this title no matter he is the designer of building project or a principal of an architectural firm. An *Electrical Engineer* is identified by his ability to using knowledge of electrical engineering to solve problems. An Actor holds irrespective of what is being done. A *Civil Engineer* will always be a civil engineer. He or she has a well-defined and (momentarily) static and innate attributes (skills, expertise, background, academic qualification, for example). The Role that is assigned to him or her depends on the context. This engineer can be assigned the role of *Designer*, or *Project Manager*, *Construction Manager*, *Owner*, *Quality Controller*, *Safety Consultant*, or *Permitting Agent* based on the context. Additionally, a design firm (an Actor) can assume the role of a *Designer*, *Project Manager*, or *Consultant*. In some cases, the firm can be the *Owner* or *Owner Representative*. Similarly, a contracting company is an Actor that can assume the role of *Contractor*, *Cost Consultant*, *Project Manager*, or *Safety Consultant*. A bank is an Actor that could assume the role of *Financier*, *Client*, or *Financial Consultant*. A civil engineer is an actor that can assume the role of *Designer*, *Project Manager*, or *Construction Manager*. Irrespective of the role assigned to such company, it has a static set of attributes that allows it to play various roles in different contexts (for example, resources, expertise, bonding capacity). These attributes qualify the company to assume different roles in different contexts. Consequently, additional role-related attributes are assigned to this company. For example, if the company assumes the role of *Contractor*, it will be responsible for safety, quality and project deliverables. If the company, however, is assigned the role of *Constructability Consultant* it will have different set of these dynamic attributes.

In short, in this ontology the concept of "Actor" is context independent and defined by the most generic attributes. The concept of "Role" on the other hand is context dependent and is defined by the most dynamic attributes.

Innate and external attributes are a fuzzy continuum. Therefore, it is not always easy to define the line between actors and roles. For example, according to the proposed

model, an "*Architectural Designer*" is a type of role (a *Designer*). However, one could argue, persuasively, that this concept belongs more to the actor category given the fact that a great deal of the required attributes of such concept are innate and formally define the individual (or firm) that does this job. In other word, these attributes are more static. A clearer example could be presented by the case of trade personnel. Is a carpenter an actor or a role? According to the previous examples, which associate roles to professional education, one can argue that similarly in the labour domain, a carpenter can be seen as an actor—someone who possess the carpentry expertise for ever and is qualified (through training of otherwise) to hold such post. On the other hand, and in a small job, a regular labourer can assume the tasks of carpentry. In other words, anyone can assume the role of carpenter (especially in a small job). By the same token, in a small job, a non-architect can do the architectural design tasks, which makes the case for "architectural designer" to be a role. Similarly, if we assume that a machine operator is an actor we could find that in certain situations that any one can assume such task (or role). Moving machine operator to be a role, means that we accept that "*Heavy Machine Operator*" is also a role, which kind of violates the rule just established that a qualified trade person should be categorized as an actor.

Similar arguments and counter arguments have been discussed by researchers in this domain for a long time. Compromise has to be exercised. We have to accept a good-enough solution to this problem. In doing so, three rules have been devised to help simplify the categorization problem in this ontololgy:

1. On the extreme end, innate and static attributes that require legal or professional accreditation and qualifications (including belonging to a union or a trade) define the pure actor (an actor with substantial resemblance to the universal actor). Shades of these attributes can qualify a concept to be an actor as long as they are deemed substantial or enough. What does not qualify as an actor is a role.
2. We have to yield to industry use and linguistic habits as much as possible. It is important to realize that one of the most important concepts that can help discern the role of linguistic habits in setting what is a role and what is an actor is the context of discussion. We have always to think of a trilogy of actor, role and context (or process).
3. While it is impossible to find a simple and crisp rule of discerning roles and actors at various contexts, axioms can be of great help in doing that. We should carefully draft a set of axioms that explain the categorization of concepts based on the context that they belong to. For example, we may specify that "on large projects, the role of *Architectural Designer* has to be performed by an *Architect*", or we could go even further as to say that "on large projects, the role of *Architectural Designer* coincides with the actor *Architect*". We could also define that "on a small project, almost any role can be performed by any actor"

Table 1 shows a partial view of the fundamental categories suggested for actors and roles. Actors are divided into two major categories: individuals and organizations. A third category names "other actors" is used to house concepts such as a "computer agent" or a "driver-vehicle unit". These are further subdivided according to their

professional or labour status—for example: engineering professionals, accounting professionals, skilled labourers, etc. on the role side, three fundamental categories have been suggested: customer-related roles, professionals-related roles, and labour-related roles.

In limited cases, concepts that equally qualify as an actor as a role will be assigned two closely worded terms in both categories. For example, a machine operator can be seen as an actor given that he/she belongs to a trade. Yet, a machine operator is also a role that can be assumed by almost anyone (especially for small machines). Two entries are proposed for this concept: *Machinist* (in the actor category) and a *Machine Operator* (in the role category).

Table 1: Major Categories of Actor-Role Taxonomy

			Customer-Related					Professional-Related				Labour-related		
			Owner	Client	Agent	Supplier	Regulator	Designer	Planner	Contractor	Financier	Installer	Carpentry work	Machine operator
Individual	Engineer	Civil Eng.												
		Mechanical												
	Accountant													
	Lawyer													
Organization	Government Agency	Municipality												
		Court												
	For-Profit Org.	Contracting firm												
		Consulting firm												
	None-profit org.													
Other														

The Semantics of Actor and Role

An Actor is defined through a set of attributes. These include professional attributes (such as educational degree, certification level, skills, etc.), logistical attributes (such as address, e-mail, etc.), personal attributes (habits, interests, motivation level, etc.), and performance attributes (productivity, innovation level, etc.) These attributes tend to be static and are associated with the actor for a sustained time.

In this ontology, a Role is more associated with the process than with the actor. This is because a role is basically a collection of functions that has to be performed to realize a process. Functions, in turn, identify a set of necessary attributes that has to exist to achieve or perform the process. Consequently, roles are defined as three-dimensional entities. The first dimension repersnets the stages of a process. Any process is divided into a set of typical stages. These include: initiation stage (where some actors initiate a process), planning/design stage (where the team responsible for the project develops the process scope and action plan), execution stage (where the process is actually executed), and evaluation stage. The second dimension represents the basic roles (generic functions) that are needed to achieve these stages. For example (see Figure 2), an *Initiator* is needed to initiate a process. A *Planner* is

needed to plan the process. In some cases, an *Observer* or a *Collaborator* is engaged in a process. Thirdly, based on the process and context, each of these roles mandate certain attributes. For example, in a large project, the *Executioner* of the field construction process has to be a bonded, qualified and licensed actor. The executioner of the design process has to be a qualified, licensed and insured actor. Both actors have liabilities and lines of authority, are required to meet certain standards and contractual obligations. Based on the context, these roles could be assigned to a contracting firm, consulting firm, or an internal department at the owner organization.

Through this model we can gain great flexibility in representing roles. For example, an *Architect* who is assigned the role of a *Designer* will assume all controller/executioner sub-role and may be the planner sub-role (and all their associated attributes) in a design process. Based on the context, a *Civil Engineer* can be assigned the sub-role of *Observer* or *Collaborator* at most stages of the design process.

Proposed Actor Taxonomy

The concepts encapsulated in the taxonomy of actors are from a broad literature reviews and existing occupation classification systems. The highest level of subclasses of Actor includes *Individual Actor* and *Organizational Actor* (see Figure 2a).

The primary reference for *Individual Actor* is the National Occupational Classification (NOC 2006). It is the nationally accepted reference on occupations in Canada. It includes 520 occupational group descriptions throughout Canada's labour market. About 80% job titles listed in the NOC are qualified as actors, others are classified as roles. The NOC groups all job titles into a matrix, using skill level as one dimension and skill type as the other dimension. Actor's taxonomy follows this structure, and uses skill level as the first level of subclasses (*Management Individual*, *Professional Individual*, *Skilled Individual*, and *General Labour*), followed by skill type as the next level of subclasses. As the NOC covers all job titles in Canadian labour market and we are mainly concerned about actors related to construction, three coverage levels are employed:

- The core concepts closely related to construction industry are fully covered. For example, there are 87 subclasses in *Heavy Equipment Operator* to cover almost all actors in this field.
- The most important supporting concepts are covered. Those concepts are important to support construction industry and may not be able to ignore. For example, *Accountant* in financial service and *Bus Driver* in transit service.
- Concepts are not related to construction industry are not covered. However, the taxonomy still list the concept in the NOC major groups for two reasons: (1) other taxonomies using the same NOC as primary reference can easily coordinate with this taxonomy, and (2) this taxonomy can be easily extended in the future to fit more application requirements.

Some other reference sources used in developing taxonomy of actors include Standard Occupational Classification (SOC 2000), Occupational Outlook Handbook

(OOH 2008), Dictionary of Occupational Titles (DOT 1994), Occupational Network (O*NET 2006), and various textbooks.

The primary reference for *Organizational Actor* is the North America Industry Classification System (NAICS 2007), which is the result of collaboration work among USA, Canada, and Mexico in categorizing industries in North America. The taxonomy for organizational actors follows the structure of NAICS 2007 Canadian version and uses some other references as complement, like NAICS 2007 US version and European standard for industry classifications (NACE).

Taxonomy of Roles

The concepts in taxonomy of roles are collected partially from the NOC 2006 and partially from broad domain literatures in construction. Roles are grouped according to different modalities: process modality, event modality, project modality, product modality, and organization modality. In each group of modality, roles are organized based on their functionality (see Figure 2b). In addition to the modalities for roles shown in Table 1, additional modalities are used to create types of roles. For example, project vs. corporate modalities, local vs. national or international modalities, and seniority modality.



Figure 2a: Partial Actor Taxonomy

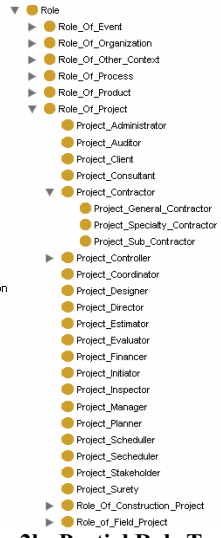


Figure 2b: Partial Role Taxonomy

Mapping Actors and Possible Roles

The dynamic of assigning roles to actors is context dependent. Based on the context,

some role-actor associations are very typical, others are less likely and a third is not possible. For example, a *Structural Engineer* "mostly be" a *Designer* of a *Construction Project*, and "could be" a *Constructability Analyst* of a design. He/she can be *Manager* of a project or the *President* of a consulting firm. He/she almost is never the *Art Designer* in a project.

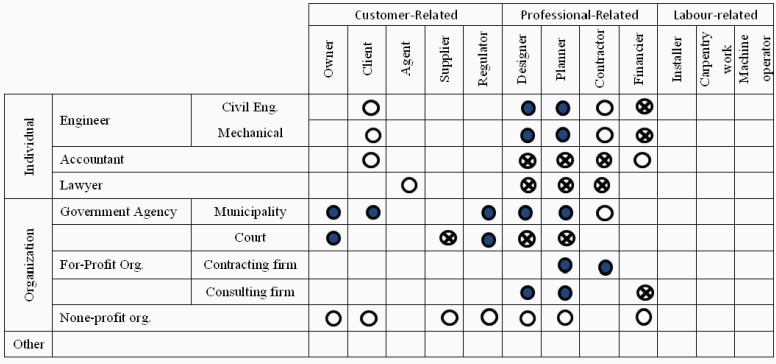


Figure 3: Actor-Role Assignment

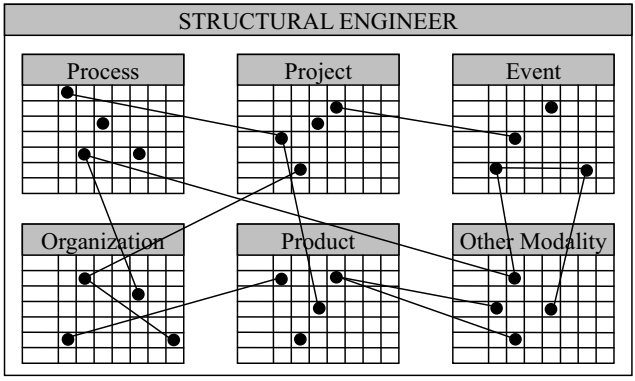


Figure 4: Outline of Actor Semantic Profile

In the ontology, this dynamism is modeled mainly through axioms. As shown in Figure 3, pictorially, this is represented by solid circles in case of a "most probable" assignment, an empty circle for "possible" assignment, and a circle with a cross for "not probable" assignment. Finally, if no circle is placed at the intersection, then the taxonomy makes no assumption about the relationship. It is left to the user to define that based on the context.

Consequently, one can start establishing a more precise profile of actors. This includes his/her typical, possible and not possible roles and engagement in product

development, in processes, in projects and in organization (see Figure 4). Profiling the actor in this detailed manner, means that we can, for example, direct the right information to this actor based on his or her exact needs and expertise. The ontology has great potential in developing computer applications of semantic information management systems.

REFERENCES

Cherns, A. B. and Bryant, D. T. (1984). "Studying the client's role in construction management", *Construction Management and Economics*, 2(2), 177-184.

Goffman, E. (1961). *Encounters: two studies in the sociology of interaction*, MacMillan Publishing Co.

Hodgson, G. and Jeffry, J. A. (1999). "A critical examination of the designer's role under the ICE design and construct conditions of contract and the Highway Agency's design and build conditions of contract", *RICS Research Papers*, 3(2), 1-24.

Michener, A. H. and DeLamater, J. D. (1999). *Social psychology*, Harcourt Brace College Publishers.

Murdoch, J. and Hughes, W. (2000). *Construction contract: law and administration*, London: Arnold.

Price, J. (1994). *Sub-contracting*, Basingstoke: Macmillan.

Steimann, F. (2000). "On the representation of roles in object-oriented and conceptual modelling", *Data and Knowledge Engineering*, 35: 83–106.

THE CURRENT USE OF OFFSITE CONSTRUCTION TECHNIQUES IN THE UNITED STATES CONSTRUCTION INDUSTRY

Na Lu[1], Ed.D. AIC

[1]Assistant Professor of Construction Management, Roger Williams University, One Old Ferry Rd., Bristol, RI 02809; email: nlu@rwu.edu

Abstract: Even though the use of offsite construction techniques provides numerous significant advantages the current level of using these techniques in the US construction industry is limited. This study aimed to 1) identify the driving forces and challenges in using these techniques in residential, commercial, and industrial sectors, 2) investigate the perceived benefits and barriers, and 3) compare the perceived benefits and barriers in using these techniques in residential, commercial, and industrial construction sectors. The results indicated that benefits of using these techniques include 1) reducing the project schedule, 2) reducing the need for skilled craft workers, 3) reducing the negative environmental impact, and 4) increasing safety performance. The most significant barriers were 1) transportation restraints and 2) inability to make changes onsite. The top 3 driving forces for its use were 1) to reduce the construction duration, 2) to reduce the overall project schedule, and 3) to compensate for the effect of incremental weather conditions. The top 3 challenges were 1) the inability to make changes onsite, 2) transportation constraints, and 3) limited design options. Several practical recommendations were proposed in this study based on the findings.

Keywords: construction workforce, offsite construction techniques, modular buildings, panelized building systems, construction productivity.

Introduction

A large amount of construction research suggests that the shortage of a skilled construction workforce and the declining number of new entrants present significant challenges for the United States construction industry, which would potentially cause project schedule and cost overruns (CII, 1998; Liska, 1999; Hass, 2000). In 2005, the Construction Management Association of America conducted its sixth annual survey of owners and found that more than 40% of its members had experienced construction schedule overruns due to the shortage of skilled craft workers, which also resulted in the escalation of project costs (CMAA, 2006).

Offsite construction techniques, including offsite preassembly, hybrid system, panelized system, and modular building appear to be one of the most effective approaches to overcome these challenges in the construction industry. However, the current level of using offsite techniques in the United States construction industry is still very limited (Lu, 2007; CII, 2002; Beliveau, 2000). Therefore, it would be beneficial to investigate the challenges and the driving forces of using these techniques, and also to identify the opportunities to increase the level of use with these techniques in the US construction industry.

Research Objectives

The primary purpose of this study was 1) to investigate the current degree of utilization of offsite construction techniques, 2) to identify benefits and barriers of using offsite construction techniques in the United States, and 3) to identify the challenges and driving forces of using these techniques in the US construction industry. To achieve the research objectives, the following questions were investigated in this study:

- To what degree the offsite construction techniques being used in the building sector of U.S. construction industry in 2006?
- What were the perceived benefits and barriers of using these techniques in the US construction industry?
- What were the top 3 reasons that would motivate Architects/Engineers (A/Es) or General Contractors (GCs) to use offsite construction techniques in the building sector of the US construction industry?
- What were the top 3 challenges that would restrain A/Es or GCs from using offsite construction techniques in the building sector of the US construction industry?

Methodology

Sample Design

The population of this study comprised of architects/engineers (A/Es) and general contractors (GCs) in the U.S. construction industry with their majority of work concentrated in the residential, commercial, and industrial sectors. The sampling frame for general contractors in this study was a composite list purchased from the Dun & Bradstreet (D&B) using general contractors whose annual volume was more than $1 million U.S. dollars in 2006. 600 general contractors were randomly selected from a total of 11,000. The sample frame for A/Es was the American Institute of Architects (AIA) 2006 national membership list. 600 design firms were randomly selected from a total of 49,595.

The study utilized a 95% confidence interval. The estimated total sample size was determined by the formula: $N = (t\alpha * \sigma)^{2} / E^{2}$ (Kumar, 2005). For a conservative estimate the researchers used 0.2 as the standard error of the mean in this study, which limits the standard deviation of the difference between sample mean and

population mean to no greater than 0.2, σ was 3.5. Based on the calculation, the sample size of 1200 was selected with 600 for each of A/Es and GCs group.

Research Procedures

This study began with a comprehensive literature review of using offsite construction techniques in the building sectors of the United States and some overseas construction industries. The researcher then conducted case studies of several offsite manufacturing facilities and interviewed representatives of these organizations. A series of in-depth open-ended interviews with selected industry practitioners, including architects, general contractors, manufacturers, and developers, was followed. A structured interview questionnaire was developed by the researcher based on the result of literature research and case studies. The majority of interviews were conducted by phone with several done face-to-face, with the average being approximately one hour.

The utilization of a self-administrated questionnaire with a well-defined scope was determined to be the most feasible approach to gather data for this study because of the geographic dispersion of the subjects. In addition, using a randomly selected sample and anonymous respondents would reduce interviewer bias and improve the validity of the study. Therefore, two self-administrated survey questionnaires were developed based on the information gathered from the researcher's previous studies.

To enhance the validity and reliability of the survey instrument, a pilot study was conducted using 10 representatives from each of the A/E & GC groups. Feedback from the respondents regarding the content, scope, question structure, and response scales was solicited and used to improve the survey questionnaire.

In January 2007, the researchers mailed 1,200 self-administrated survey questionnaires to the randomly selected sample of A/Es and GCs, with noted return date within 2 weeks. In order to improve the respondent rate, a personalized cover letter addressed directly to the president of each company was developed and sent with the questionnaires. A self-addressed business reply envelope was provided for ease of return.

Instrument

The survey instrument consisted of 4 sections: Section I - general information about the respondent and the degree of using offsite construction techniques; which included the information of each respondent's job title, the company's size and market sectors, the percent of using offsite construction techniques, and past experience with using offsite construction techniques.

Section II - the perceived benefits and barriers of using offsite construction techniques. Participants were asked to rate the statements of benefits and barriers of using offsite construction techniques by their level of agreement/disagreement, by using seven-

point lickert scales with 1 indicating "strongly disagree", 2 "moderately disagree", 3 "slightly disagree", 4 "neither disagree nor agree", 5 "slightly agree", 6 "moderately agree", and 7 "strongly agree".

Section III - the identification of the top three reasons for using offsite construction techniques. Section IV - the identification of the top three challenges of using offsite construction techniques. Participants were asked to circle the top 3 reasons/challenges of using offsite construction techniques from the given options.

Data Analysis

Data collected from the questionnaires were analyzed by using the SAS computer program. Descriptive statistics were used to describe and summarize the data for each survey question. A series of two-tail t-tests were used in the SAS program to analyze the data.

Findings

Response Rates

Of the 1200 questionnaires sent, within two (2) weeks 138 questionnaires were returned. Seven returned questionnaires were not usable. Therefore, 131 respondents were used in this study. 67 (51%) of those respondents were architects/engineers, and 64 (49%) were general contractors. The average annual revenue of the architects/engineers respondents in 2006 was $21.43 million with a range from $0.1 million to $300 million, and the average annual revenue of the general contractors' respondents in 2005 was $290.364 million U.S dollars, with a range from $1.3 million to $ 12 billion.

For A/Es group, 13 (19.4%) firms concentrated in the residential sector, 35(52.2%) firms focused on the commercial sector, 1 (1.5%) were heavily involved in the industrial sector, and 18 (26.9%) firms worked in the institutional sector. Of the 64 participating GCs, 14 (21.8%) of them concentrated in the residential sector, 32 (50%) focused on the commercial sector, 7 (10.9%) in the industrial sector, and 11(17.3%) were institutional contractors, as presented in Table 1.

Table 1 Respondents' market sectors

	Residential	**Commercial**	**Industrial**	**Institutional**	**Total**
A/Es	13 (19.4%)	35 (52.2%)	1 (1.5%)	18 (26.9%)	67
GCs	14 (21.8%)	32 (50%)	7 (10.9%)	11 (17.3%)	64

The level of using offsite construction techniques

In 2006, the A/E respondents reported that 26.75% of their design work incorporated the use of one or more types of offsite construction techniques, of which 19.57% were

offsite preassembly, 1.6% were hybrid systems, 4.88% were panelized systems and 0.72% were modular buildings. GC respondents reported that 19.62% of their work used one or more types of offsite construction techniques, of which 12.32% were preassembly techniques, 0.09% were hybrid systems, 6.17% were panelized systems and 1.04% were modular buildings, as shown in Table 2.

Table 2 the current degree of using offsite construction techniques

	Preassembly	**Hybrid systems**	**Panelized Systems**	**Modular**	**Total**
A/Es	19.57%	1.58%	4.88%	0.72%	26.75%
GCs	12.32%	0.09%	6.17%	1.04%	19.62%

The perceived benefits and barriers by A/E & GCs

To investigate the perceptions of using offsite construction techniques, each survey questionnaire listed 16 statements regarding the benefits and barriers of using these techniques. 13 of these statements were designed to be answered by both A/Es and GCs. The other 3 statements were addressed differently to A/Es and GCs. The respondents were asked to indicate their levels of agreement/disagreement for each statement using 7 point lickert scales, with 1 indicating strongly disagree to 7 indicating strongly agree. The results are presented in Table 3.

Table 3 the perceived benefits and barriers of using offsite construction techniques

	A/Es' Mean	GCs' Mean
The use of offsite construction techniques reduces the overall project schedule (including design, procurement and construction phases)	5.11	5.42
The use of offsite construction techniques reduces the project construction cost	4.27	4.45
The use of offsite construction techniques increases product quality	4.63	4.47
The use of offsite construction techniques increase overall labor productivity	4.93	5.29
The use of offsite construction techniques limits design options	3.97	4.62
The use of offsite construction techniques increases safety performance	4.36	4.73
The use of offsite construction techniques reduces onsite disruptions	4.42	4.98
The use of offsite construction techniques reduces the negative environmental impact of construction operations	4.58	4.45
The use of offsite construction techniques increases the overall project cost	2.89	3.44
The use of offsite construction techniques limits the ability to make changes onsite	4.97	5.19
Transportation constraints (size restraints, transportation cost, and impact on the building structures) limits the use of offsite construction techniques	4.76	5.17
The owner's negative perception of offsite construction techniques limits the use of offsite construction techniques	3.59	4.36
The use of offsite construction techniques increases project design efficiency	3.88	NA
The use of offsite construction techniques increases design cost	3.46	NA

Complicated computer software for designing offsite construction techniques limits their uses	3.15	NA
The use of offsite construction techniques increases jobsite management efficiency	NA	4.59
The local building regulations restrict the use of offsite construction techniques	NA	3.55
Lack of skilled assembly craft workers limits the use of offsite construction techniques	NA	3.17

Top 3 Reasons of using offsite construction techniques

Each questionnaire listed 15 reasons that may encourage firms to use offsite construction techniques. Each participant was asked to circle the top 3 reasons why his or her firm used offsite construction techniques from the given options. The top 3 reasons selected by the A/Es in rank order were: 1) to reduce the construction duration, 2) to reduce the overall project schedule (including the design, procurement and construction phases); and 3) to reduce the overall project cost, as presented in Table 4.

Table4 the top three (3) reasons to use offsite construction techniques for A/Es

Categories	Frequency	Percentage
To reduce construction duration	29	43.28%
To reduce overall project cost	24	35.82%
To reduce project overall schedule	24	35.8%
To increase product quality	20	29.85%
To compensate for the shortage of skilled craft workers	13	19.40%
To compensate for the local weather conditions	10	14.93%
To reduce environmental impact	10	14.93%
To increase overall labor productivity	7	10.45%
Project owners require using off-site construction techniques	5	7.46%
To reduce design duration	4	5.97%
To compensate for the restricted working space onsite	4	5.97%
Other reasons	2	2.99%
To enhance your company's reputation	0	0%
To improve project safety performance	0	0%

The top 3 reasons selected by GCs in rank order were 1) to reduce construction duration, 2) to reduce the overall project schedule (including the design, procurement and construction phases), and 3) to reduce the overall project cost and to compensate for local weather conditions, as presented in Table 5.

Table 5 the top three (3) reasons to use offsite construction techniques for GCs

Categories	Frequency	Percentage
To reduce project overall schedule	21	32.81%
To reduce construction duration	20	31.25%
To compensate for the local weather conditions	11	17.19%
To reduce overall project cost	11	17.19%
To increase overall labor productivity	10	15.63%
To compensate for the shortage of skilled craft workers	10	15.63%
To increase product quality	10	15.63%
Project owners require using off-site construction	7	10.94%

techniques		
To compensate for the restricted working space onsite	7	10.94%
To increase your company's profit margin	4	6.25%
To reduce environmental impact	2	3.13%
To improve project safety performance	2	3.13%
To enhance your company's reputation	0	0%
Other reasons	0	0%

The Top 3 challenges of using offsite construction techniques

Each questionnaire listed 13 reasons that may restrain the use of offsite construction techniques. Each participant was asked to circle the top three (3) reasons from the given options. The top 3 challenges selected by A/Es in rank order were: 1) inability to make changes onsite, 2) transportation restraints, and 3) limited design options, as presented in Table 6.

Table 6 the top three (3) challenges of using offsite construction techniques for A/Es

Categories	Frequency	Percentage
Inability to make changes onsite	35	54.69%
Transportation restraints	34	53.13%
Limited design options of using offsite construction techniques	31	48.44%
General contractors do not have expertise of assembling prefabricated building components onsite	22	34.38%
Lack of skilled assembly craft works locally	10	15.63%
The project owners do not allow using offsite construction techniques	10	15.63%
Using offsite construction techniques will increase the construction cost	8	12.50%
Any other reasons	8	12.50%
The local building regulation restricts the use of off-site construction techniques	6	9.38%
The local zoning ordinance restricts the use of offsite construction techniques	5	7.81%
Designing offsite construction components requires special computer software	4	6.25%
Using offsite construction techniques will increase the design cost	3	4.69%
The financial institution restricts the use of offsite construction techniques	0	0%

Likewise, the top 3 challenges selected by GCs in rank order were 1) transportation restraints, 2) limited design options, and 3) inability to make changes onsite, as presented in Table 7.

Table 7 the top three (3) challenges of using offsite construction techniques for GCs

Categories	Frequency	Percentage
Transportation restraints	30	46.88%
Limited design options of using offsite construction techniques	29	45.31%

Inability to make changes onsite	26	40.63%
The project owners do not allow using offsite construction techniques	11	17.19%
The financial institution restricts the use of offsite construction techniques	9	14.06%
Using offsite construction techniques will increase the design cost	7	10.94%
The local zoning ordinance restricts the use of offsite construction techniques	7	10.94%
Using offsite construction techniques will increase the design cost	7	10.94%
Using offsite construction techniques will increase the construction cost	6	9.38%
Other reasons	5	7.8%
The local building regulation restricts the use of offsite construction	4	6.25%
General contractors do not have expertise of assembling prefabricated building components onsite	1	1.56%

Conclusions

Results of this study indicated that using offsite construction techniques could be one of most effective approach to overcome the current challenges in the US construction industry, including the shortage of workforce and aggressive schedules. However, the current level of using these techniques is limited to offsite preassemblies, predominately precast concrete products and preassembled trusses.

Findings indicated that, at the 95% confidence interval, both A/Es and GCs groups in the building sector of the US construction industry strongly suggested that the benefits of using offsite construction techniques included: 1) reducing overall project schedule(including the design, procurement, and construction phases); 2) improving product quality; 3) increasing overall labor productivity; 4) increasing onsite safety performance; and 5) reducing negative environmental impact of construction operations. In addition, the results also suggested that GCs group perceived the 2 other significant benefits of using offsite construction techniques as: 1) the reduced need for skilled craft workers onsite; and 2) reduced project construction cost.

Findings also indicated that A/Es and GCs perceived the significant barriers of using offsite construction techniques as: 1) transportation constraints associated with size restraints, transportation cost, and the negative impact on the structural integrity of building component during the mobilization, and 2) the inability to make onsite changes. None of these groups indicated that the owner's perceptions of these techniques have significant impact on its use.

According to this study, the top 3 reasons for A/Es to use offsite construction techniques in rank order were: 1) to reduce the construction duration; 2) to reduce the overall project duration (including the design, procurement, and construction phases), and 3) to reduce overall project cost. The top 3 reasons for GCs in rank order were: 1) to reduce the construction duration, 2) to reduce the overall project duration

(including the design, procurement and construction phases), and 3) to reduce the overall project cost and to compensate for local weather conditions.

The top 3 challenges of using offsite construction techniques for A/Es in rank order were: 1) inability to make changes onsite; 2) transportation restraints, and 3) limited design options. The top 3 challenges for GCs in rank orders were 1) transportation restraints, 2) limited design options, and 3) inability to make changes onsite.

Recommendations

Based on the findings the researcher proposed four major recommendations summarized below: 1) construction companies, material suppliers, and professional organizations should conduct more R & D in the area of customized design and alternative materials; 2) Develop and provide awareness training to manufactures, general contractors, and designers in the use of offsite construction techniques; 3) develop new and improving existing offsite construction certification schemes, and 4) owners, designers, and general contractors should collaborate with each other on pre-project planning to minimize the possibility of onsite changes.

References

Bakens, W. (1997). "International trends in building construction research." Journal of Construction Engineering and Management, 123 (2), 102-124.

Blismas, N. et al, (2006). "Benefit evaluation for off-site production in construction." Construction Management and Economics, 24 (2), 121-130.

Construction Industry Institute. (1998). "Multi-skilling labor strategies in construction: implementing multi-skilling in the construction industry." (CII Publication No. RR137-13). The University of Texas at Austin, Austin.

Construction Industry Institute. (2002). "Develop a decision support tool for prefabrication, preassembly, modularization, and off-site fabrication." (CII Publication No. RR171-12). The University of Texas at Austin, Austin.

CMAA (2006). "FMI/CMAA Sixth annual survey of owner." URL http:// cmaanet.org/foundation_research.php

Gibb, A. G. F. (2001). "Off-site fabrication: prefabrication, pre-assembly and modularization." UK: Whittles Publishing.

Gibb, A. G. F. & Pendlebury, M. (2005). "Build offsite – promoting construction offsite: glossary of terms." UK: Whittles Publishing.

Hass, C. T. (2000). "*Prefabrication* and preassembly trends and effects on the construction workforce (CII Report No. 14)." The Construction Industry Institute, University of Texas at Austin.

Kumar, R. (2005) "Research Methodology (2nd ed.)" Sage Publications Ltd.

Liska, R. W. & Piper, C. (1999) "Attracting and maintaining a skilled workforce, Construction Industry Institute." University of Texas at Austin, Austin.

Lu, N. (2007) "Investigation of the designers' and general contractors' perceptions of offsite construction techniques in the United States construction industry" (Doctoral dissertation, Clemson University, 2007) UMI Publishing.

O'Brien M., Wakefied, R., & Beliveau, Y. (2000). "Industrializing the residential construction site." Report of U.S. Department of Housing and Urban Development Office of Policy Development and Research. Washington, DC.

Ott, R. L. & Longnecker M. (2001). "An introduction to statistical methods and data analysis." Duxbury Publishing.

Pasquire, C.L., & Gibb, A.G.F. (2002). "Considerations for assessing the benefits of standardization and pre-assembly in construction." Journal of Financial Management of Property and Construction, 7 (3), 151-161.

FORECASTING CONSTRUCTION MANPOWER DEMAND: AN ECONOMETRIC MODEL

James MW Wong[1], S Thomas Ng[1], Albert PC Chan[2] and YH Chiang[2]

[1] Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong
[2] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

Abstract
Manpower forecast has become an important management tool for decision makers and policy makers to match and structure the skills of the workforce. National planners are also increasingly aware that the competitiveness and growth of the nation, as well as its social welfare, depend in no small degree on the full exploitation of the skills of its people. However, there is very limited research in establishing a comprehensive manpower demand forecasting model in construction. This paper aims to present the framework of an advanced econometric model for estimating the manpower demand in construction. Vector error correction modeling, regression analysis and exponential smoothing technique were applied to develop the relationships between manpower demand and the relevant variables in the construction industry. The forecasting models developed can benefit the construction industry by providing critical information on the future construction manpower requirements and assist policy makers and training planners to formulate training strategies. Apart from this practical use, the research also contributes new knowledge and a solid framework to the area of manpower forecasting and planning.

Keywords
Forecasting, manpower planning, vector error-correction model, construction industry

Introduction

Since the early 1960s, most of the developed and developing countries have recognized the value of manpower planning. Manpower planning at national level is

[1] Corresponding author: James Wong, Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong. Tel.: +852-2241-5348; fax; +852-2559-5337; Email address: jmwwong@hkucc.hku.hk

crucial for any country or industry to deal with the problems of growing unemployment, knowledge obsolescence and changing skills requirements. It aims to find the right number of workers with the right skills, otherwise structural unemployment or skill shortage would impede industrial development (Schmidt *el at*., 2003).

In construction, the pace of technological change, combined with increased specialization especially on large-scale projects, will also focus more attention on the pattern of future skill requirements (Agapiou, 1996). It would be, in the long term, rather naive to depend upon importation of labor and expansion of investment in the construction sector to solve skill shortages and surplus, respectively. Rather, planning of the skill training holds the key to resolve the demand and supply balance (Schmidt *et al.*, 2003). If manpower demand forecasts were available to provide advanced warning of likely shortfalls, training providers would have the necessary indication to enable adjustments of skill supply and hence alleviate the damaging effects of resources mismatch (Hillebrandt and Meikle, 1985; Agapiou *et al.*, 1995a).

In Hong Kong, the existing manpower demand forecasts for the construction industry play an important role in the local strategic education and training planning for meeting future needs. However, without carefully examining the determinants of the construction manpower demand and failing to predict the volume of construction work accurately, the reliability and applicability of these models are questionable (Wong *et al*, 2005). Hence, more advanced modeling technique to improve the accuracy of the manpower demand forecasts for the construction industry is recommended.

Additionally, although the Construction Industry Review Committee[2] Report (2001) has addressed the importance of a sound mechanism for projecting construction manpower supply and demand, lack of research still concerns manpower planning especially on methodology for compiling and exploiting manpower statistics to facilitate manpower forecasting, and to provide a reliable consistent basis for reference by policy makers and the industry stakeholders. The EMB (2000) and CIRC (2001) also highly recommend developing a detailed econometric model to produce short- to medium-term manpower forecasts in Hong Kong. To have a thorough understanding of the future labor market and to avoid structural unemployment or skill shortage, there is a genuine need to re-visit this very important concept of the demand for construction manpower

This paper, based on an earlier research work by Wong (2006), aims to provide a complete overview of a recent developed manpower requirement forecasting model for the Hong Kong construction industry. Applications of the model are discussed. Areas for further development on manpower forecasting are also recommended.

[2] In April 2000, the Construction Industry Review Committee (CIRC) was appointed by the Chief Executive of the Hong Kong SAR to comprehensively review the current state of the industry and to recommend improvement measures.

The Manpower Demand Forecasting Model

General framework

The major manpower demand forecasting approaches at the industry level can be broadly categorized into four clusters: (i) time series projection; (ii) 'bottom-up' coefficient approach; (iii) 'top-down' approach and (iv) labor market analysis (Wong *et al*., 2004). Although time series projection can provide prompt and economical forecasts, it is not sensitive to the effects of changes in governmental or organizational policy upon required manpower levels and it is more appropriate to be used for short-term forecasts. Similarly, labor market analyzes are only able to detect the occupational mismatch in the labor market in a short time span. Another limitation of the market analyses is that the 'signals' for semi-skilled/unskilled workers are usually not accessible thus adversely affecting the comprehensiveness of the forecasts. For the 'bottom-up' approach, aggregating the project-based manpower demand, as derived from all future projects, provides the prospect of the overall labor market requirements. However, it is extremely demanding to collect past employment records and the details of the future project estimates, especially in the private sector and the maintenance sector, for the forecasting at the industry level.

Considering the ability to capture the determinants of the manpower requirements and reliance on econometrical modeling with rigorous verifications, the 'top-down' approach is proposed to build the industry-based manpower demand forecasting models as shown in Figure 1. It allows the testing of "what if" scenarios, such as assessing the impacts of major development projects or migration flows on employment and economic output, notwithstanding sophisticated calculations that it might involve.

To comply with the official manpower statistics, the forecasting framework consists of three separate levels: (i) aggregate level (total manpower demand in the construction industry); (ii) broad occupational level (i.e. seven broad occupational groups, namely, Managers and Administrators, Professionals, Associate Professionals, Clerks, Craft and Related Workers, Plant and Machine Operators and Assemblers, and Elementary Occupations as defined by the Census and Statistics Department (C&SD), HKSAR Government); and (iii) detailed occupational level (19 professional job titles e.g. Architects, Civil Engineers, Land Surveyors, etc.; 22 technician job titles e.g. Draughtsman, Civil Engineering Technician, Site Agent, etc. as defined by the Vocational Training Council (VTC, 2007)). The data were acquired from various official statistics reports issued by the C&SD of the HKSAR Government and the Vocational Training Council. The data series are cautiously selected and examined for developing the forecasting models.

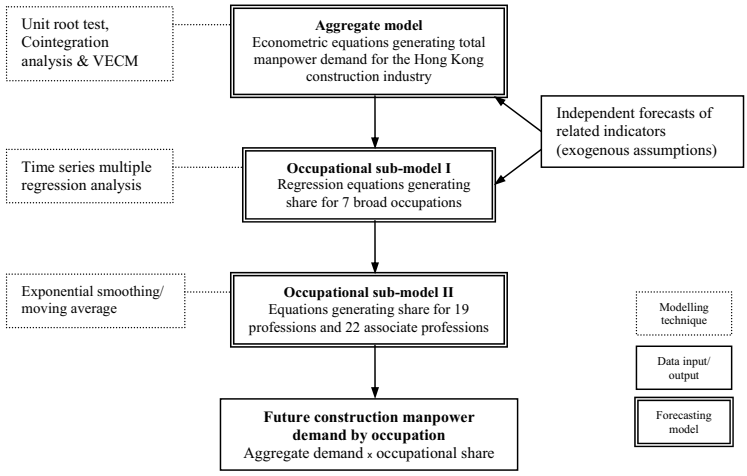


Figure 1 Framework of the Manpower Demand Forecasting Model for the Hong Kong Construction Industry

Aggregate model

Cointegration analysis and vector error correction modeling (VECM) technique are selected for forecasting the aggregate construction manpower demand. The VEC specification allows investigating the dynamic co-movement among variables and the adjustment process toward cointegrated long-term equilibrium, a feature unavailable in other forecasting models (Masih, 1995). Empirical studies (e.g. Anderson *et al*., 2002; Darrat *et al*., 1999; Crane and Nourzad, 1998) have also demonstrated that the VECM achieved a high level of forecasting accuracy in the field of macroeconomics.

The starting point for deriving an econometric model of aggregate manpower demand is to establish the properties of the time series measuring industry employment and its key determinants, i.e. tests for the integrated order (Briscoe and Wilson, 1991). Only variables integrated of the same order may be cointegrated. Augmented Dickey-Fuller (ADF) unit root tests, which were developed by Dickey and Fuller (1979) and extended by Said and Dickey (1984) based on the following auxiliary regression, can be employed

$$\Delta y_t = \alpha + \delta t + \gamma\, y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + u_t \qquad (1)$$

The variable Δy_{t-i} expresses the lagged first differences, μ_t adjusts the serial correlation errors and α, β and γ are the parameters to be estimated. This augmented

specification is used to test for $H_0 : \gamma = 0$ vs. $H_a : \gamma < 0$ in the autogressive (AR) process.

Cointegration analysis and VEC model are then applied to derive manpower demand specification. Although many economic time series may have stochastic or deterministic trend, groups of variables may drift together. A vector of time series is said to be cointegrated with cointegrating vector if each element is stationary only after differencing while linear combinations are themselves stationary (Engle and Granger, 1987). A VEC model is a restricted VAR designed for use with nonstationary series that are known to be cointegrated. The VEC has cointegration relations built into the specification so that it restricts the long-run behavior of the endogenous variables to converge to their cointegrating relationships while allowing for short-run adjustment dynamics. The cointegration term is known as the error correction term since the deviation from long-run equilibrium is corrected gradually through a series of partial short-run adjustments (Lütkepohl, 2004).

The manpower demand model at the aggregate level attempts to link construction manpower demand to variables in equilibrium identified with economic theory, *viz.* construction output, real wages, material prices, bank rate and labor productivity. If the economic theory is relevant, it is expected that the specific set of suggested variables are interrelated in the long run. Hence there should be no tendency for the variables to drift apart increasingly as time goes on, i.e. the variables in the model form a unique cointegrating vector.

To test for the cointegration, the maximum likelihood procedures of Johansen and Juselius may be employed because of its dynamic nature and sensitivity to a variety of factors affecting the manpower demand, and its taking into account indirect and local inter-sectoral effects. Suppose that the variables in the manpower demand function are in the same integrated order, these variables may cointegrate if there exists one or more linear combinations among them. A VAR specification is used to model each variable as a function of all the lagged endogenous variables in the system. Johansen (1988) suggests that the process y_t is defined by an unrestricted VAR system of order (p):

$$y_t = \delta + \Gamma_1 y_{t-1} + \Gamma_2 y_{t-2} + \ldots + \Gamma_p y_{t-p} + u_t \qquad t = 1, 2, 3, \ldots, T \tag{2}$$

where y_t are $I(1)$ independent variables, Γ's are estimable parameters and $u_t \sim$ niid (0, Σ) is vector of impulses which represent the unanticipated movements in y_t. However, such a model is only appropriate if each of the series in y_t is integrated to order zero, I(0), meaning that each series is stationary (Price, 1998). Using $\Delta = (I - L)$, where L is the lags operator, the above system can be reparameterized in the VEC model as:

$$\Delta y_t = \delta + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + u_t \tag{3}$$

where Δy_t is an $I(0)$ vector, δ is the intercept, the matrix Γ reflects the short-run aspects of the relationship among the elements of y_t and the matrix Π captures the long-run information. The number of linear combinations of y_t that are stationary can be determined by the rank of Π, which is denoted as r. If there are k endogenous variables, Granger's representation theorem asserts that if the coefficient matrix Π has reduced rank $r < k$, then there exists k x r matrices, α and β, each with rank r such that $\Pi = \alpha \beta'$ and $\beta' y_t$ is stationary. The order of r is determined by using likelihood ratio (LR) trace test statistic (Q_r):

$$Q_r = -T \sum_{i=r+1}^{k} \log(1 - \lambda_i) \tag{4}$$

for $r = 0, 1, \ldots, k\text{-}1$ where T is the number of observation used for estimation, λ_i is the i-th largest estimated eigenvalue and is the test of $H_0(r)$ against $H_1(k)$. The models will be rejected where Π has a full rank, i.e. $r = k\text{-}1$ since in such a situation y_t is stationary and has no unit root, thus no error-correction can be derived. If the rank of Π is zero, this implies that the elements of y_t are not cointegrated, and thus no stationary long-run relationship exists. As a result, the conventional VAR model in first-differenced form shown in Equation 2 is an alternative specification. Based on the assumption that Π does not have a full rank, the estimated long-run construction manpower demand in Hong Kong can be computed by normalizing the cointegration vector of manpower demand as a demand function.

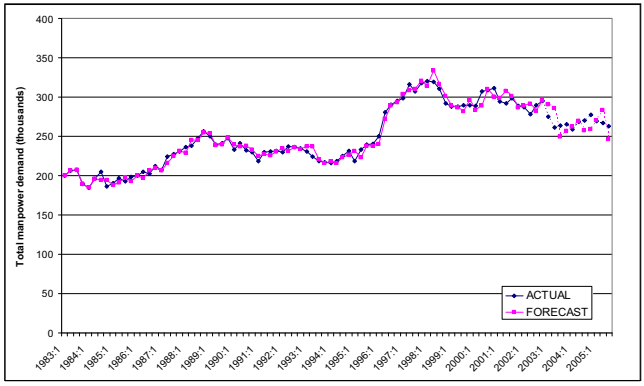
While the cointegrating vectors determine the steady-state behavior of the variables in the vector error correction model, the dynamic representation of the construction manpower demand to the underlying permanent and transitory shocks are then completely determined by the sample data without restriction. One motivation for the VECM(p) form is to consider the relation $\beta' y_t = \text{c}$ as defining the underlying economic relations and assume that the agents react to the disequilibrium error $\beta' y_t - \text{c}$ through the adjustment coefficient α to restore equilibrium; that is, they satisfy the economic relations. The cointegrating vector, β are the long-run parameters (Lütkepohl, 2004).

Estimation of a VEC model proceeded by first determining one or more cointegrating relations using the aforementioned Johansen procedures. The first difference of each endogenous variable is then regressed on a one period lag of the cointegrating equation(s) and lagged first differences of all of the endogenous variables in the system. The VEC model can be written as the following specification:

$$\Delta d_t = \delta + \alpha(\beta' y_{t-1} + \rho_0) + \sum_{i=1}^{p} \gamma_{1,i} \Delta y_{1,t-i} + \sum_{i=1}^{p} \gamma_{2,i} \Delta y_{2,t-i} + \ldots\ldots + \sum_{i=1}^{p} \gamma_{j,i} \Delta y_{j,t-i} + u_t \tag{5}$$

where y_t are $I(1)$ independent variables, d is the total construction manpower demand, α is the adjustment coefficient, β are the long-run parameters of the VEC function, the $\gamma_{j,i}$ reflects the short-run aspects of the relationship between the independent variables and the target variable.

Various diagnostic tests should be applied to assess the adequacy and reliability of the developed models. These include the Lagrange multiplier tests (LM) for up to respectively one and forth order serial correlation in the residuals, White's test (White, 1980) for heteroscedasticity (H) in the residuals and for model misspecification, the Jarque-Bera test for normality (NORM) of the residuals (Jarque and Bera, 1980). In addition, a sensitivity analysis is helpful to detect the sensitivity of the construction manpower demand to the changes in a series of key indicators using the VEC model. The predictive adequacy of the developed VEC forecasting model is further evaluated by comparing the *ex post* forecasts with the actual occupational share. In addition, mean absolute percentage error (MAPE) was used to quantitatively measure the predictability of the developed forecasting models as shown in Figure 2. The prediction percentage error of VEC model is consistently within the acceptable limit of 10%, giving a fairly low MAPE i.e. 4.52%.



Note: solid line – *ex post* simulation period; dotted line – *ex post* forecasting period
Figure 2 Predictability of the VEC model

Occupational share model – broad occupations
Once the aggregate manpower demand forecasts have been produced, the broad occupational share forecasting models[3] are formulated using a time series regression analysis. It attempts to derive the relationship between the individual occupational share and the identified determinants including time trend, output cycle, technology and various work-mix variables. Multiple regression analysis is superior in its capability to provide a means of objectively assessing the degree and character of the relationship between the dependent and independent variables, and thereby formulating an equation to predict the dependent variable (Gujarati, 1988). Regression analysis is also a suitable tool for revealing a trend or a long-term development in a time series. With this technique it is possible to estimate the

[3] Seven broad occupational groups are covered, namely, Managers and Administrators, Professionals, Associate Professionals, Clerks, Craft and Related Workers, Plant and Machine Operators and Assemblers, and Elementary Occupations.

effectiveness of the intervention taking into account any underlying trends and serial correlation (Ostrom, 1990). In addition, each significant independent variable is weighted by the regression analysis procedure to ensure maximal prediction from the set of independent variables (Hair *et al*., 1998).

Lead and lag relationships between the dependent and independent variables are anticipated as individual occupational share is influenced by the past changes in the independent variables. Therefore, a maximum lag of four quarters is used for this study as an adequate period for the influence of a change in a factor on the occupational share to be completed. The proposed model is in the form:

$$P_s = \beta_0 + \beta_{i1}\sum_{i=0}^{4} X_{1,t-i} + \beta_{i2}\sum_{i=0}^{4} X_{2,t-i} + ...+\beta_{ij}\sum_{i=0}^{4} X_{j,t-i} + \mu_i \qquad (6)$$

where P_s represents the percentage share for labor demand of occupation s, $X_1, X_2, ..., X_j$ are the independent variables; the parameters $\beta_{i1}, \beta_{i2}, ..., \beta_{ij}$ are the partial regression coefficients; the intercept β_0 is the regression constant.

Equation 6 is estimated using stepwise regression analysis. The variables that enter and remain in the regression equation are determined by the stepwise regression criteria. Based on economic theory, this analysis allows specifying the economic relationships with the precise quantification of the lag distribution being best left to the data (Burridge *et al*., 1991). Likewise, diagnostics tests of autocorrelation, normality and heteroscedasticity should be conducted to ensure the reliability and robustness of the developed occupational share models.

The prediction percentage error of the broad occupational share models, except for the 'Managers and Administrators', are within the acceptable limit of 10%. These indicate the robustness and reliability of the models.

Occupational share model – detailed occupations

The coverage of the forecasts and the selection of forecasting methodologies depend heavily on the availability and nature of the data (Rosenfeld and Warszawski, 1993). At the detailed occupational level, since only 13 biennial data points are available for the manpower engaged in the construction industry, merely simple univariate extrapolation is applicable for estimating future detailed occupational share. Three non-seasonal exponential smoothing (ES) methods are employed, including single exponential smoothing (SES), double exponential smoothing (DES) (Brown, 1959), and Holt-Winter's no seasonal method (HW) (Holt, 1957; Winters, 1960), as shown in Table 1.

Description	**Forecasts (for all $k > 0$)**	**Smoothing method (by the following recursion)**
1. Single Smoothing	$\hat{y}_{T+k} = \hat{y}_T$	$\hat{y}_t = \alpha y_t + (1-\alpha)\hat{y}_{t-1}$ where $0 < \alpha \leq 1$

2. Double Smoothing	$\hat{y}_{T+k} = 2S_T - D_T + \frac{\alpha}{1-\alpha}(S_T - D_T)k$	$S_t = \alpha y_t + (1-\alpha)S_{t-1}$ $D_t = \alpha S_t + (1-\alpha)D_{t-1}$ where $0 < \alpha \leq 1$
3. Holt-Winters (no seasonal)	$\hat{y}_{T+k} = a(T) + b(T)k$	$a(t) = \alpha y_t + (1-\alpha)(a(t-1) + b(t-1))$ $b(t) = \beta(a(t) - a(t-1)) + (1-\beta)b(t-1)$ where $0 < \alpha, \beta \leq 1$

Table 1 Models for non-seasonal linear forms of exponential smoothing

ES is an effective way of forecasting when there are only a few observations on which to base the forecast (Bowerman and O'Connell, 1993). This method produces a time trend forecast, but in fitting the trend, the parameters are allowed to change gradually over time, and earlier observations are given exponentially declining weights. In general, ES methods have a proven record for generating sensible point forecasts (Gardner, 1985; Makridakis and Hibon, 2000). Each method in Table 1 contains a measurement equation that specifies how series values are built from unobserved components. The α and β are so-called smoothing parameters. These parameters can be estimated by minimizing the sum of squared errors. The best method for estimating the detailed occupation share shall be chosen by comparing the root mean square error (RMSE). The rates derived at broad and detailed occupational levels can subsequently be combined to the corresponding employment level to forecast the future manpower demand series.

Applications of the Manpower Demand Model

The forecasting models developed at the aggregate level, broad occupational level and detailed occupational level have been validated through diagnostic tests and predictability tests. The models can be used concurrently to generate reliable forecasts of the short- to medium-term construction manpower demand. These demand-side forecasts, together with the future labor force supply, allow the construction industry to identify early imbalance in the occupations of the labor market and thereby to assist in formulating training strategies. In addition, addressing the most significant factors affecting the manpower demand, as identified from the VEC modeling, namely construction output and labor productivity, on policy formulation and implementation is critical in order to maintain a sustainable labor market.

Apart from this practical use, the research also contributes new knowledge and a solid framework to the area of manpower forecasting and planning by employing advanced econometric modeling techniques. Combining the driving force from the five independent variables for estimating the long-run aggregate construction manpower in Hong Kong, the model also improves on earlier relatively primitive employment specifications carried out in a bivariate setting (e.g. Pehkonen, 1991; Harvey *et al*., 1986).

Areas for Further Development

Refining the model specifications
The occupational share equations for estimating the demand for detailed occupations at the industry level are relatively simple specifications, without dynamic characteristics and having to consider the relationship with determinants of the occupational share. Such modifications, however, will only be possible when more reliable and detailed data exists. Improving the manpower statistics is therefore important for comprehensive manpower planning in construction.

The forecast of total construction manpower demand is the central component of the industry-based model, because this governs the occupational estimates. The aggregate forecasting equation is developed by incorporating five main explanatory variables in construction, namely, industrial output, real wages, material price, interest rates, and labor productivity. The values of each of these variables are in turn dependent upon changes in exogenous factors in the macro economy. However, both the global economy and Hong Kong government policy are subject to continuous change, thus it is difficult to anticipate far in advance the likely value of these macro determinants. The link between the macroeconomic forecasts and the industry-based model should therefore be further studied in order to obtain more realistic demand forecasts.

User feedback should be obtained as the models are put to use and the forecasts are distributed to those involved in manpower planning. One important group of users who might be expected to provide feedback information is government officers. They have a prime responsibility for estimating industry-based manpower demand and training provision but research resources are usually lacking to make longer-term predictions. Similar considerations apply to the various specialist trade associations and employer groups in the construction sector. If all these potential users are to benefit from the workings of the model, it is important that their feedback is taken into account in developing improved models.

Extending the forecasting models
The industry-based model has been developed for the Hong Kong construction industry, but the definition of 'construction' could be rather arbitrary in the final analysis. Inevitably, construction supply chain overlaps at a number of points with various engineering industries, materials supply, transport and communication and also with local government. Occupational demand changes in construction are likely to have an impact on each of these sectors. The model at present does not look beyond construction to explore skill requirement changes in such associated sectors. Hence, it is valuable to identify these relationships so as to, for instance, make more explicit impact of planned changes in the manufacturing sector on construction manpower demand. The extension of these types of relationships will complicate the workings of the model, but such an extension should produce a greater body of information for those planning employment and training.

In addition, international dimensions of the forecasting model could be extended to enhance the comprehensiveness of the manpower planning framework. Increasing construction demand in developing cities such as Macau, China and Middle East has been apparent recently. A significant international movement of construction manpower is observed in these neighboring areas. There are likely considerable flows in both directions in future. The major concern is with the direction of the net flow and any resulting change in the skill composition. It will become important to model the flows and to integrate such a migration model into the main manpower demand forecasting framework. Obviously much data would be required to serve such an exercise and co-operation and intensive cross-border/cross-country construction planning authorities would be required.

Future developments in manpower forecasting are inevitably linked to development in information technology (Bartholomew *et al*., 1991). It is anticipated that, given the improvement of the time series data available, econometrics modeling techniques and the advanced development in information technology and statistical software packages, improved modeling capability can be realized. Such developments will make manpower planning more accessible and accurate at every level of the society.

Acknowledgement

The authors would like to acknowledge the financial support of the Research Grants Council of the HKSAR Government through the Competitive Earmark Research Grant (Grant No.: 7152/07E).

References

Agapiou, A. (1996) *Forecasting the Supply of Construction Labour*, PhD Thesis, Loughborough University.

Agapiou, A., Price, A.D.F. and McCaffer, R. (1995a) Planning future construction skill requirements: understanding labour resource issues, *Construction Management and Economics*, 13(2), 149-61.

Anderson, R.G., Hoffman, D.L. and Rasche, R.H. (2002) A vector error-correction forecasting model of the US economy, *Journal of Macroeconomics*, 24, 569-98.

Bartholomew, D.J., Forces, A.F. and McClean, S.I. (1991) *Statistical Techniques for Manpower Planning*, Chichester, New York : Wiley.

Bowerman B.L. and O'Connell, R.T. (1993) *Forecasting and Time Series: An Applied Approach*, 3ed., California: Duxbury Thomson Learning.

Briscoe, G. and Wilson, R. (1991) Explanations of the demand for labour in the United Kingdom engineering sector, *Applied Economics*, 23, 913-26.

Brown, R.G. (1959) *Statistical Forecasting for Inventory Control*, New York: MsGraw-Hill.

Burridge, M., Dhar, S., Mayes, G., Neal, E., Tyrell, N. and Walker, J. (1991) Oxford economics forecasting system of models, *Economic Modelling*, 8(3), 227-54.

CIRC (2001) *Construct for Excellence*, Report of the Construction Industry Review Committee, HKSAR.

Crane, S.E. and Nourzad, F. (1998) Improving local manufacturing employment forecasts using cointegration analysis, *Growth and Change*, 29(2), 175-95.

Darrat, A.F., Shelor, R.M., and Dickens, R.N. (1999) Forecasting corporate Performance: VECM comparison with other time-series models, *Studies in Economics and Finance*, 19(2), 49-61.

Dickey, D.A. and Fuller, W.A. (1979) Distribution of the estimators for autoregressive time series with unit roots, *Journal of American Statistical Association*, 74, 427-431.

Eagle, R.F. and Granger, C.W.J. (1987) Co-integration and error correction: representation, estimation, and test, *Econometrica*, 55(2), 251-276.

EMB (2000) *Final Report on Consultancy on Best Overseas Manpower Forecasting Practice*, Education and Manpower Bureau, HKSAR: the Government Printer.

Gardener, E.S. (1985) Exponential smoothing: the state of the art, *Journal of Forecasting*, 4, 1-28.

Gujarati, D.N. (1988) *Basic Econometrics*, 2ed., Singapore: McGraw Hill.

Hair, J.F., Anderson, R.E., Tatham, R.L. and Black, W.C. (1998) *Multivariate Data Analysis*, 5ed., USA: Prentice-Hall International Inc.

Harvey, A.C., Henry, S.G.B., Peters, S. and Wren-Lewis, S. (1986) Stochastic trends in dynamic regression models: an application to the employment-output equation, *The Economic Journal*, 96, 975-85.

Hillebrandt, P.M. and Meikle, J.L. (1985) Resource planning for construction, *Construction Management and Economics*, 3, 249-63.

Holt, C.E. (1957) *Forecasting Trends and Seasonal by Exponentially Weighted Averages,* ONR Memorandum no. 52, Pittsburgh, PA: Carnegie Institute of Technology.;

Jarque, C.M. and Bera, A.K. (1980) Efficient tests for normality, homoscedasticity and serial independence of regression residuals, *Economics Letters*, 6, 255-259.

Johansen, S. (1988) Statistical analysis of cointegration vectors, *Journal of Economic Dynamics and Control*, 12, 231-254.

Lütkepohl, H. (2004) Vector autoregressive and vector error correction models. *In:* Lütkepohl, H. and Krätzig, M. (eds.) *Applied Time Series Econometrics*, London: Cambridge University Press.

Makridakis, S. and Hibon, M. (2000) The M3 competition, *International Journal of Forecasting*, 16, 451-76.

Masih, R. (1995) Modelling the dynamic interactions among crime, deterrence and social-economic variables: evidence from a vector error-correction model, *Mathematics and Computers in Simulation*, 39, 411-16.

Ostrom, C.W. (1990) *Time Series Analysis: Regression Techniques*, 2ed., Newbury Park, Calif.: Sage Publications.

Pehkonen, J. (1991) Real wages-employment relationship in Finnish manufacturing: a VAR approach, *Applied Economics*, 23, 1559-68.

Price, S. (1998) Cointegration and modelling the long run. *In*: Scarbrough, E. and Tanenbaum, E. (eds.) *Research Strategies in the Social Sciences: A Guide to New Approaches,* Oxford: Oxford University Press.

Rosenfeld, Y. and Warszawski, A. (1993) Forecasting methodology of national demand for construction labour, *Construction Management and Economics,* 11(1), 18-29.

Said, E.S. and Dickey, D.A. (1984) Testing for unit roots in autoregressive-moving average models of unknown order, *Biometrika*, 71(3), 599-607.

Schmidt, S.L., Schömann, K. and Tessaring, M. (2003) *Early Identification of Skills Needs in Europe*, Federal Ministry of Education and Research, European Centre for the Development of Vocational Training, Cedefop Reference series, 40, Luxemburg.

VTC (2007), *Manpower Survey Report of the Building & Civil Engineering Industry*, Hong Kong: the Vocational Training Council.

White, H. (1980) A Heteroskedasticity – consistent covariance matrix and a direct test for heteroskedasticity, *Econometrica*, 48, 817-38.

Winters, P.R. (1960) Forecasting sales by exponentially weighted moving averages, *Management Science*, 6, 324-42.

Wong, J.M.W., Chan, A.P.C. and Chiang, Y.H. (2005) The quality of projections: manpower demand for the construction industry, *In*: *QUT Research Week International Conference*, 4-8 July 2005, Queensland University of Technology.

Wong, J.M.W. (2006) *Forecasting Manpower Demand in the Construction Industry of Hong Kong*, PhD Thesis, The Hong Kong Polytechnic University, Hong Kong.

THE CORE OF EDEN: A CASE STUDY ON MODEL-BASED COLLABORATION FOR INTEGRATED PROJECT DELIVERY

Kihong Ku, DDes[1]

ABSTRACT

The paper examines the model-based design processes in the Eden Core project in Cornwall, U.K., concentrating on key aspects of the collaboration between the architect, consultants, design-build general contractor, and fabricator, within the specific context of an innovative biomimetic design which integrates sustainability and a biologically inspired complex geometric roof structure. It is analyzed how 3D models support building simulation processes and how various computer modeling techniques are used to resolve the complex geometric issues of the timber grid-shell roof fabrication design. The paper aims to contribute to the understanding of model-based practices in the design of sustainable and complex-shaped buildings, and adds to the growing body of descriptive literature on integrated practice. The study provides (1) a 3D modeling process map which describes how modeling supports collaboration and how it integrates into traditional design processes, and concludes with (2) alternative approaches to overcome the challenges of model-based collaboration approaches.

INTRODUCTION

As clients demand greater certainty of delivery to satisfy their needs for larger, more complex, yet cost effective, faster, and simultaneously environmentally responsible solutions, the imperative of integrated project delivery is becoming more and more intense (Bedrick 2006). This integrated practice vision is founded on effective collaboration that is supported by Building Information Modeling (BIM) (AIA 2007). However, despite the rising awareness of the benefits of model-based collaboration and its integration with the design and construction process, the widespread adoption of this methodology is slow and professionals continue to struggle to effectively integrate model-based applications into the daily management processes (Hartmann and Fischer 2007). A growing body of descriptive literature (Olofsson et al. 2008) identifies the lack of understanding of digital modeling processes (Gao and Fischer 2007; Kolarevic 2003; Eastman et al. 2008; Chaszar and Glymph 2003).

[1] Assistant Professor of Building Construction, School of Construction (0156), Virginia Tech, 410A Bishop-Favrao Hall, Blacksburg, VA24061, email: kku@vt.edu

The implementation of integrated practice and integration of model-based processes are challenging because it involves understanding of new technologies (e.g., BIM, computer-aided design and manufacturing (CAD/CAM), etc.), and furthermore, organizational and managerial changes at various levels. The key to leverage the benefits of enhanced design and communication capabilities is *collaboration* (Allen et al., 2005). Thus, this study examines the collaborative use of 3D modeling within the specific context of the Eden Core project to highlight the 3D information needs, communication processes, and collaboration challenges.

MODEL-BASED COLLABORATION

Collaboration only happens under mutual trust and respect which allows a team of specialists to constantly share information and knowledge during the decision-making process (Gray and Hughes 2001). Maher et al. (1998) suggest three types of design collaboration (i.e., mutual; exclusive; and dictatorship) among which the 'exclusive collaboration' model is the most effective where participants "work on separate parts of the problem, negotiating occasionally by asking advice from the other." Kvan (2000) further supports this view and discusses the needs for tools and conditions for a loose-coupled process. As opposed to a close-coupled process where "the participants work intensely with one another, observing and understanding each other's moves, the reasoning behind them and the intentions," people are rationally bounded, and thus, model-based design processes should adequately address the challenges of such collaboration processes.

Various research efforts have attempted to apply and explain various model-based processes to construction projects. Virtual Design and Construction (VDC) processes have been termed by the Center of Integrated Facilities Engineering (CIFE) (Bedrick 2006). VDC is a "computer simulation of the building, its performance, and its construction" conducted before actual construction. Eastman et al. (2008) provide a comprehensive guide to BIM which involves the use of intelligent BIM and parametric modeling tools, new practice models and redefinition of design roles. Kam and Fischer (2005) reviewed the needs for interoperability in product modeling. While the industry long-term vision suggests collaboration on a single shared model (Suomi, 2002), current practice is based on federated models each created and managed by the individual collaborators (NIBS, 2007). These research efforts concentrate on the technology needs and general framework for modeling processes rather than specific aspects of collaboration. Ku et al. (2008) and Cardenas (2007) focused on collaboration strategies for model-based processes in free-form architecture. Ku (2005) discusses the challenges of effective geometry control strategies between external design team members and Cardenas illustrates parametric modeling strategies for CAD/CAM processes.

The focus of this paper expands the latter views and identifies the challenges to and strategies for model-based collaboration. To achieve the goal of this research, the Eden Core project case study was developed to address the following research questions:

- Who controls and who operates on the model?
- How do design participants access and verify the validity of the 3D geometry?

- What are the contractual arrangements considering the control and authority over the model?

CASE STUDY BACKGROUND

The case study demonstrates the efforts and high levels of creativity attained by the design team in challenging digital tools to achieve greater degrees of complexity. The case study brings detailed insights into 3D collaboration barriers and how the design team effectively addressed these issues.

'The Core' is the education center and the fourth addition among the constructions of the horticultural centers and tourist attractions at the Eden Project. 'The Core' accommodates exhibition and education spaces which had been scattered in temporary tents. The Core was financed through a £10 million grant from the Millennium Commission which allocates money from the National Lottery fund to monumental projects, along with £2.89 million from the South West Regional Development Agency.

The key participants had a long history of working together since the mid-1990s when the earlier phases of the biomes construction initiated. Eden Project Ltd (Eden), the owner, selected McAlpine Joint Venture (McAJV) as the design-builder including Grimshaw (architect), Anthony Hunt Associates (structural engineer), Buro Happold (services engineer). Besides, Davis Langdon Everest acted as the owner's project manager and cost consultant, and Scott Wilson as design manager to verify drawings and engineering. Many of the individuals had worked with each other since the Biome phases, growing from junior staff status to project manager level, and thus forming a strong trust-based relationship. In addition, Eden also hired sculptor Peter Randall-Page to introduce art into the building.

Following the project delivery strategy of the earlier stages, McAJV had a Guaranteed Maximum Price (GMP) with profit sharing, splitting 50/50 between the contractor and owner. The design team members were first employed by Eden to prepare a schematic design for fund raising, and to prepare tender documentation.

The project started in March 2003 with a challenging fast-track approach, staging design in parallel to construction. The Core opened in September 2005.

The Idea

"An inspirational hub for events, exhibitions and learning ... for everyone. It will be an exhibit in its own right: inspired by plant form, crafted from plant materials..." The architect incorporated the client's ecological concepts developing a concept based on a tree (Figure 1) with a structural trunk in the center to support the building and a timber canopy roof analogous to the canopy of a tree which allows in dappled light, simultaneously producing energy with photovoltaic panels that mimic the function of photosynthesis in plants; additionally, the building is serviced through the ground for heating, plumbing, etc., resembling roots of a tree. Sympathetic to the contours, three floor plates spiral up around the center of the building. (Figure 2)

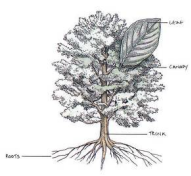


Figure 1. Tree concept

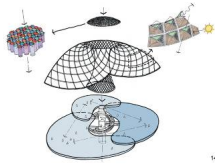


Figure 2. Design concept

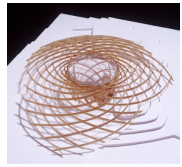


Figure 3 Grid shell model

Formal Concept

An initial series of physical wireframe models evolved into the idea of mapping Fibonacci spiral grids onto a torus and a timber grid shell concept (Figure 3). The symmetrical 'Fibonacci' spirals, although aesthetically pleasing, proved to be structurally less efficient. With the help of Peter Randall-Page, the team explored spiral phyllotaxis, a natural growth pattern which can be observed in the arrangement of scales on a pinecone or the seeds in a sunflower head, a pattern called spiral phyllotaxis – the predominant pattern in plant growth. This is the only mathematical pattern that allows growing from a central point whilst keeping spacing reasonably even around the perimeter.

Environmental Concept

Grimshaw utilized its own proprietary audit system, Environmentally Viable Architecture (EVA). The EVA audit system, identifies 12 impacts on: humans (building users); flora, fauna and natural resources; water/hydrology; climate-related factors (air and atmosphere); embodied energy; transport; energy in use; minimizing energy loss/use; use of clean energy; land and soil; local communities and cultural features. The architects evaluated sustainability of their design by obtaining a final score which is based on the responses to the questions contained with the 12 impacts in the EVA system (Figure 4, 5).

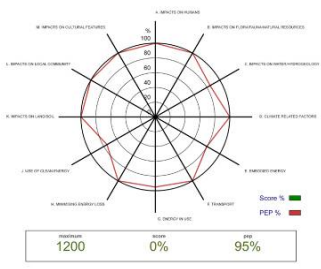
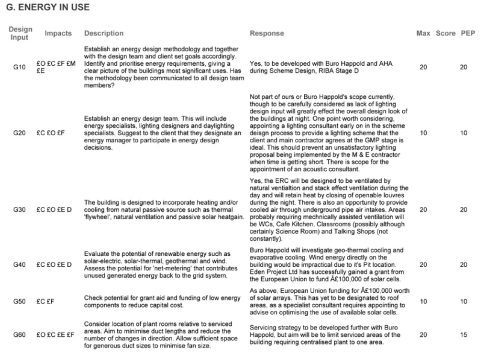


Figure 4. EVA score



G. ENERGY IN USE

Design Input	Impacts	Description	Response	Max	Score	PEP
G10	EO EC EF EM EE	Establish an energy design methodology and together with the design team and client set goals accordingly. Identify and prioritise energy requirements, giving a clear picture of the buildings most significant uses. Has the methodology been communicated to all design team members?	Yes, to be developed with Buro Happold and AHA during Scheme Design, RIBA Stage D	20		20
G20	EC EO EF	Establish an energy design team. This will include energy specialists, lighting designers and daylighting specialists. Suggest to the client that they designate an energy manager to participate in energy design decisions.	Not part of ours or Buro Happold's scope currently, though to be carefully considered as lack of lighting design input will greatly effect the overall design look of the buildings at night. One point worth considering, appointing a lighting consultant early on in the scheme design process to provide a lighting scheme that the client and main contractor agrees at the GMP stage is ideal. This should prevent an unsatisfactory lighting proposal being implemented by the M & E contractor when time is getting short. There is scope for the appointment of an acoustic consultant.	10		10
G30	EC EO EE D	The building is designed to incorporate heating and/or cooling from natural passive source such as thermal 'flywheel', natural ventilation and passive solar heatgain.	Yes, the ERC will be designed to be ventilated by natural ventilation and stack effect ventilation during the day and will reduce heat by closing of openable louvres during the night. There is also an opportunity to provide cooled air through underground pipe air intakes. Areas probably requiring mechnically assisted ventilation will be WCs, Cafe Kitchen, Classrooms (possibly although certainly Science Room) and Talking Shops (not constantly).	20		20
G40	EC EO EE D	Evaluate the potential of renewable energy such as solar-electric, solar-thermal, geothermal and wind. Assess the potential for 'net-metering' that contributes unused generated energy back to the grid system.	Buro Happold will investigate geo-thermal cooling and evaporative cooling. Wind energy directly on the building would be impractical due to its Fit location. Eden Project Ltd has successfully gained a grant from the European Union to fund Â£100,000 of solar cells.	20		20
G50	EC EF	Check potential for grant aid and funding of low energy components to reduce capital cost.	As above. European Union funding for Â£100,000 worth of solar arrays. This has yet to be designated to roof areas, as a specialist consultant requires appointing to advise on optimising the use of available solar cells.	10		10
G60	EO EC EE EF	Consider location of plant rooms relative to serviced areas. Aim to minimise duct lengths and reduce the number of changes in direction. Allow sufficient space for generous duct sizes to minimise fan size.	Servicing strategy to be developed further with Buro Happold, but aim will be to limit serviced areas of the building requiring centralised plant to one area.	20		15

Figure 5. EVA questionnaire

In accordance with EVA, Grimshaw informally consulted Happold for mechanical

engineering and environmental strategies in the ERC project to discuss thermal comfort strategies through heating and natural cooling.

MODEL-BASED PROCESSES IN DESIGN AND CONSTRUCTION

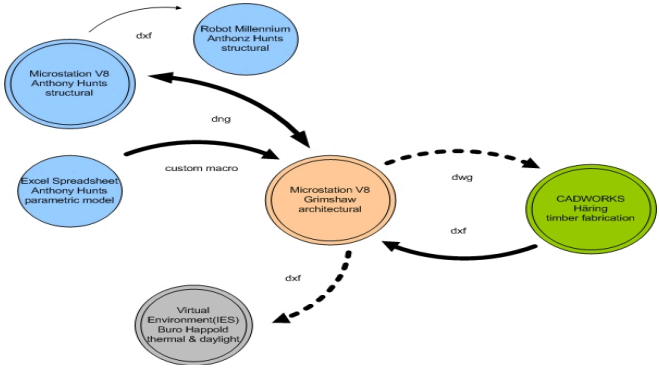
The ERC project participants exchanged geometry data between different software applications at different stages during the design. 3D information was exchanged for structural design; for thermal & daylight analysis; and for final engineering of the timber structure and roof panels. However, only Grimshaws and Anthony Hunts used commonly Microstation V8, while Buro Happold (IES VE) and Häring (CADWORK) respectively used specialty software, resulting in file translation errors, and therefore necessitating data reentry (Figure 6).

Parametric definition and Control geometry

Grimshaw and Hunt decided on the rough parameters for the roof geometry, including the number of spirals to be put in and the size of the center core, as well as the lines of the perimeter of the building, to make the building the right size and area to suit the budget and client's aspiration.

Purvis established a parametrical formula of the primary roof structure geometry in an Excel spreadsheet which calculated the two dimensional (2D) grid points (xy coordinates) of the spiral timber beam node coordinates and projected them onto a torus, to derive the z coordinate of the timber beam top surface. He also developed a macro script to import the Excel coordinates into Microstation V8. Tate then worked on the 3D node points with B-splines.

Purvis used a simplified version of the 3D geometry, connecting the node points with straight lines for structural analysis purposes. This 3D model was exported in DXF file format to Robot Millennium for the structural analysis.



Legend: CAD/electronic Data Exchange Manual Transcription

Figure 6. Data exchange

Building Service Systems Development

The design team collaborated with all consultants from the beginning to make long term strategic decisions. Tate evaluates that Happold's use of a special thermal

modeling tool (i.e., IES Virtual Environment) was essential to optimize the fenestration-to-solid-cladding ratio to conserve energy in winter, reduce heat gain in summer and generally provide adequate fresh air and daylight in all rooms.

The thermal modeling software advantageously included both thermal analysis and daylight visualization capability. However, because of file transfer constraints with the architects' CAD drawing files, Buro Happold had to rebuild a separate 3D model from scratch (ModelIT), with internal partitions, and a simplified roof shape (Figure 7).

The early introduction of thermal and daylight solutions minimized problems with building services by reducing the overall heat load of the building. Happold introduced an energy efficient ventilation/heating system (Figure 8). During summer, daytime natural ventilation was induced by automatic opening windows with supplementary perimeter displacement ventilation while nighttime utilizing free cooling at night. During winter daytime heating utilized the displacement ventilation system with trench heating which was adjacent to the full height glazing and trickle background vent. The system utilizes the constant temperature 1½m below ground level, replacing the use of conventional HVAC ductwork. Happold's design scope also included the typical design work of general mechanical, electrical and plumbing.

Simon Wright, Happold's senior engineer, notes two reasons for reconstructing their model: (1) Thermal and daylighting modeling are almost always simplified in some way to make the analysis manageable. (2) Early stage designs are not accurate in every detail and hence always require interpretation of the 'design intent'. The complex geometric roof was manually evaluated and approximated.

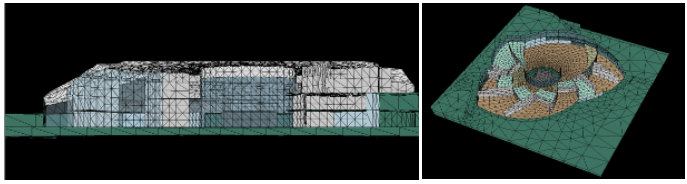


Figure 7. Thermal model for occupancy and ventilation studies by Buro Happold

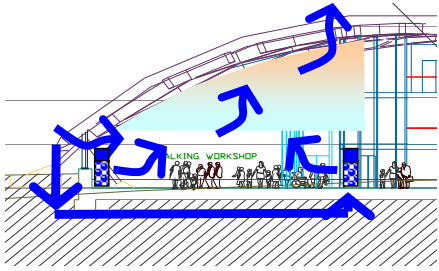


Figure 8. Heating and Ventilation concept

Project Control

By September 2003, the design team fixed the phyllotactic geometry of the roof for tender purposes. McAJV had worked out a fast-track schedule, identifying

high risk areas such as the timber grid shell roof which were phased ahead of other parts of the building for early procurement purposes. Häring was selected out of five competitors. Incorporating Häring's lump-sum contract cost, McAJV then submitted an initial GMP to the owner about £3 million over budget. In order to reduce cost, Eden, McAJV, Grimshaw and Anthony Hunts set out on an intensive value engineering study (Figure 9).

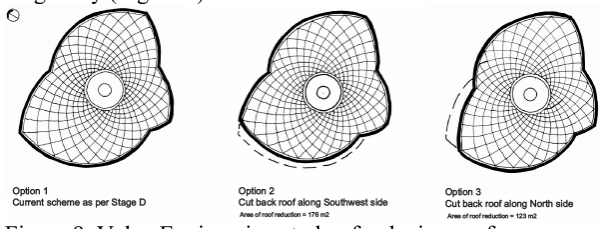


Figure 9. Value Engineering study of reducing roof area

The team went through lengthy iterations of adjusting the Excel model and 3D Geometry to fit the site constraints and geometry. The building size was reduced by eliminating two lines from the perimeter of the building. The final building geometry and a GMP contract between Eden and McAJV was fixed in February 2004. Under the design and build contract, Grimshaw had been employed to supply construction information until completion. Because of the risk of proceeding design and construction in parallel, Grimshaw had regular design development meetings with Häring as part of the design team.

Construction Documentation and Panelization Strategies

Before phasing any actual production, the design team embarked on an intensive 4-month design period together with Häring who contributed mainly their expertise in connection detailing and cost information. In order to proceed with the final engineering and fabrication of the timber roof structure, Grimshaws issued on February 12, 2004, a revised spreadsheet coordinate and a set of design intent documents to Häring, including, referenced plans, 3D grid file in DWG format, structural setout drawing, perimeter prop schedule drawing, phyllotaxis 'generator' excel file, etc. 3D CAD information was not contractual, whereas global coordinates were. One reason was because of file translation problems between different software. For example, changes happened in the model when putting DWG files into CADWORK. The other reason was liability. For complex geometry projects, Grimshaw prefers that the contractor is responsible for the final detailed design, taking ownership of the model. The difficulty to manually verify 3D information from CADWORK which did not produce decent translated CAD files (very large DXF files) enabling validation of dimensions was another challenge.

Close collaboration with Häring resulted in innovative approaches including panelization by organizing several panel cells into units of identical spiral sections to be prefabricated in the factory. This idea of having identical boxes with variations in one corner of the panel, streamlined the on-site assembly process by maximizing prefab elements from glulam beam installation, attaching the roof panel units with

small wood blocks, and adding gutters in between the panel units, and finishing up the roof with on-site copper cladding.

PROCESS MAPPING

Figure 10. shows the CAD data exchange (the small images depict the data format and level of detail of the 3D models, and 2D sketches, developed at each stage) and illustrates that Häring were the only ones who actually utilized Grimshaw's 3D model among the contractors. The architect worked in parallel on the roof panel design, while Häring began working on the roof beams' fabrication. However, because of the file translation problems between Microstation and Härings' CAD/CAM software, Häring re-built from scratch their own 3D model, based on Grimshaw's coordinates, for direct translation and control of CNC machines to cut and fabricate beams and panels.

Strategically, Grimshaw's DWG 3D model and coordinates, representing the design intent, which were defined and fixed at tender stage to prevent any misinterpretation or translation difficulties, proved to be successful means to control the geometry of the building. The close collaboration between Grimshaw, Hunt and Häring was instrumental to agree on the required level of detail and effectively identify and resolve many issues before construction and thus avoid expensive rework. For example, as Häring developed their own 3D model using CADWORK, the three teams exchanged information to coordinate the roof structure with foundations, roof cladding packages, and internal walls with embedded floor steel frames for wall stud connections. Sharing mainly coordinates and DWG/DXF files, it transpired at a relatively late stage in the development of the structure that Häring's grid file slightly deviated from Grimshaw's B-Spline curves. Accordingly, as the differences were minimal and the roof structure was already in fabrication, the design team simply swapped the DXF grid files and adjusted interior wall lines and cladding packages to suit the roof geometry.

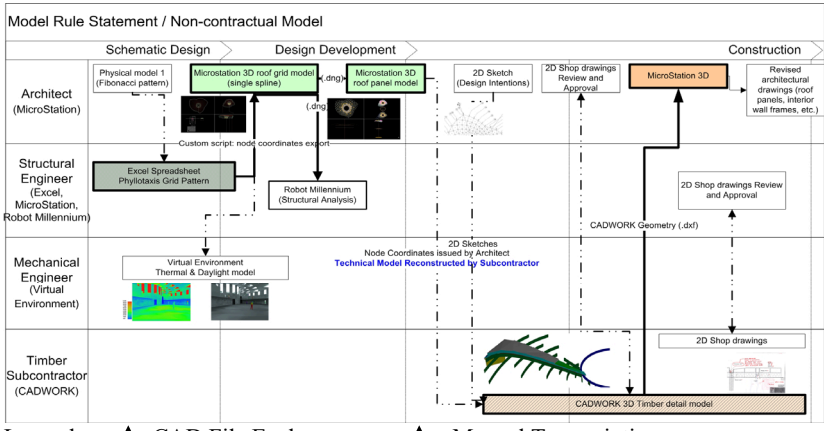


Figure 10. Process map of model data sharing

CONCLUSIONS

The model developed by the architect was used as the basis for collaboration to evaluate the various configurations from an aesthetic, structural, and environmental standpoint. The architect utilized the model as a tool to develop the design rather than a tool to generate a final model. Thus, node coordinates and geometric rules were shared with the fabricator who was involved early on in the design process to contribute their expertise in methods of manufacturing timber grid shell roof structures. While it would have been impossible to implement the project complexity of the curved shape within the given time constraints without the model, the process suggests improvements: (1) the parametric variations of the continuous design iterations and data exchange between individual tools (spreadsheet, Microstation, CADWORK, etc.) could be streamlined with the use of advanced parametric and algorithmic modeling tools (e.g., CATIA, scripting) to capture the design intent via design rules; and (2) implicit geometric constructs (e.g, B-Splines) between individual CAD packages should be verified and agreed upon before detailed development of the model; (3) the general contractor, particularly as design-builder in this project, should participate in the model-based collaboration process. The case study illustrates one mode of model-based collaboration via the architect's geometry statement that is the result of a rule-based design process. As our industry is moving towards integrated practice, it is important to understand that the architect's approach towards geometry control, the selected project delivery method, team building and technical skills of the team, and design arrangements, impact the communication process that may enable different forms of model-based collaboration (Ku et al., 2008; Ku 2005).

IMAGE CREDITS

All images courtesy of Grimshaw architects except Figure 6 and Figure 10. Figure 10 was created by the author except the inserted project images provided by Grimshaw.

ACKNOWLEGEMENTS

This case study was originally written by the author as part of his doctoral dissertation and has been adapted for this paper. The author would like to thank Jerry Tate, former project architect of Grimshaw, Mike Purvis, senior engineer (at time of case writing) of Anthony Hunts, Simon Wright, senior engineer (at time of case writing) of Buro Happold, for their generous participations during the research.

REFERENCES

AIA National, AIA California Council. (2007). "Integrated project delivery: A guide." http://www.aia.org/ipdg#ipdguide

Allen R. K., Becerik B, Pollalis S. N., and Schwegler B. R. (2005). Promise and barriers to technology enabled and open project team collaboration, *Journal of professional issues in engineering education and practice*, Vol. 131, No. 4, 301-311.

Bedrick J. R. (2006). Virtual design and construction : New opportunities for leadership, *The architect's handbook of professional practice update 2006*, The American Institute of Architects, Wiley, 33-45

Cardenas, C. (2007) *Modeling strategies: parametric design & fabrication in architectural practice*, Design and Technology Report Series 2007-4, Harvard Design School

Chaszar A. and Glymph J. (2003). CAD/CAM in the business of architecture, engineering and construction (James Glymph of Gehry-Partners on the organizational, contractual and legal issues facing designers and builders). *Architectural design*, No. 166, 117-123.

Eastman, C., Teicholz, P., Sacks, R., Liston, K., *BIM Handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, Hoboken, N.J. : Wiley, c2008

Gao, J., Fischer, M., TR172: "Framework and Case Studies Comparing Implementations and Impacts of 3D/4D Modeling Across Projects" http://cife.stanford.edu/online.publications/TR172.pdf

Gray C. and Hughes W. (2001). *Building design management*, Butterworth-Heinemann, Oxford.

Hartmann, T., Fischer, M. (2007) "Supporting the constructability review with 3D/4D models", *Building Research & Information*, 35:1, 70-80

Kam C., Fischer M., Hänninen R., Karjalainen A., and Laitinen J. (2003). The product model and Fourth Dimension project, *ITcon*, *Special Issue IFC - Product models for the AEC arena*, Vol. 8, pg. 137-166, http://www.itcon.org/2003/12

Kolarevic B. (2003). We have seen the future, and it is pixellated, *In Architecture*, VNU eMedia, Inc.

Ku K, Pollalis S, Fischer M, Shelden D (2008) 3D model-based collaboration in design development and construction of complex shaped buildings, *ITcon Special Issue Case studies of BIM use*, Vol. 13, pg. 258-285, http://www.itcon.org/2008/19

Ku, K. H., (2005). *3D model-based collaboration for complex-shaped buildings: effective practices for geometry control*, Doctoral Thesis, Harvard University, Graduate School of Design, Cambridge, MA.

Kvan, T. (2000), "Collaborative design: what is it?", Automation in Construction, 9 (2000) 409-416

Maher, M.L., Cicognani, A., Simoff, S.J. (1998) An experimental study of computer mediated collaborative design, *Int. J. Des. Comput.* 1, 06 http:rrwww.arch.usyd.edu.aurkcdcrcmcdrpaperx

NIBS (2007) National Building Information Modeling standard A/R 106, National Institute of Building Sciences, http://www.facilityinformationcouncil.org/bim/pdfs/NBIMSv1_p1.pdf

Olofsson, T., Lee, G., Eastman, C. (2008) "Editorial- case studies of BIM in use", *ITcon*, *Special Issue IFC - Product models for the AEC arena*, Vol. 13, pg. 244-245, http://www.itcon.org/data/works/att/2008_17.content.01398.pdf

Suomi, J. (2002). Tekla Xsteel & Xengineer Model based collaboration, IAI Summit, http://cic.vtt.fi/vera/Seminaarit/2002.04.24_IAI_Summit/Tekla.pdf

VISUALIZATION CONFIGURATION MODEL FOR INTEGRATING PRESENTATION OF CONSTRUCTION PROJECT MANAGEMENT DATA

Jianguo David Ye, [1] and Thomas Froese[2]

[1]Ph.D. Candidate, Department of Civil Engineering, University of British Columbia; Vancouver, BC, Canada, V6T 1Z4 ; jgyie@civil.ubc.ca
Lead Scheduler, North American Enterprises Ltd., Edmonton, AB, Canada

[2]Professor, Ph.D., P.Eng., Department of Civil Engineering, University of British Columbia; 2002 - 6250 Applied Science Lane, Vancouver, BC, Canada, V6T 1Z4 ; Tel: (604) 822-2027; fax: (604) 822-6901; tfroese@civil.ubc.ca

Abstract – Construction management tasks involve and produce voluminous, multidimensional data. Although many tasks currently are supported with software tools, it still requires great mental effort for project personnel to read information in datasets and analyze relationships from one dataset to another. Information visualization is widely considered to hold the potential of providing insights from datasets by visually presenting project management data and information relationships. Many visualization solutions are available to the construction domain, but they usually focus on specific application tasks, lacking flexibility and data integration in user-interaction for construction management. This paper proposes a Visualization Configuration Model (VCM), a novel visualization technique for construction project management. Integrated with the Industry Foundation Classes (IFC) data model, the VCM is developed to be a configurable visualization environment, facilitating user-interactions to explore voluminous information. The model framework and underlying theories for integrating model components are provided. Through analysis of two case scenarios, the paper demonstrates the capability of the VCM supporting view configuration and illustrates the potential of visualization to benefit construction management tasks.

Keywords *– Integration, Project Management, Information Visualization, Visualization Configuration Model, IFC*

1. INTRODUCTION

Construction project management (PM) includes a wide variety of functions such as scope management, quality control, etc. Each function is usually fulfilled through carrying out several tasks (e.g. a change order process for scope management). Each individual task involves and generates voluminous data, which are usually

multidimensional, and presented in different formats associated with heterogeneous information systems. These data embed rich PM information, by which a person understands the project, communicates and makes decisions. However, it is a challenge for PM personnel to understand these data promptly and accurately when many tasks are addressed daily, since processing these data is error-prone and time-consuming. For example, when entering PM data in a system or reading them from one application for another, interpreting them requires comprehensive domain knowledge, and perceiving their interrelationships demands great mental efforts.

To improve these issues, visualization, coupled with the IFC technology (data standards) is an effective solution—the IFC supports structured representation of PM data and enables information integration and system interoperability (Froese, 2003) (IAI, 2002) (Staub-French & Fischer, 2001), and visualization can bring potential in obtaining insights from data and achieving effective communication (Korde et al., 2005) (Songer et al., 2004) (Ahlberg & Shneiderman, 1994).Visualization is the process of forming a mental model by encoding data with graphic images in an appropriate manner. To visualize multi-dimensional PM data, there are three aspects that need to be considered: what visualization strategy is suitable for a specific datasets, how to present data in multiple dimensions, and how to facilitate user-interaction for data exploration (e.g. filtering data or reformulating search goals). For decades, many research and development efforts, e.g. (Shneiderman, 1996) (Nagappan, 2001) (North, et al., 2002), have considered these issues. These efforts are good indicators on how to visualize PM data, yet no one has address integrated visualization of all three of these issues. In addition, many computer applications in the PM area have well-developed visualization capabilities (e.g., Autodesk Revit, the Primavera E/C solution). However, they are generally unique to their particular data views and offer little or no provision for visualization of integrated multi-dimensional presentation of project management data (which, to date, have only existed in rare, highly specialized situations). Thus, the ability to integrate PM data at the presentation layer has received limited attention to date.

This paper proposes a Visualization Configuration Model (VCM), integrating previous efforts in the three aspects and tailored to present multidimensional PM data. The PM data are represented in compliance with the IFC technology, yet, this paper will not focus on the IFC model, but rather, on how to visualize construction management data related to abstract, intangible concepts or events, e.g. changes and performance. The paper is structured as follows: Section 2 introduces work related to the development of the VCM model. Section 3 details the model and its components. Section 4 illustrates the model using example scenarios with a prototype. Section 5 provides concluding remarks.

2. RELATED WORK IN THREE ASPECTS OF VISUALIZATION

A visualization strategy here refers to a design of how to appropriately use graphs and retinal properties to present information in a specific data format; a strategy must considers fundamental principles in visualization theory, data type and density (Songer, et al., 2004). Typical strategies for visualization include taxonomies of “data

type vs. task" and "functional requirements vs. visual techniques". Shneiderman (1996) proposed a "type vs. task" taxonomy of information visualizations; seven data types and seven domain user-actions or tasks were identified in the taxonomy. Qin, et al. (2002) presented a taxonomic framework of data type vs. analytic task for end users, and a framework of representation mode vs. interaction level for system developers, considering that visualization merges representation function and interaction function. Keim (2002) suggested an orthogonal classification method with three axes, namely data type to be visualized, visualization technique, and interaction and distortion technique.

Multidimensional data is usually decomposed into small datasets in order for convenient presentation. Nagappan's composition model takes a strategy similar to "divide-and-conquer," by which data is decomposed into a collection of simple components in the data layer, which are then mapped to individual visualizations in the presentation layer (Nagappan, 2001). A very popular tool for exploring multidimensional data is the Online Analytical Processing technology (OLAP Council, 1997). Our research leverages this technology, designing a dataset as a combination of dimensions, each of which includes several levels – this approach enables views configurable in the data layer and presentation layer in a system. This paper doesn't provide details on how to configure views in the data layer.

Visualization coordination can integrate decomposed views into a holism and support user-interaction to improve PM data exploration. A good reference to this approach is North's Snap visualization model, which provides coordination between data design and visualization design. The primary guiding principle of the model is to establish a tight analogy between relational data concepts and visualization concepts (North at el., 2002). Through the model, coordination is generated according to JOIN association of data schemas; thus, the Snap provides convenient coordination without the need of user's programming.

Among the research efforts mentioned above, Qin presented a comprehensive knowledge of functional requirements in visualization; Shneiderman and Keim identified presentation tasks forming a body of visualization interactions. A combination of these contributes to the development of VCM in classifying visual techniques for PM data in different data types. Moreover, we use the OLAP technology to configure data views in the data layer. And the Snap solution suggests how to coordinate views in the presentation layer. However, individually, none of these approaches provide a standalone solution covering all aspects required for visualization. This calls for an integrated visualization tool for presenting multidimensional PM data.

3. VISUALIZATION CONFIGURATION MODEL

3.1 Initial Idea

The VCM draws inspiration from nature. Natural flowers consist of sepals and petals in different sizes, shapes, colors, and layers. A complex arrangement of flower

components configured in diverse patterns appears naturally brilliant. Enlightened by such a configuration, the VCM adopts a similar structure consisting of graphic elements, graph components, views and scenes, which are placed in coaxial layers. Such a structure supports the arrangement of data graphics in an appropriate way that can draw end users' attention first to the overview and then to the details. Moreover, it facilitates flexible visualization configuration through simple drag-and-drop actions.

3.2 Model Schema

As shown in Figure 1, the model consists of four coaxial layers. Different from other model structures or system architectures designed in layers where information typically flows from one layer to another, the VCM does not require information to flow between layers. Rather, it arranges all relevant information items for explicit presentation in a view(s). Moreover, the VCM schema shows a hierarchical relationship between layers where graphics in an outer layer are composed of those in a direct inner layer, while some systems, e.g. an AutoCAD system, display an organizational relationship between layers in which all attributes combine to produce an entire image and make it distinct from others.

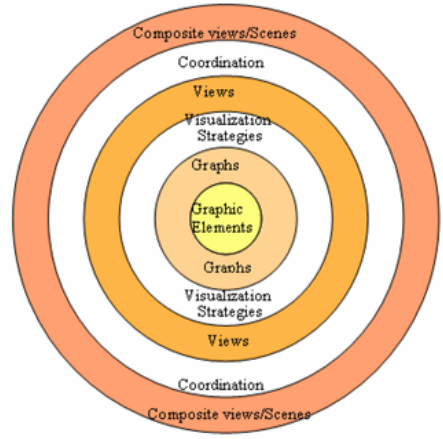


Figure 1: Visualization Configuration Model Schema

The VCM's four layers include:

- Graphic Elements Layer. Located at the center, this layer is composed of various atomic components, such as dot, line, button, etc., which may be in different sizes, colors, and tone and shade scales.
- Graphs Layer. This layer presents simple graph components that are configured with graphic elements. Examples of graph components include, but are not limited to, table, bar chart, tree map, etc.
- Views Layer. This layer presents common data views or user-defined specific views in visualization, which reflect a particular project issue from primary perspectives. A view may have one or many graph components to present its rich meaning.

- Scenes Layer. This layer encompasses scenes composed of primary views presented in the Views layer. In a scene, views are user-interactive and coordinated with each other; information items in one view may be tied or linked to one or many items in another.

Between the VCM layers, visualization components (including graphic elements, graph components, views and scenes) are bound together according to visualization strategies and coordination methods, which guide configuration of visualization from simple graph components to complex views. For example, selecting which shape, color or size to use in displaying an object depends on visualization principles and strategies; moreover, view coordination needs to be applied when combining relatively independent views to present their limited information interdependency.

3.3 Model Components

The visualization components are grouped into four categories according to their layers. These four categories are Graphic Element, Graph, View and Scene. Figure 2 shows a representation of these categories in UML notation, in which classes abstracting relevant categories of information are displayed with rectangles, and lines with blacked diamonds indicate one-to-many class composition relationships.

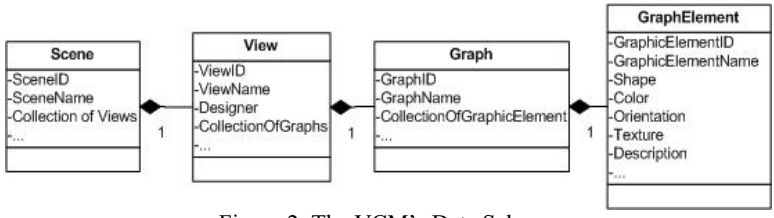


Figure 2: The VCM's Data Schema

A Graphic Element is a type of atomic visualization component which is often used to encode data or indicate intentions such as task reminder, trend, flow, etc. Graph elements utilize retinal properties such as shape, size, orientation, color, texture, etc. Graph refers to a visual technique comprised of multiple graphic elements and rendering them on a 2D (or 3D which consists of several 2D projections) coordinate system. Commonly used graphs in the PM domain have 2D table or list, bar chart, pie chart, 3D product, network, etc. Views in visualization intuitively reflect an issue or process (named as Scene) from different perspectives. For example, a change order process involves cost change, time control, resource consumption if a change is related to rework or extra physical work, document review, analysis of impact, etc. These are different views displaying of different aspects of the change process. A scene visualizes a theme of interest to project participants for an individual PM task, e.g. change order process.

3.4 Integration between Layers

The VCM has strong integration characteristics arising from its combined taxonomy of visual technique classification, correspondence between model components and

data components, and a derived view coordination model for coupling separated views in user-interaction.

3.4.1 A Combined Taxonomy of Visual Technique Classification

Based on Keim, Qin, and Songer's work, a combined taxonomy for classifying visual techniques is established for guiding the development of VCM's graph elements and graphs. The taxonomy considers data type, functional requirements, visual techniques and domain application as necessary factors. Shown in Figure 3, a checked mark indicates that data in a particular PM domain data dimension in a column may be appropriate to be presented in visual techniques of a corresponding data type in a row. Figure 4 represents a classification of visual techniques, based on user functional requirements which are grouped into six types. In the tabular figure, the Visual Techniques column includes typical techniques corresponding to different data types, which are borrowed from Songer's work. Other columns list the six types of requirements. Under each column of functional requirements, a checked mark indicates that this type of requirement can be implemented in corresponding visual techniques**.** In addition, visual techniques within different data types can be combined to fulfill many functional requirements.

Data Type	Domain Data in Dimensions					
	Process	Resource	Actor	Document	Cost	Product
1D	√	√	√	√	√	
2D						
3D						√
Multidimensional	√	√	√	√	√	√
Temporal	√					
Hierarchical	√	√	√	√	√	√
Network/Graph	√					

Figure 3: Identification of Data Types in Dimensions

3.4.2 Correspondence between Model Components and Domain Data Components

In the VCM model, graph elements, graph components, views and scenes enable integrated presentation of project management complexities. These visualization components defined in layers establish correspondence to underlying PM data components. As shown in Figure 5, VCM components are matched to data components in different layers (different rows in the tabular figure); meanwhile, from Graph to View, and from View to Scene, these components are interrelated through or constrained by their interactions. Typically visualization components' interrelationships have two types. One is an internal relationship or tight combination which means that graph elements are fixed according to a predefined underlying data relationship, e.g. a relationship between a Task class and a Cost class in a predefined data model. The other is an external relationship or loose combination between graphs in a view, which can be configured by end-users, e.g., when using a system.

3.4.3 A Derived View Coordination Model

Resembling North's coordinated-visualization interface (CVI), a scene in the VCM is expressed as a function of views and coordination: Scene = (V, C), where:

$V = (v_1, v_2 \ldots v_i \ldots, v_n)$ $v_i = (graph_{i1}, graph_{i2} \ldots graph_{in}, dataset_i)$
$C = (c_1, c_2 \ldots c_j \ldots, c_m)$ $c_j = ((v_p, action_p), (v_q, action_q))$ $v_p, v_q \in V$

Data type	Visual Techniques	Functional Requirements					
		Overview	Detailing	Comparison	Clustering	Dependency	Trend/Pattern
1D	Histograms, pie charts, Tukey box plots	√	√	√	√		
2D	Scatter plots, linked histograms	√	√	√	√	√	√
3D	Physical data: Three orthogonal axes	√	√	√		√	
	Relational data: See multi-D below	√	√	√			
Multidimensional	Glyphs and Cleveland's rules: Position, length, direction, area, volume, curvature, shading, color saturation	√	√	√	√		√
	Statistical methods: Perturbation=scatterplot matrix, mosaic glyphs, small multiples and multidimensional icons	√	√	√	√		√
	Visual separation: Micro=macro strategies, colour, layering	√	√	√			√
	Others: Star plot, parallel coordinate plot, hyperbox, etc.	√	√	√			√
Temporal	1D + Time: Time series	√	√				√
	Multi-D + Time: Small multiple, parallel axis time series	√	√				√
Hierarchical	Tree (Orthogonal or Circular), treemap	√	√			√	
Network/Graph	Simple, circular, three-dimensional, aggregated, fisheye view, webbook & webforage,webview, net map	√	√			√	√

Figure 4: Requirement-based Classification of Visual Techniques

Layer	Example Instances	Configuring Components	Interaction	Data Components
Graphic Element	Dot, Line, Button, Navigation Bar, etc.			Data Items
Graph	Table, Bar Chart, etc.	Elements	Viz. Strategies	Dimension of Data
View	Plan View, Supply View, etc.	Graphs	Internal Relationship or Tight Combination	A group of Dimensions
Scene	Change Order Process, Time Control, etc.	Views	External Interaction or Loose Combination	Multidimensional Datasets

Figure 5: Correspondence between VCM Components and Data Model Components

However, different from CVI, this formulation supports view-coordinated visualization where there may be more than one graph in each view. Derived from the formulation, a coordination data model for VCM is designed, shown in Figure 6. The model in UML notations consists of the Coordination class, the Register class and the View class. The Coordination class defines various coordination events or objects serving as mediators. The Register class constructs instances of linkage between views and keeps information about actions that each selected view encompasses.

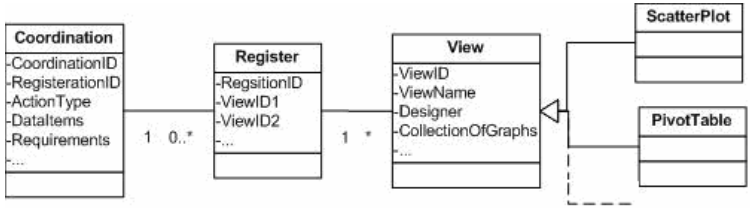


Figure 6: The Visualization Coordination Data Model in UML Notation

4. CASE SCENARIOS

In order to illustrate the model, we use a window-based prototype to demonstrate how a view for a change order process is configured in visualization and what potential the VCM can bring to the change management practice.

In order to identify resource usages for a particular change process task, summarize and display resources by trades over time, and display attributes for an individual resource usage, a Supply view employing three graphs is designed, shown in the top of Figure 7. The top left graph in the view is a tree list graph, using the texture retinal property for presenting hierarchical data; the top right is a Gantt chart graph, using retinal properties of bar, color, etc. to present temporal data; the below one takes a multi-field tabular list as a graph using texture property to present PM data with multiple attributes. This view is populated with a change order process dataset; within the view, the tree list is mapped to a dimension for resource usage and the Gantt chart is mapped to a task-resource dimension; these two graphs are related by establishing a coordination link to their resource ID keys in the data model. Different from other applications, such as Autodesk Revit and Primavera PM Solutions, this view is configured by a front-end user at system running time, rather than designed by developers; moreover, presenting the view in such a structure facilitates users to efficiently form various interfaces for different PM purposes.

As another scenario, an accounting staff collects daily time cards and inputs data into an accounting system. From a time card which typically includes an employee number, job code, name, date, regular and actual hours and project number, she cannot figure out on which work item an individual spent time on a specific date since the job code in a time card just indicates a category of work. Now, the user wants to know how many direct man-hours the physical work for a change order has actually consumed. For this purpose, she configures a Time Sheet view and makes it linked with a Plan view and the Supply view (mentioned above) in the prototype system. Also shown in Figure 7, these views form a scene based on the VCM model. The user clicks the “Work Execution” item in the Plan view, all rows related to this work task in the Time Sheet view are immediately “selected” and highlighted in red color. Thus, the interrelationship of a task and associated daily man-hours are explicitly displayed. Then, the user can conveniently determine the actual man-hours for the change and compare them with the budget in its change proposal. This scenario demonstrates view coordination by clicking one item in a view and highlighting corresponding

items in others. Such an approach benefits users in understanding hidden information relationships with little mental effort; moreover, through view cooperation, multi-views, e.g. the Time Sheet View and Plan views in Figure 7, can be incorporated in a scene which gives an overall picture of a change order.

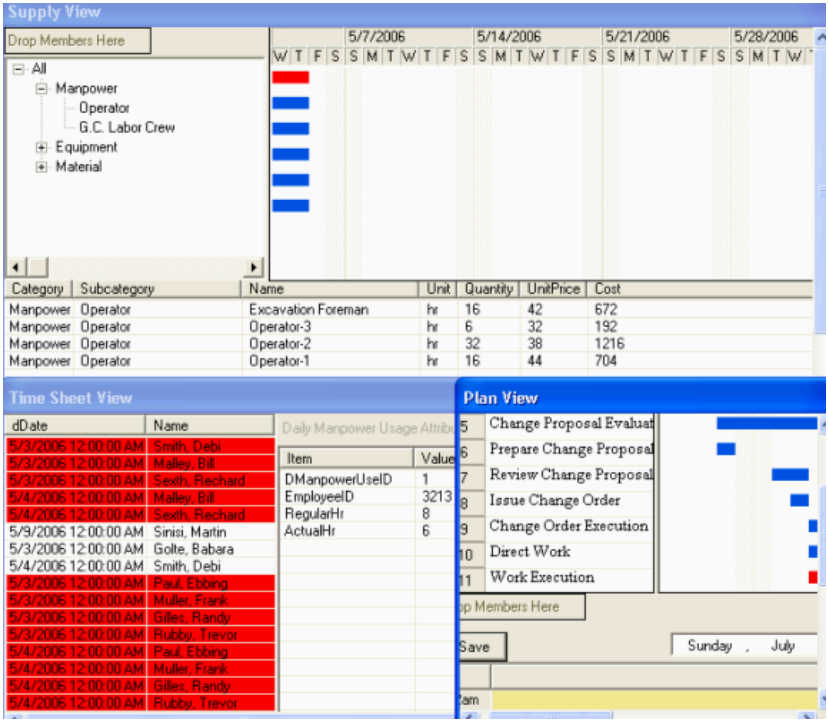


Figure 7: A Scene Example Based on in the VCM Model

5. CONCLUSION AND FUTURE WORK

This paper has presented a Visualization Configuration Model enlightened by natural flower configuration patterns. The model features a coaxial layered structure consisting of Graph Element, Graph, View in Visualization, and Scene components. The development of the model established a correspondence between VCM components and data components in a structure, and incorporated previous research results tailored to construction management. The contribution of the model lies in a strong structure for visualizing PM data through configuring graphic elements at different layers into interfaces. Through analysis of two case scenarios, the paper demonstrated configuring visualization for a change order process and illustrated beneficial potential of exposing information relationships and effectively presenting data with different perspectives.

The VCM is a part of ongoing research about information integration, which leverages IFC data standards, the OLAP technology, and information visualization, and then leads to unified construction project management. In the future, the development of VCM should extend further in formalizing the use of visual applications in the PM domain. Moreover, we will also be exploring effective approaches to cooperate user designed views with external application interfaces.

6. REFERENCES

C. Ahlberg and B. Shneiderman. (1994). "Visual Information Seeking: Tight Coupling of Dynamic Filters with Starfield Display." CHI' 94, ACM Press: New York; 313-317.

T. Froese. (2003). "Future Directions for IFC-based Interoperability." ITcon Vol. 8, Special Issue IFC - Product models for the AEC arena , pg. 231-246, http://www.itcon.org/2003/17

IAI. (2002). "IAI Vision, Mission and Goal." Accessed in 2002, at http://www.iai-international.org/About/Mission.html

D. A. Keim. (2002). "Information Visualization and Visual Data Mining." IEEE Transaction on Visualization and Computer Graphics, 8(1), 1-8.

Tanaya Korde, Yugui Wang, and Alan D. Russell. (2005). "Visualization of Construction Data". 6th Construction Specialty Conference, Toronto, Ontario, Canada. June 2-4, 2005.

Rajehndra Nagappan. (2001). "A Compositional Model For Multidimensional Data Visualization." Proceedings of SPIE -- Volume 4302. Visual Data Exploration and Analysis VIII, May 2001, pp. 156-167.

Chris North, Nathan Conklin, Kiran Indukuri, and Varun Saini. (2002). "Visualization Schemas and a Web-based Architecture for Custom Multiple-view Visualization of Multiple-table Databases." Information Visualization, Vol. 1, Issue 3/4, 2002.

OLAP Council. (1997). "The APB-1Benchmark." Available at http://www.olapcouncil.org/research/bmarkly.htm

Chengzhi Qin, Chenghu Zhou, and Tao Pei. (2003). "Taxonomy of Visualization Techniques and Systems – Concerns between Users and Developers are Different." Accessed in March 2005 at http://www.hku.hk/cupem/asiagis/fall03/Full_Paper/Qin_Chengzhi.pdf

Ben Shneiderman. (1996). "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations." Proc. 1996 IEEE Conference on Visual Languages (Boulder, CO, Sept.3-6, 1996) 336-343. CS-TR-3665, ISR-TR-96-66.

A.D. Songer, B. Hays, and C. North. (2004). "Multidimensional Visualization of Project Control Data." Construction Innovation. London: Sep 1, 2004. Vol. 4, Iss. 3; p. 173.

Sheryl Staub-French and Martin Fischer. (2001). "Industrial Case Study of Electronic Design, Cost, & Schedule Integration." CIFE Technical Report #122, January, 2001. Stanford University.

STAKEHOLDER VIEWS ON IT IN CONSTRUCTION: A NORTH AMERICAN PERSPECTIVE

Kasun N. Hewage[1], Janaka Y. Ruwanpura[2], and George F. Jergeas[3]

[1]Assistant Professor, University of British Columbia – Okanagan, School of Engineering, 3333 University Way, Kelowna, BC, V1V 1V7, PH (250) 807- 8176, Fax (250) 807-9850, Email: Kasun.Hewage@ubc.ca
[2]Canada Research Chair in Project Management Systems, Director and Associate Professor, Department of Civil Engineering, Schulich School of Engineering, University of Calgary, Calgary, Alberta, T2N 1N4, PH (403) 220-6892, Fax (403) 282-7026, Email: janaka@ucalgary.ca
[3]Professor, Department of Civil Engineering, Schulich School of Engineering, University of Calgary, Calgary, Alberta, T2N 1N4, PH (403) 220-8135, Fax (403) 282-7026, Email: jergeas@ucalgary.ca

Abstract
Recent research study at the University of Calgary, Canada emphasized the immediate need of effective communication among all the construction project stakeholders – i.e. workers, construction managers, consultants, and clients. All these stakeholders identified lack of 'on-site' communication as a key reason for low productivity. Construction industry is known for its' resistance in using Information Technologies (IT) compared to manufacturing, military, and agriculture industries. However, the construction workers participated in this study expressed their willingness and ability to use modern communication technologies in the work environment. The construction companies (managers) were not confident to acquire information technologies to the construction workface. They pointed the unavailability of information on worker abilities, technologies, possible outcomes, related costs, and benefits as the reasons for this resistance. Technology developers had difficulties to understand specific communication needs of the construction industry. This paper presents a summary of the views and concerns expressed by the construction industry stakeholders in North America regarding the possibilities and opportunities in using IT in construction projects. The paper is concluded with a set of recommendation to optimize the IT use in the construction industry.

Background
The origin of information technology (IT) in general may be best attributed to the invention of the first automatic loom in 1801 by Joseph-Marie Jacquard, in which

punch cards were used to produce different weave patterns (IEEE 2001). The construction industry is seen by many as backward in deploying technology; especially the information technology. Application of IT has been quite piecemeal and very few contractors have a comprehensive and integrated information system for its core business (Mak 2001), even though construction is a dynamic information dependent industry (Lee 2003). Eisenblaetter (2001) attributes this to the harsh construction environment which makes it difficult to deploy computers. However, the demand for improving project communication is a major issue in the construction industry (Hewage and Ruwanpura 2006a). A by-product of this demand for improved productivity is that construction businesses tend to invest large amounts of money in communication in order to obtain competitive advantage (Betts and Smith 1999). Today's workforce is increasingly mobile. Clients search for real-time applications that can be accessed utilizing mobile enterprise technology from a variety of devices (Olofsson and Emborg 2004). Despite an explosive growth in Internet use in the last five years in many areas of business and commerce, the construction industry has not kept pace to the same degree (Brandon 2000 and Abduh et. al. 2004).

Rivard et al. (2004) conducted eleven case studies with Canadian construction companies. The case studies covered architecture, engineering, construction management, and specialized contractors. These companies have used 3D-CAD (three dimensional computer aided design), custom web sites, commercial web portals, and software developed in-house. The authors concluded that none of the companies used wireless communication (except cellular phones) systems at the site level. Fischer and Kunz (2004) mentioned the use of 3-D (three dimensions – length, width, and depth) and 4-D (3-D models with time factor – it is possible to visualize the changes in 3-D model with respect to the time) models, construction information models, and knowledge based and simulation models in construction projects. They cited the extensive research work on going at Stanford University in regard to the use of these models on the job site. The use of mobile technology is not foreign to construction industry workers. Mobile phones have been a major success story in this industry, replacing the old 'land line' connection to the site office and providing an effective means of communication between participants (Perry et al. 2001). Magdic et al. (2002) concluded that some important experience has already been gained and the main building blocks for mobile computing in the construction industry are already available on the market. Magdic et al. (2002) showed that the efficiency of information interchange with and at a building site can be improved significantly by using current mobile computing components: unmodified, currently available PDAs (portable Digital Assistant), mobile phones, and web services. Despite the barriers to implement IT at site level, a Japanese construction firm—Daito Trust Construction Company—developed a large-scale mobile computing system called the DK Network. The company reports that the system made the process of construction easier and greatly increased productivity (Daito, 2003).

There are several nation-wide US construction change initiatives to promote the use of information technology as a tool to increase productivity, through automating tasks and enhancing collaboration (ISR, 1999). FIATECH is a USA based organization which collaborates with industry and academia. It has initiated a 7 year

project beginning in 2004 with a mandate to develop IT in construction (Capital Projects Technology Roadmap, 2004).

Hewage and Ruwanpura (2006a, 2008) noted the dissatisfaction of construction workers on the available communication systems and practices in construction projects. Workers identified inadequate communication as the main reason for low motivation and productivity. A similar problem was identified by the work of previous researchers such as Bowden et al. (2006) and Mohamed and Stewart (2003). These researchers found that only 20% of the information passes to the operational (worker) level from the management level at a construction site. Two-way radios were the only observed communication device in use on the site level of construction projects during the observations conducted by the researchers during the last three years. This was not adequate to solve the issues related to the on-site communication.

Present status of technology adoptability- i.e. takes up the ideology, practice, and method of someone's technology and uses it as one's own - in the construction industry has not been comprehensively analyzed and documented by academics and the industry (Rivard 2004). Hence, the University of Calgary has conducted an extensive research to investigate the potential uses of information technology in construction industry by contacting the major stakeholders in construction; construction workers, construction managers, and technology providers. Six leading commercial construction companies and three research organizations participated in this research.

The scope of this paper is to summarize the views expressed by the major stakeholders (in construction) on the use of IT in construction projects. It also provides recommendations to improve on-site communication with the use of information technology.

Summary of the Research Objectives

The overall objective of the research presented in this paper is to identify the communication needs and concerns of the construction industry and recommend appropriate practices to improve on-site communication. Following are the sub-objectives:

a) Identify the present communication needs of the construction industry.
b) Investigate the background and the factors that contribute to the communication deficiencies in construction.
c) Recommend practices, guidelines, and tools to improve on-site communication in construction projects.

Summary of the Research Methodology

Following research methods were selected to achieve the defined objectives.

a) Identify on-site communication needs: This was achieved by observations, questionnaire surveys, interviews, and workshops with the construction managers and workers.
b) Identify the technology preferences and concerns of the construction workers: This was achieved via workshops, questionnaire surveys, and interviews.

c) Identify the technology adopting concerns of the construction managers: Interviews and questionnaire surveys were conducted.
d) Identify the strengths and concerns of the technology vendors: Questionnaire surveys and interviews were conducted.

Please refer Hewage and Ruwanpura (2006a and 2008) for a detailed description of overall research methodology. More than 120 construction workers, 30 construction managers, and 20 construction technology providers in both Canada and USA participated in this research. The overall response rate for questionnaire surveys was about 38%.

Research Results

Results of the research presented in this paper are described under four main areas; i.e. construction on-site observations, construction workers' opinions, construction managers' opinions, and technology developers' opinions.

Construction On-Site Observations

Following are some of the key observations made in the commercial construction projects related to on-site communication.

a) It takes a considerable amount of time (approximately 2-3 hours) to pass important information from the site office to the foremen level. Usually foremen were less informed about important information during morning or afternoon coffee breaks or lunch time.
b) None of the construction sites who took part in the study used audio-visual demonstrations to disseminate safety practices. Several workers who had serious accidents (lost time) on site attributed the injury to a lack of knowledge around safe, correct and workplace practices.
c) During the winter season, workers moved to the site trailer several times a day to change their clothes. Most workers were not informed about the expected weather changes for any particular day. This also shows that the workers did not bother to check weather predictions throughout a day
d) At large construction sites (more than 100 workers/shift), office managers had a limited awareness about "real-time" site progress. They were dependent on the information provided by on-site managers such as foremen. Foremen were not in a position to satisfactorily update site activities through two-way radios.
e) At some of the observed sites, there were close to 600 workers on site during peak periods. Managers faced many difficulties, particularly the task of assigning workers to their working areas. Office managers were making work changes without the knowledge of the actual congestion and material needs at the site level.
f) Managers had difficulties in assigning particular machines or tools for an "immediate" activity because of the lack of available real-time information. Workers spent about 15% of their total working time searching/moving/lifting materials, tools, and equipment (Hewage and Ruwanpura 2006a).
g) The need for a real-time information system to track materials, tools, and machinery was very apparent.

Construction Workers' Opinions

As mentioned, construction workers' (including foremen) opinions regarding the on-site communication were collected through one-on-one interviews, questionnaire surveys, and workshops. Following are some of the key opinions expressed by the workers.

a) Only 11% of the workers were satisfied with the current communication methods and standards in the selected construction sites. A common experience described was the inability to locate foreman for clarifications/instructions. There were a series of frustrations stemming from this lack of communication. Workers found management may be overconfident in the workers' awareness of what is necessary to accomplish in a particular job.
b) Foremen strongly suggested the use of a PDA (Portable Digital Assistant) to facilitate immediate access to information. Further, they indicated a preference for a PDA with digital camera capabilities to facilitate the communication of on-site progress.
c) The general workers' opinions were slightly different than those of the foremen. Workers did not identify technologies as necessary to overcome communication issues; instead they described procedural changes. The number one change they sought is an increase in on-site instruction time from their managers.
d) Workers wanted their supervisors to clarify the work assignments before giving instructions to them. Further, 9% of the workers reported that supervisors' and workers' spend too much time on discussions focused on personnel issues.
e) All the workers who participated in the research stated that they were unaware of the long-term schedule for the construction operations. About 70% were unaware of the schedule for even the next two weeks. Workers tend to be given only the daily targets on daily basis.
f) Workers were usually only informed about immediate changes which impact the daily target. They remained unaware of the longer term goals and any changes to those goals.
g) Foremen needed the help of top managers to verify the changes in targets based on the actual performance on site. In response to the lack of a central knowledge transfer system, the foremen tend to define targets beyond the approach and complete as much as possible. Employees want to know, at a minimum, time expectations for each and every work target.
h) In general, workers were not satisfied with the present technology usage on construction sites. Only 26% of the construction workers were satisfied with the present status of technology usage. Interestingly, 22% of the workers believed that the use of technology on the construction site was slowly improving. However, it was not at a level where workers believed technology is adequate to cope with their work demands.
i) 12% of those surveyed described training experiences at carpentry schools where the use of modern technologies such as modern power tools, laser levels, and modern surveying devices was not encouraged or valued. Instead, performance of carpentry duties via a hands-on use of skills held more respected.

j) Workers were critical of the only available IT communication device in construction: two-way radios. There were many observed instances where the radio signals were weak and unclear. After several failed communication attempts workers were forced to stop their work and walk to the location of the party they were trying to speak with.
k) All of the interviewed workers agreed that the use of information and communication technologies could improve the present working standards except one restricted worker who felt that IT could complicate the present working styles.
l) About 70% of the interviewed workers expressed their preference to view 3-D drawings before and during the construction. Many workers (about 32%) complained that they did not even see 2-D drawings before they began construction.

Construction Managers' Opinions

Following are some of the key opinions shared by the construction managers on the communication and IT needs in construction projects.

a) A key area of concern identified by the senior construction managers was the lack of knowledge about information technologies by the on-site managers. Managers noted that most of the experienced foremen typically resist to any changes in the working environment.
b) Some senior managers suggested formal training programs for the on-site managers and lead workers on a priority basis. These training programs should focus on modern construction methods, standards and management issues such as LEED (Leadership in Energy and Environmental Design), planning and scheduling techniques, communication technologies, human resource management, and leadership.
c) Increasing difficulty of handling tools and materials with the introduction of new "LEED" standards in construction.
d) Construction companies experimented several soft managerial approaches to improve communication on construction sites. These approaches include changing field leaders, scheduling daily work targets, and morning meetings. However, there were still many visible issues which could be linked to poor communication systems.
e) Some of the surveyed managers (62%) suggested the use of information technology to overcome communication barriers.
f) Lack of efficient scheduling techniques was another challenge faced by the managers. According to the managers, there is no suitable scheduling technique to address the highly unpredictable construction operations. Managers were providing two-week look-ahead schedules to the site level without actually knowing constructability, productivity, weather related issues, material availabilities, sub-trade requirements. However, the authors note that the interviewed construction managers did not have much exposure to Monte-Carlo based scheduling techniques and related software which are capable to consider risks and uncertainties to develop dynamic schedules (Moussa et al. 2007).

g) According to the surveyed construction managers, the percentage of total annual revenue spent on information technologies varies from 0.5% to 3.0% (average around 1%) depending on the project and the company. Managers identified the need for their organizations/companies to increase spending on IT because they believe it will enable them a competitive edge in the construction business.
h) Managers wanted to analyze all the possible technological options before investing. These technological options should be proven in an actual site environment by independent third parties (not the IT developer) by considering workers' expectations and ideas. IT investment should be a steady but slow process according to 35% of the surveyed managers.
i) Managers suggested a joint effort between industry, technology vendors, and researchers to find common areas for IT implementation on construction sites.
j) Managers had some concerns about their workers' skills level, if IT becomes a part of the work place due to learning curve issues. There is also a belief held by some management employees that construction work is a hands-on experience and modern technologies may disrupt and thus reduce the existing productivity level. About 25% of the surveyed managers had a different opinion about the worker's abilities. They believed that with proper training and demonstration, the present construction workers could use any technology on the market.
k) Real-time information sharing was not a regular practice in the commercial construction industry. Interestingly, almost all the managers expressed their willingness to implement such a system on their construction projects.

Technology Developers' Opinions

Technology developers were questioned about the following issues and concerns related to the development of new technologies for the construction industry.

a) Almost all the large construction companies preferred to develop "in-house" technologies rather than developing industry wide technological standards. However, according to the technology developers, all these companies are facing similar communication and productivity issues. Without the support of the construction companies, it is almost impossible for the technology developers to invent or develop software/technology which addresses the industry wide needs.
b) Technology developers are experiencing tremendous pressure to convince construction managers to consider new innovations in technologies.
c) Developer companies also face the difficulty of convincing their shareholders and boards of directors to invest more in construction technologies. This is mainly due to the low demand for modern technologies from construction industry.
d) The construction industry is known for the lack of clarity and understanding of its own requirements.
e) Technology developers had a difficulty in understanding the needs of the construction companies and how to address the overall technology integration to successfully increase the level of automation.
f) When two systems need to integrate – the customer is faced with making key decisions before any coding and/or integration can take place. Most of these decisions are depending on the needs of the owner of the data. According to technology developers, every customer is unique during the implementation.

g) Effectively execute the technological developments in accordance with the existing rules and a procedure is another issue identified by the IT developers. Major problems often provoke from the construction managers who had little or no formal training in software engineering and tools.
h) Software development is an ongoing process with several validation and fine-tuning attempts. Construction industry personnel typically cannot tolerate the on-going changes to software as they expect software tools to be finished products that produce "ultimate solutions."
i) Technology developers recommended having a third party consultant who can educate construction managers about the options and functions of modern technologies.

Conclusion

Use of IT to overcome communication issues was quite limited in the construction industry. Construction companies lag behind other industries in the creation of long-term strategic plans for the implementation of information technology. Investing wisely on IT was a priority for the managers. They wanted to deploy proven technologies which they believed would provide a quick return on investment. Managers prefer to have external parties to analyze, pilot test, and train workers on possible IT solutions which may improve construction productivity.

It was found through interviews that both the managers and the workers are not satisfied with the "communication" in their construction projects. Construction workers in construction projects were also not satisfied with the present level of use of information technologies to overcome widely visible communication barriers. They have expressed the willingness to use IT at site level to improve the communication standards.

Technology developers are facing many challenges in their attempts to convince construction managers to adopt their new developments. The technology innovation process for construction is slow because of the low demand and the lack of technological knowledge of the construction managers. As a result, actual needs of the construction industry are not properly communicated to technology developers because of these knowledge barriers. Technology developers have used several marketing strategies to convince construction managers to buy their products. According to technology vendors, the most successful strategy is to develop a long-term relationship with the construction companies which benefit both parties. As there are many innovative technologies available in the market which may ultimately increase construction productivity, technology developers are attempting to develop new industry-wide information standards to facilitate the development of future software and hardware which are compatible to construction companies

Recommendations

Following are recommended to improve on-site communication with the use of information technology. These recommendations are based on the observations and the views of major construction stakeholders.

a) Information transfer device: The radio devices in current use are not adequate to communicate complex design changes and related information. There is a desire

and a need for a faster, more reliable method of information transfer. The device needs to have the rugged features to suit it to the construction site environment.

b) Develop a materials and tools management system: Construction workers were spending about 15% of their total working time on materials and tools searching (Hewage and Ruwanpura 2006a). Construction managers could not find a feasible solution to minimize the said materials and tools time. Use of information technology is quite possible in this area (refer Zhang and Ruwanpura 2008 for details)
c) Develop a total on-site communication system: This research has proposed a potential IT based communication framework for construction projects. Research data analysis supported the use of IT to improve productivity and efficiency (refer Hewage and Ruwanpura 2006b for details).
d) Safety was identified as the number one priority on present day construction sites by the managers and workers. None of the observed construction projects used information technologies to improve the safety knowledge of the construction workers. At minimum, a comprehensive study needs to be conducted to identify needs and expectations of workers and managers on construction site safety..
e) Each construction project is unique. It is not possible to propose a general information model for all the construction companies and activities. It is necessary to conduct a comprehensive information needs analysis (of both workers and managers) before the implementation of any technology.
f) Construction companies may plan to have continuous training sessions to educate both current and new workers on the functions of IT.
g) Interviews with the construction managers revealed that the construction companies do not have expertise to maintain high technological devices. Software development is not a single step process. Hardware maintenance may also need experts' knowledge. Therefore it is advisable to initiate long-term partnerships with the technology and software developers for the implementation of IT in construction projects.

References

Abduh, M., and Skibniewski, M.J. (2003). "Electronic networking technologies in construction." J. Construction Research, 5 (1), 17-42.

Betts, M., and Smith, D. (1999). "Strategic management of IT in construction." Oxford, Blackwell Science Ltd.

Bowden, S., Dorr, A., Thorpe, T., and Anumba, C. (2006). "Mobile ICT support for construction process improvement." Automation in Construction, 15, 664-676.

Brandon, P. (2000). "Construction IT: Forward to What? Implementing IT to obtain a competitive advantage in the 21st century." Proc. Int. Conf. on Construction Information Technology: 2000 (INCITE 2000), January 17-18, Hong Kong.

Capital Projects Technology Roadmap (2004). "FIATECH, Element 4 –Intelligent and Automated Construction Job Site (IACJS)." <http://www.fiatech.org/projects/roadmap/jobsite.html>, (Aug. 5, 2008).

Daito (2003), "DaitoTrust Construction Co. Annual Report." <http://www.kentaku.co.jp/ir/pdf/annual/annual2003.pdf>, (Jan. 18, 2008).

Eisenblaetter, K. (2001). "Investigation and prototype development for a personnel digital assistant for document access from construction sites." Research project report, Dresden University of Technology, Germany.

Fischer, M., and Kunz, J. (2004). "CIFE annual report number 156, Stanford University." <http://cife.stanford.edu/online.publications/TR156.pdf>

Hewage, K.N., and Ruwanpura, J.Y. (2006a). "Carpentry worker issues and efficiencies related to construction productivity in Alberta's commercial construction projects." Canadian J. Civil Eng., 33(8), 1075-1089.

Hewage K.N., and Ruwanpura J.Y., (2006b). "Technology adoptability and adaptability issues related to communication in Alberta commercial construction projects." 1st International Const. Specialty Conference, Canadian Society for Civil Engineering, Calgary, Alberta, May 23-36.

Hewage K.N., and Ruwanpura J.Y. (2008). "IT Usage in Alberta's Building Construction Projects: Current Status and Challenges." J. Automation in Const., 17 (2008), 940-947.

Industry Science Resource (ISR) (1999). "Building for Growth: An analysis of the Australian building and construction industries." <http://www.industry.gov.au/assets/documents/itrinternet/Building_for_Growth_Industry_Analysis20050808135954.pdf> (May 06, 2008).

Institute of Electrical and Electronics Engineers Inc. (IEEE) (2001). <http://www.computer.org/> (June 05, 2008).

Lee, H.J. (2003). "Modeling computer integrated construction site management." M.Sc. thesis, School of Engineering, Faculty of engineering and information technology, Griffith University, Gold Coast campus, Australia.

Magdic, A., Rebolj, D., Cus-Babic, N., and Milan, R. (2002). "Mobile computing in construction." Int. Council for Research and Innovation in Building and Construction, CIB w78 conference, June 12-14, Aarhus, Denmark.

Mak, S. (2001). "A model of information management for construction using information technology." J. automation in const., 10 (2), 257–263

Moussa, M., Ruwanpura, J.Y., and Jergeas, G. (2007) "CTAN for Risk Assessments Using Multilevel Stochastic Networks." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 133(1), 96-101

Mohamed, S., and Stewart, R. A. (2003). "An empirical investigation of users' perceptions of web-based communication on a construction project." J. Automation in Const. 12 (1), 43-53.

Olofsson, T., and Emborg, M. (2004). "Feasibility study of field force automation in the Swedish construction sector." Electronic j. information technology in const. (ITCON), 9, 285-295.

Perry, M., O'hara, K., Sellen, A., Brown, B., and Harper, R. (2001). "Dealing with mobility: understanding access anytime, anywhere." Computer-Human Interaction, 8(4), 323-347.

Rivard, S., Froese, T., Waugh, L., El-Diraby, T., Mora, R., Torres, H., Munir, G. S., and O'Reilly, T. (2004). "Case studies on the use of information technology in the Canadian construction industry." Electronic j. information tech in const., 9, 19-34.

Zhang, G. and Ruwanpura, J.Y. (2008). "An efficient material management model to improve productivity" Proceedings of the CIB 2008 conference, Dubai, UAE.

RULES AND GUIDELINES FOR IMPROVING THE MECHANICAL, ELECTRICAL, AND PLUMBING COORDINATION PROCESS FOR BUILDINGS

Thomas M. Korman[1], Ph.D., P.E.

[1]Assistant Professor, Department of Construction Management, California Polytechnic State University, San Luis Obispo, 1 Grand Avenue, San Luis Obispo, CA 93407-0284; PH 805-474-5957; email: tkorman@calpoly.edu

Abstract

The coordination of mechanical, electrical, and plumbing (MEP) systems has become a major challenge for complex buildings and industrial plants. The coordination process involves locating equipment and routing connecting elements for each system to avoid physical interferences. For the past several years the MEP coordination has involved sequentially comparing and overlaying drawings from multiple trades, in which representatives from each MEP trade work together to detect, and eliminate spatial and functional interferences between MEP systems. This multidiscipline effort is time-consuming and expensive. With the recent development of Building Information Modeling (BIM) this process is now able to evolve with the software technology; however, the software technology available today is limited to performing geometric clash detection. Based on observational research, this paper recommends a process for performing MEP coordination and describes how rules and guidelines can improve the MEP coordination process in buildings using BIM software.

Introduction

Mechanical, electrical, and plumbing (MEP) systems are the active systems of a building that temper the building environment, distribute electric energy, allow communication, enable critical manufacturing process, provide water and dispose of waste [Barton 83]. Design and construction professionals commonly use the acronym MEP to refer to these systems. MEP coordination is the arrangement of the building system components that must fit within the constraints of architecture and structure. The process involves defining the locations for components of building systems, in what are often congested spaces, to avoid interferences and to comply with diverse design and operations criteria. Ideally, the result of such a coordination

effort is the most economical arrangement that meets critical design criteria and performance specifications. The level of difficulty associated with this process directly relates to the complexity and number of building systems in a facility, which in recent years has increased. Building systems can now range from 15 to 60 percent of the total building cost [Tao 01].

Many construction industry professionals have cited MEP coordination as one of the most challenging tasks encountered in the delivery process for construction projects [Tatum 00]. There are three primary reasons for this. First, the process is highly fragmented between design and construction firms. Second, the level of technology used in different coordination scenarios varies significantly. Third, the current manual process does not provide a facility model for use over the complete life cycle [Korman 01].

In the past, there has been a wide variation in the level of technology used in the MEP coordination process. At the low-tech end of the spectrum, specialty contractors drafted plan-views on translucent media and prepare section-views when necessary. At the other extreme, progressive contractors have used 3D computer-aided-design (CAD) to improve the process. With the recent development of Building Information Modeling (BIM) software, the process has gravitated toward the use of BIM software. This paper recommends a process for performing MEP coordination and describes how rules and guidelines can improve the MEP coordination process in buildings using BIM software.

Overview of the MEP Coordination Process

Coordination is an integral part of many activities during the life of a construction project. In fact, the entire construction process requires coordinating key resources such as information, material, equipment, and labor. Many coordination activities relate to MEP systems. A few are as follows:

- integration of MEP systems into the architectural and structural envelope
- integration of detailed MEP trade drawings with each other
- creation of equipment matrices and selection of suppliers
- installation and procurement scheduling for MEP systems
- acquisition of supplier drawings for components of MEP systems
- tracking and formalizing procedures for submittals
- general contractor's management of MEP specialty contractors.

MEP coordination is only one link in the chain of coordination events. It is the arrangement of various building system components, which are critical to the building functioning properly. The MEP coordination process involves defining the exact location for each building system component throughout the building to comply with diverse design and operations criteria. Often specialty contractors must arrange components in congested areas to avoid interferences with architecture, structure, and other building system components. The process is a multi-disciplinary effort with input from many people. Iterative in nature, the process requires many revisions.

This process occurs only after engineers have completed preliminary design drawings and results in a final set of coordination drawings.

Description of current practice. Currently, MEP coordination begins after design and preliminary routing of all building systems (mechanical, plumbing, electrical, etc.). The design is complete when engineers have sized all components (e.g., HVAC duct, pipe, conduits), completed the engineering calculations, and produced the diagrammatic drawings; however, engineers have not defined specific routing. Usually, they size HVAC and piping systems during this initial design. Other trades, such as electrical and fire protection, do not. Therefore, they draw some of the systems to scale and others simply as lines with references to component sizes. The design consultants typically assign full responsibility for coordination to the specialty contractors, including checking for clearances, field conditions, and architectural conditions.

Representatives from each of the specialty contractors (primarily HVAC wet and dry, plumbing, electrical, and fire protection) meet to discuss their particular designs and drawings, which indicate the proposed routing for each system to follow to service each required location. Most specialty contractors refer to these contract drawings as schematic design drawings. The stamp that the engineer provides only insures that the design of the systems will work functionally. In this scenario, the design consultant remains the engineer of record (EOR) and retains liability for the system; however, these drawings are not detailed enough to either fabricate components or construct the systems. The required size of components, such as conductor wire, duct dimensions, and pipe diameter are called out on the drawings, but no scaling of the components is shown in the drawings. It is the specialty contractor's responsibility to build the particular building system from these design documents. This requires that the contractor produce shop drawings, also known as fabrication drawings. The shop drawings include the detailed information required by the specialty contractor to fabricate and install a particular building system.

Specification requirements typically found in most construction contracts state that it is the specialty contractor's responsibility to field coordinate the multiple building systems between the trades. Therefore, once specialty contractors have produced the shop drawings, the coordination process begins. During MEP coordination, all the specialty contractors meet to determine the exact location of each system.

The architectural and structural drawings set the envelope for routing MEP systems. Common constraints for them to consider in routing MEP systems are corridors, openings in shear walls, and architectural requirements, such as ceiling type and interstitial space. Specialty contractors then prepare preliminary routing drawings reflect these constraints; each trade routes their system to their own advantage. This includes decreasing the overall length of lines, routing lines close to support points, choosing prime locations for major components, and locating system lines to facilitate the construction needs of their own trade.

During coordination meetings, the participating specialty contractors compare preliminary routing for their systems to identify and resolve conflicts. The MEP trades use a sequential comparison overlay process to compare their design drawings until they resolve all interferences. This often requires preparing section views for highly congested areas to identify interferences. The preliminary shop drawings that each specialty contractor brings to the meeting indicate the path preferred for each branch of the system to reach the required locations and perform essential functions. Architectural, structural, and diagrammatic drawings constrain this routing. Within these constraints, specialty contractors route systems based on the lowest cost; however, they generally do not consider the other systems. They also decide which contractor(s) will revise their design and submit requests for information regarding problems that require an engineering resolution.

The product of this process is a set of coordinated shop drawings that the specialty contractors submit to the design engineer for approval. Upon completion, all specialty contractors involved (mechanical, electrical, plumbing, and fire protection) sign-off on each others' drawings, indicating that they accept the coordinated design for the specific area of the facility. Specialty contractors then prepare cut sheets for duct fabrication and spool sheets for piping, based on the coordinated shop drawings. They fabricate duct and larger pipe in shops and ship the pieces to the site. The contractors' crews install the systems, using the shop drawings to define location. Quality control personnel generally inspect the system using the diagrammatic drawings from the engineer. To complete the system, the contractors prepare as-built or record drawings by marking and editing the shop drawings or by consolidating electronic files.

Problems with current practice. Even with the aid of 3D-CAD software, specialty contractors may still need to produce cross-section and projection views to visualize congested spaces. In some extreme cases, specialty contractors construct full-scale mock-ups of very congested areas to identify places of conflict in order to alleviate concerns regarding constructibility, operations, and maintenance.

Upon the completion of the current coordination process, no electronic models of the facility remain with the owner for use over the facility's life cycle. Facility managers and maintenance personnel use as-built drawings provided by the contractor. Furthermore, the coordination process often must take place in two stages, once for the coordination of the building systems under the core-and-shell construction contract and again under the construction contract for tenant improvement. Facility managers must prepare as-built drawings of core-and-shell construction in order to provide information for tenant improvement contracts.

Positive aspects of current practice. Despite the many problems with the current practice, some of its positive aspects are as follows:

- it provides opportunity to value-engineer the entire project
- it allows interaction of representatives from many disciplines and construction trades to gather and discuss configuration alternatives

- it promotes sharing knowledge regarding the multiple systems
- it allows for the identification of many problems prior to field work, but it not thorough enough to detect all conflicts
- it instigates discussion of construction scheduling and installation sequencing, but does not allow for a detailed investigation.

Recommended Procedure for Performing MEP Coordination using BIM software

As stated above, the MEP coordination process takes place in a series of meetings in which representatives from each of the specialty contractors bring together their preliminary drawings to resolve coordination problems. At coordination meetings, the underlying goals of the group are to meet code requirements, insure that the systems function to meet user needs, verify that the systems are feasible to install, and maintain an economical routing and design.

Sequential Comparison Process. Figure 1 depicts a recommended sequence for use in comparing multiple CAD files created by the specialty contractors. Using BIM software, the files are combined into a common in a 3D CAD model to identify interferences with different types of design criteria. When specialty contractors produce drawings using BIM software, they frequently use a number of software systems products such as GraphiSOFT's ArchiCAD™ or AutoCAD's Revit™ for collusion detection and interference checking. Revisions to the CAD model capture the decisions resolving these problems. For example, a model containing the standard MEP building systems may still involve four or five specialty contractors: Sheet metal, HVAC process piping, water distribution piping, sanitary drainage piping, and electrical conduit and cable.

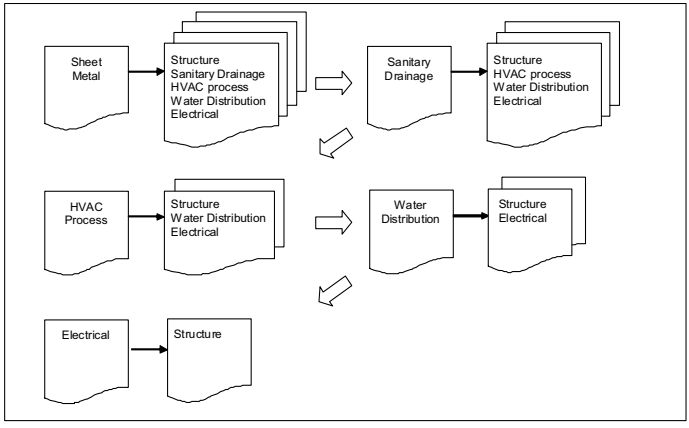


Figure 1 – Recommend sequential comparison process

The HVAC sheet metal is the first to be compared against the structure, sanitary drainage, process piping, water distraction, and electrical. HVAC sheet metal is used a base because it has the largest components, primarily composed of large ductwork and variable-air-volume (VAV) boxes. It is often the hardest to relocate because the large duct sizes restrict the routing to a few locations where adequate space is available.

The sanitary drainage system is recommended to be compared next. This includes all horizontal graded waste lines, vertical soil stacks, and vent lines. The requirement to slope all graded lines and waste lines to allow for gravity flow gives the plumbing system is the next highest level of priority after the HVAC dry system. The gravity drain lines typically slope 1/8 inch for every foot. This requirement forces the drain lines to compete with the large HVAC dry ducts at the higher elevations because they must start as high as possible to maintain the grade without falling below the ceiling tiles. Engineers route HVAC dry ducts at higher elevations because of their large volume.

The HVAC process piping is next, which includes heating and cooling water lines. These piping lines feed directly into the HVAC sheet metal to heat and cool air at various interface points. The HVAC sheet metal and HVAC process piping systems work together and must be tightly coordinated. Routing of the HVAC wet system is based on the HVAC dry system routing and location.

Where manufacturing process piping is included as a building structure, it would be coordinated following the HVAC process piping system. Most manufacturing process piping systems are pressure-driven and thus can yield to larger building system components and gravity-driven system lines that are more difficult to re-route due to the risk of affecting their functionality. In cases where a special routing is required for process piping to function at its optimal performance level, engineers assign priority to the manufacturing process-piping system.

Where fire protection piping system in included in the building structure, it would be coordinated following the manufacturing process piping system. This is a pressure-driven system; however, the fire protection main lines must be slightly graded to allow scheduled draining as required by operations and maintenance. This complicates the coordination of the main lines. Specialty contractors are advised to compare drawings individually with HVAC Sheet metal, HVAC process piping, and sanitary drainage system.

Water distribution piping is recommended to be compared next. This includes potable hot and cold water distribution plumbing lines. Water distribution systems are pressure-driven systems and therefore are easier to re-route around larger components.

Consideration of the electrical system follows the water distribution system.

Engineers consider the electrical system to be one of the more flexible systems because the components are generally smaller and installers can be easily route electrical conduit in the field. However, this is only true for branch conduits which are 1/2-inch diameter and smaller. Larger electrical main conduits should receive priority. This is because the greater the number of elbows and bends, the more difficult it becomes to pull cable.

The control systems and telephone/datacom systems should be coordinated last if a CAD file is produced for them. The control system is the most flexible because of its smaller diameter tubing and conductors. Components in the control system run along other systems, such as HVAC dry and process piping. Therefore, specialty contractors usually coordinate the control system in the field. The primary problem with the telephone/datacom systems is routing these lines adjacent to electrical distribution cables. Engineers usually avoided this problem by segregating telephone/datacom lines from transmission lines by at least three (3) feet. Table 1 summarizes the priority order.

Table 1 - Priority order for sequential comparison process Resolving common coordination problems

System	Priority/special notes
HVAC Sheetmetal	Usually first due to large size of components
Sanitary Drainage system	Design criteria for slope essential for system performance
HVAC process piping	Follows HVAC Dry due to interdependence of these systems
Manufacture Process piping	Takes first priority if critical to manufacturing process
Fire Protection	Most flexible routing, especially small diameter pipe
Water Distribution	Lower priority because less difficult to re-route
Electrical	Flexible routing within safety and architectural requirements
Control systems	Flexible routing but must limit bend radius for pneumatic tubes
Telephone/Data communications	Flexible routing but must limit bend radius for fiber optic cables

Resolving common coordination problems. There are many locations in facilities that repeatedly cause coordination problems. These include building corridors, points of entry and exit, openings in shear walls, and vertical chases. Table 2 lists some of the more typical coordination problems found in these areas by observing coordination meetings and by interviews with MEP coordination experts. The table

also list options coordination experts use for avoidance or resolution.

Table 2 - Typical problems encountered during coordination Indicators of Good Coordination Efforts

Coordination issue	Ways to avoid or resolve
Graded plumbing lines interfering with ductwork	• Drop ceiling grid • Move one component to side • Penetrate ductwork • Flatten ductwork • Drop ductwork below plumbing line • Split ductwork around plumbing line
Graded plumbing line interfering with structural member	• Cope structural member • Penetrate structural member
Components interfering with access space for valves	• Move components away from valve
Ductwork interfering with lighting fixture removal clearance space	• Drop ceiling grid • Move ductwork away from lighting • Flatten ductwork
Vertical space not adequate to place all components	• Drop ceiling grid • Place electrical conduit in floor slab • Use alternative ductwork shape
As ductwork drops below structural element, bottom of ductwork falls below ceiling grid	• Drop ceiling grid • Flatten ductwork • Penetrate structural member
Components too close to structural system, therefore not allowing proper area for fire proofing	• Move components down to allow for proper thickness of fire proofing
No access space for maintenance	• Move components to sides to create access area
Component support systems interfere with other components	• Create common support systems for all systems

Indicators of Good Coordination Efforts. As a part of this research, it was also a goal to identify what industry professionals deemed to be indicators of good coordination. Table 3 lists the indicators for evaluating the quality of the MEP coordination effort classified by project phase. Industry professionals consider coordinated building systems with these characteristics to be well-coordinated projects.

Table 3 – Indicators for evaluating the quality of MEP coordination efforts

Project Phase	Indicator
Design	• minimize number of fittings and connections • group and centralize similar systems • group similar systems at same elevation • route systems on grid pattern, perpendicular to building walls • minimize the number of diagonal lines
Construction	• decrease cost for installing components • decrease schedules for installing systems • maximize number of prefabricated components • minimize level of rework in the field • consider installation sequence
Operations and Maintenance	• provide adequate access space for operations and maintenance • reserve adequate space for future expansion

Conclusions

MEP coordination has become a major challenge for projects. The need for MEP coordination grows out of the lack of detailed design provided for fabrication and installation of building systems, and exists regardless of the project delivery process used. The current conditions in the design and construction industry drive current practice for MEP coordination and create an opportunity to improve. Often the parties involved do not take the opportunity to align goals and define requirements [Bergthold 98]. In addition, the MEP design consultants' do not consider constructibility issues, and designers must make assumptions about constructibility or ignore the issue totally. In order to use BIM software effectively to assist in the MEP coordination process, it is authors' opinion that indicators of good coordination results need to be adhered to and an approved process should be followed. Resolving all physical interference during the MEP coordination process does not necessary ensure that a facility has been well coordinated. This idea stretches the concept that there are multiple types of interferences beyond physical interferences. Additionally, when one model is shared among the project team, physical conflicts between the structure, mechanical, electrical, and plumbing systems can be identified early in the design process and resolution is expedited and the building trades are not restricted to only relying on paper plans and written specifications.

References

Barton, Paul K. (1983), Building Services Integration, E. & F. N. Spoon Ltd., London, 1983.

Bergthold, Rudy (1998), Telephone interview with Rudy Bergthold, Vice President, Cupertino Electric, January 26, 1998.

Hanna, Awad S., Russell, Jeffery S., Gotzion, Timothy W., and Nordheim, Erik V., (1999) "Impact of Change Orders for Mechanical Construction." Journal of Construction Engineering and Management, Volume 125, No. 5., May/June 1999, pp. 176-184.

Korman, Thomas M. (2001), "Integrating Multiple Products over their Life Cycle: An Investigation of Mechanical, Electrical, and Plumbing Coordination" Ph.D. Thesis, Stanford University, CA, June 2001.

Tao, William K. Y., and Janis, Richard R. (2001), Mechanical and Electrical Systems in Buildings, Prentice Hall, Columbus, 2001.

Tatum, C.B., and Korman, Thomas M. (2000), "Coordinating Building Systems: Process and Knowledge," ASCE Journal of Architectural Engineering, Volume 6, No. 4, December 2000, pp. 116-121.

Tatum, C.B., and Korman, Thomas M. (1999), "Improving MEP Coordination in Buidling and Industrial Projects", CIFE Working Paper#54, Center for Integrated Facility Engineering, Stanford University, March 1999.

ASSESSING THE ENVIRONMENTAL IMPACTS OF LEAN SUPPLY SYSTEM: A CASE STUDY OF REBAR SUPPLY IN HIGH-RISE CONDOMINIUM CONSTRUCTION PROJECTS

Bae, Jin-Woo[1] and Kim, Yong-Woo[2]

ABSTRACT

Lean production is a systemic approach to meeting customer expectations by reducing waste. Many believe that implementing lean leads to achieving "green." The authors explore the validity of this statement. They investigate the environmental impacts of prefabrication with just-in-time (JIT) delivery on reinforced bar using a building construction case study. The results suggest that prefabrication with JIT delivery consumes less energy but emits more CO_2. The study also finds that delivery batch size per truck as well as delivery distance are important factors.

INTRODUCTION

The construction industry is one of the largest and most important industries, yet at the same time it is one of the largest polluters (Horvath, 2004). The natural environment is increasingly important to construction firms and many contractors are subject to intense public scrutiny and an increasing number of contractors publish annual environmental-performance reports.

The growing number of recent literature demonstrates the importance of these issues. Attempts to assess sustainable impacts have already been made to evaluate the life-cycle effects of commercial buildings (Junnila and Horvath 2003), but most studies thus far have focused on specific building materials (Guggemos and Horvath 2005). In many studies, the impacts of the construction material supply system on sustainability are ignored or simply approximated because the analysis of supply system is complicated or the methodologies of analysis are limited.

[1] Ph.D. Student, Construction Engineering Program, Dept. of Civil and Env. Eng., Univ. of Washington, Box 351610, Seattle, WA
PH (425) 361-5778; FAX (206) 685-1976 jbae@u.washington.edu
[2] Assistant Professor, College of Architecture and Urban planning, Dept. of Constr. Mgmt, Univ. of Washington, Box 351610, Seattle, WA
PH (206) 616-1916; FAX (206) 685-1976 yongkim@u.washington.edu

The supply system of reinforced steel bar to construction is considered one of critical factors in meeting the budget and schedule goals of a construction project (Polat and Ballard, 2003). The tradition of the construction industry has long been to deliver rebar from a rebar supplier or the warehouse of a contractor to the construction site in large batches, fabricate (i.e., cut and bend) rebar on-site and position it for assembly. The traditional rebar supply system requires large on-site yard and holding costs. Since people recognized the holding costs including yard space requirements, a new method has gained industry attention especially in construction projects in metropolitan areas. A new rebar supply system uses off-site cut & bend (i.e., prefabrication) with a frequent delivery of small batches. Even though this new system requires more frequent deliveries, it removes yard space requirements and deliveries within the sites (i.e, on-site yard to building). A recent study showed that a lean rebar supply system reduces the need for storage space on sites and improves productivity due to prefabrication (Arbulu and Ballard 2004). While most relevant research regarding supply systems focused on how lead time can be reduced using either process improvements or external integration with suppliers (Kim et al. 2007; Arbulu et al. 2003; Akel et al. 2004), few research studies have investigated the environmental impacts of a new material supply system even though it is critical in terms of sustainability.

As a pilot study to assess the sustainability impact of lean supply system, the authors studied the environmental impacts of reinforced bar supply system in two high-rise condominium construction projects. The projects were similar in all aspects except for their rebar supply chains: one is using on-site fabrication with non-JIT delivery and the other is using prefabrication with JIT delivery system. The authors investigated the environmental impacts of these supply systems: emission characteristics, energy consumption, and material loss rate depending on the type of supply chain. The assumption is that only one kind of heavy-duty truck was used because in both cases, the projects were large enough to have batch sizes larger than 20 tons of rebar. Considering just one option of transport greatly simplifies the analysis. Because the construction phases of the two projects were different, the data was gathered for two months during which rebar works were conducted actively. These two months are represented by month A and B.

This paper compares the impacts of two supply chains, which are on-site fabrication with non-JIT and prefabrication with JIT, on environments by investigating the energy consumption, CO_2 emission, and rebar loss in a case study. In addition, the authors identify the critical factors, which affect environmental

impacts of the two delivery methods. It is noted that the study did not investigate the environmental impacts of the reduced potential for products to be damaged during handling and storage caused by reduced inventory on the site.

CASE STUDY

HIGH-RISE CONDOMINIUM CONSTRUCTION PROJECT X AND Y (ON-SITE FABRICATION WITH NON-JIT VS. PREFABRICATION WITH JIT SUPPLY CHAIN)

The authors investigated two high-rise condominium construction projects. The construction of project X was conducted from Mar 2006 to Sep 2008. The project consisted of four 27-story buildings, two 30-story buildings, and two 21-story buildings in Korea. The raw rebar was delivered from the warehouse of the general contractor using a non-JIT supply chain, and processed on the construction site.

The general contractor established a rebar processing plant near Seoul, Korea in 2005 and supplied rebar to a project Y construction site in downtown Seoul. Project Y is the project which consisted of total fifty four buildings and a community complex. The rebar was distributed using JIT. The goals of the rebar processing plant are to minimize the amount of loss due to rebar waste, meet the exact specifications of the reinforcing process, and eliminate the space for inventory loading and field works.

REBAR LOSS

The general contractor estimated a rebar loss rate of 10 percent for project X construction, and a 2 percent loss rate for project Y. It means that 10 and 2 percent of total rebar consumption were processed and delivered to the construction sites unnecessarily in projects X and Y. Although the total rebar consumption in project Y is almost twice than project X, the rebar loss amount of project Y is less than 40 percent. If total rebar consumption in the two projects were the same (5,000 ton), the amount of rebar loss for the two projects would be 500 tons and 100 tons respectively. The well-planned rebar product processing at a rebar prefabrication plant may reduce the on-site rebar loss rate caused by disorganized cuttings, and the stockpiling of rebar on construction sites which often results in rust and theft of rebar. The rebar consumptions and loss in projects X and Y are shown in Table 1.

Table 1. Rebar Consumption and Loss Projects X and Y in Month A and B

Project	Project X (On-site fabrication with Non-JIT Supply Chain)		Project Y (Prefabrication with JIT Supply Chain)	
Month	A	B	A	B
Total Rebar Production of the Prefab. Plant (tons)	-	-	16,125	15,000
Total Rebar Consumption (tons)	3,544	3,150	6,125	6,500
Rebar Loss Rate (%)	10		2	
Total Rebar Loss (tons)	354	315	123	130

ENERGY CONSUMPTION FOR REBAR PROCESSING AND POSITIONING

Equipment types and the monthly duration of use for rebar processing and positioning into the installation places are shown in Table 2. Monthly hours of use per unit, the number of units, and operation rates for rebar movement were given from the survey questionnaire completed by project managers of two designated projects. Based on the data, hours of use for each equipment were estimated for several projects proportionally. For instance, a travelling overhead crane at the rebar prefabrication plant worked for several projects including project Y. In this case, the authors estimated the contribution of the crane based on hours of use of the total operation.

Table 2. Equipment Use for Rebar Processing and Positioning

Location	Equipment	Use (h)		Power Source	Power [diesel (hp)] [electric (W)]
		Project X	Project Y		
Prefab. Plant	Travelling Overhead Crane	-	118[1]	Diesel	450
	Rebar Bender/Cutter	-	475[2]	Electric	1,200
	Forklift	-	285[3]	Diesel	125
Const. Site	Tower Crane	70[4]	72[5]	Diesel	450
	Rebar Bender/Cutter	300[6]	-	Electric	850
	Forklift	405[7]	122[8]	Diesel	125

1. *290 hours (hours of use per unit) x 1 unit x 41%. The authors use a 41 percent (6,313tons of total rebar consumption (average of month A and B) / 15,563 tons of*

total monthly production of a rebar manufacturing plant (average of month A and B)) to calculate the hours of use for project Y.

2. *290 hours (hours of use per unit) x 4 units x 41%.*
3. *174 hours (hours of use per unit) x 4 units x 41%*
4. *20 hours (hours of use per unit) x 5 units x 70% (operation rate for rebar movement)*
5. *12 hours (hours of use per unit) x 10 units x 60% (operation rate for rebar movement)*
6. *150 hours (hours of use per unit) x 2 units*
7. *135 hours (hours of use per unit) x 3 units (1 for rebar processing and 2 for positioning)*
8. *61 hours (hours of use per unit) x 2 units*

Table 3 shows the energy consumption and CO_2 emission figures for the two projects for rebar processing and positioning. Projects X and Y consumed 61,465 10*MJ and 102,119 10*MJ of energy respectively for the activities. Although project Y consumed energy at the prefabrication plant and a job site, the project consumed energy effectively at the prefabrication plant. Therefore, the energy consumption per ton for project Y is lower than that for project X. According to the analysis, the project using the prefabrication with JIT delivery system consumed less energy per ton because the supply system used a travelling overhead crane, forklifts, and tower cranes more efficiently than the on-site fabrication with non-JIT delivery system.

Table 3. Energy Consumption and CO_2 Emission for Rebar Processing and Positioning

Location	Equipment	Project X		Project Y	
		Energy (10*MJ)	CO_2 (g)	Energy (10*MJ)	CO_2 (g)
Prefab. Plant	Travelling Overhead Crane			39,682	53,100
	Rebar Bender/Cutter			205	135
	Forklift			26,623	35,625
Const. Site	Tower Crane	23,540	31,500	24,213	32,400
	Rebar Bender/Cutter	92	60		
	Forklift	37,833	50,625	11,396	15,250
Total		61,465	82,185	102,119	136,510
Per ton		18.36	24.55	16.18	21.63

ENERGY CONSUMPTION AND CO_2 EMISSION FOR TRANSPORTATION

In table 4, data including the total rebar consumption, delivery sizes per truck, number of deliveries, and delivery distances for projects X and Y were estimated and the total energy consumption and total CO_2 emission were calculated. As seen in the table, the difference of delivery size per truck between projects X and Y is 2~3 tons. The reason for the difference is that lower delivery size per delivery truck for prefabricated rebar than raw rebar is needed because the prefabricated rebar takes more room than the raw rebar. As a result, project Y consumed about 2 10*MJ of more energy and emitted 4 g of more CO_2 per rebar consumption than project X for transportation.

Table 4. Energy Consumption and CO_2 Emission for Transportation

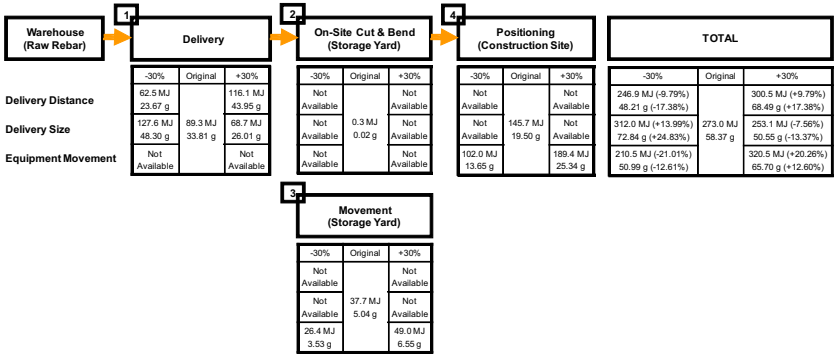
Project	Project X		Project Y	
Month	A	B	A	B
Total Rebar Consumption (ton)	3,544	3,150	6,125	6,500
Delivery Size per Truck (ton)	23	23	21	20
# of Delivery	154	137	292	325
Round Trip Delivery Distance (mile)[1]	80			
Total Delivery Distance (mile)	12,320	10,960	23,360	26,000
Total Energy Consumption (10*MJ)	31,645	28,127	59,899	66,745
Energy Consumption per Rebar Consumption (10*MJ/ton)	8.21	8.21	9.78	10.27
Total CO_2 Emission (g)	119,818	106,497	226,800	252,720
CO_2 Emission per Rebar Consumption (g / ton)	33.81	33.81	37.03	38.88

1. The authors assume that the one-way delivery distances both from a raw rebar supplier and a rebar prefabrication plant to a construction job site are same, which is 40 miles.

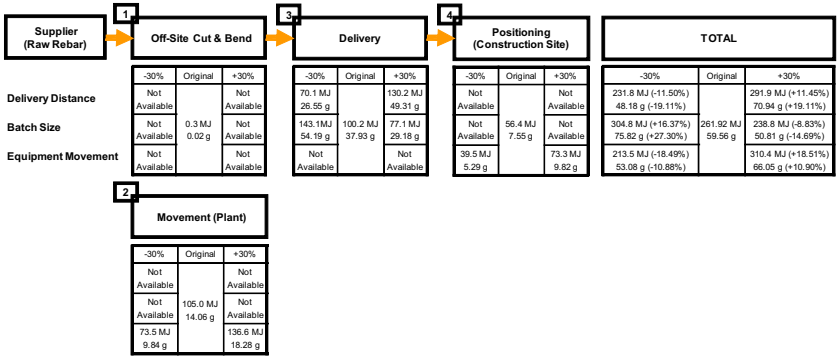
DISCUSSION

The energy consumption and CO_2 emission of projects X and Y depend on many factors such as delivery distance, delivery size per truck, and the equipment movement both at the factory and a job site. The authors tested these three factors to identify the critical factors.

Figure 1 shows the energy consumption and CO_2 emission per rebar consumption in the two supply chains and their alterations due to the change of delivery distance, batch size per truck, and rebar movement by 30% both at the factory and a construction site. The rebar supply chain for project X is divided into four activities, which are ① the delivery of rebar from a raw rebar supplier to a storage yard near a construction site, ② on-site cut & bend of the raw rebar in the storage yard, and ③ the movement of the rebar in the storage yard, ④ the positioning of the fabricated rebar to the installation position. In the similar way, ① the rebar cut & bend at a prefabrication plant, ② the movement of the fabricated rebar at the prefabrication plant, ③ the delivery of rebar from the prefabrication plant to a job site, and ④ the positioning the fabricated rebar to the installation position are identified for project Y to calculate the energy consumption and CO_2 emission for each activity.



(a) Project X: On-site Fabrication with Non-JIT Delivery



(b) Project Y: Prefabrication with JIT Delivery

Figure 1. Change of Energy Consumption and CO_2 emission per Rebar Consumption

VARYING DELIVERY DISTANCE

The delivery distance is the critical factor that affects the energy consumption and CO_2 emission per rebar consumption in the rebar supply chains. Especially, the delivery distance is directly related to the diesel consumption of a delivery truck. Therefore, when the delivery distances are changed, the diesel consumption per rebar consumption for transportation is also changed in both delivery types with the same percentage. Although delivery distances of two projects are the same, projects X and Y consumed 89.3 MJ and 100.2 MJ respectively. The difference between two delivery methods is caused by the difference of the delivery size per truck in two projects. As seen figure 1, the percentage change of CO_2 emission is larger than that of energy consumption, because the portion of a diesel truck, which emits more CO_2 than the electricity consuming equipment, is increased or decreased.

VARYING DELIVERY SIZE PER TRUCK

The delivery size per truck is another significant factor when a contractor selects a delivery method. When the delivery size per truck changes, it affects the number of deliveries and the changed number of deliveries affects the total CO_2 emission larger than total energy consumption which is consistent with the result from the change of the delivery distance.

The change rate of the delivery size per truck does not result in the same change rate of the total energy consumption and CO_2 emission. For instance, when the batch size per truck increases or decreases by 30%, the total energy consumption rate decreases by 7.56% and increases by 13.99% in project X. The reason for the difference between decreased and increased rates is that the change of the batch size per truck does not affect the change rate of the number of delivery with the same

percentage. Although the batch size per truck increases or decreases by 30%, the number of delivery decreases and increases by 42.9% and 23.1% in project X.

VARYING EQUIPMENT MOVEMENT AT A PREFABRICATION PLANT AND A CONSTRUCTION SITE

The equipment movement in a prefabrication plant, a storage yard, and a construction site is the most important factor regarding the energy consumption in both the on-site fabrication with Non-JIT delivery and prefabrication with JIT delivery. These machines are operated for the movement and positioning of rebar. Project X consumed 183.4 MJ of energy and emitted 24.54 g of CO_2 per ton, while project Y consumed 161.4 MJ per ton and emitted 21.61 g of CO_2 per ton. When the equipment movement distances vary by 30%, the total energy consumptions changed by 21% and 18.5% in projects X and Y respectively. This equipment includes a travelling overhead crane and a forklift at the prefabrication plant and a tower crane and a forklift at the construction site.

CONCLUSIONS

The environmental impact of the delivery and fabrication method of construction materials is a significant issue in the sustainable construction. In this paper, the authors investigated the on-site fabrication with non-JIT delivery and the prefabrication with JIT delivery by comparing energy consumption, CO_2 emission, and material loss in a case study.

Project X using on-site fabrication with non-JIT delivery system consumed more energy by 4% and emitted less CO_2 by 2% than project Y. The difference between projects X and Y is so small that distinguishing the two projects is meaningless when the energy consumption and CO_2 are considered. However, on-site fabrication with non-JIT system in project X generated the five times of more rebar loss than the rebar loss in project Y. The combination of prefabrication and JIT may reduce the rebar loss rate by eliminating the waste during the processing and maintaining of rebar.

Contrary to general expectations, JIT did not increase energy consumption and CO_2 emission per rebar consumption during rebar transportation regardless the delivery distance in our case where the same capacity of trucks with the on-site fabrication were used. This fact mainly depends on the size of a construction project. For instance, in a large construction project such as projects X and Y, the rebar delivery size per rebar consumption is large enough to be delivered by a large size truck, while the rebar delivery size per rebar consumption in a small construction project may be smaller than the full capacity of one truck. This means that the energy

consumption and air emission in a large construction project are not affected by the type of delivery methods.

According to our analysis, the delivery size per truck has a greater impact on environment than the frequency of deliveries, especially on CO_2 emission during transportation. The larger delivery size per truck may use less energy and produce less CO_2. Therefore, we recommend not to reduce the delivery size per truck when you reduce the amount of order size in implementing JIT.

Also we identified the equipment movement both in the prefabrication plant and a job site as one of the critical factors, especially in regard to the energy consumption. It suggests that site layout is important in determining environmental impacts.

REFERENCES

Arbulu, R.J., and Ballard, G.H. (2004). “Lean Supply Systems in Construction.” Proc., 12th Ann. Conf. of the Int. Group for Lean Const., Copenhagen, Denmark.

Arbulu, R.J., Tommelein, I.D., Walsh, K.D., and Hershauer, J.C. (2003). "Value Stream Analysis of a Re-engineered Construction Supply Chain." J. Building Research and Information, 31 (2) 161–171.

Akel, N.G., Tommelein, I.D., and Boyers, J.C. (2004). "Application of Lean Supply Chain Concepts to a Vertically-Integrated Company: A Case Study." Proc. 12th Ann. Conf. of the Int. Group for Lean Const., Copenhagen, Denmark.

Bae, J. and Kim, Y. (2007). “Sustainable Value on Construction Project and Lean Project Development.” Proc. 15th Annual Conf. of the Int. Group for Lean Const., Detroit, MI.

Ballard, G. and Kim, Y. (2007). “Lean Implementation at the Project Level” Research Report 234, Construction Industry Institute, Austin, Tx.

Guggemos, A. A., and Horvath, A. (2005). “Comparison of environmental effects of steel- and concrete-framed buildings.” J. Infra. System, Vol 11, No 2, pp. 93–101.

Horvath, A., (2004). "Construction Materials and the Environment," Annual Review of Environment and Resources, 2004, Vol. 29, pp. 181-204.

Junnila, S., and Horvath, A. (2003). “Life-cycle environmental effects of an office building.” J. Infra. System, Vol 9, No 4, pp.157–166.

Kim, Y, Ballard G., and Park, C. (2007). “A Case of Lean Implementation: Shift from Lean Production to Lean Supply Chain Management.” Proc. 15th Ann. Conf. of the Int. Group for Lean Const., Detroit, MI.

Polat, G., and Ballard, G. (2003). “Construction Supply Chains: Turkish Supply Chain Configurations for Cut and Bent Rebar.” Proc. 11th Ann.Conf. on Lean Const., Blacksburg, VA, July.

PRODUCTION FLOW IN THE CONSTRUCTION OF TALL BUILDINGS

Rafael Sacks[1], Rebecca Partouche[2]

Abstract

The time required for construction of tall buildings, whether measured per floor or per unit area built, increased consistently through most of the 20th century despite the introduction of improved construction technologies that increased productivity. The explanation for this seeming contradiction appears to lie in the ways in which resources are applied. As buildings have themselves become more technologically complex, so have the networks of subcontracting that characterize their supply chains become more extensive. Construction management has become focused on contract management and the allocation of risk and less on explicit management of the production system. Thus project participants, consciously or unconsciously, each allow buffers of time, work in process and materials to accumulate. A parametric discrete event simulation model has been compiled that enables experimentation with various aspects of the construction process of tall commercial/office buildings. The impacts of the production strategy relating to accumulation of work in progress (WIP) were explored. The simulation results explain how accumulation of WIP contributes to increasingly longer construction durations for tall buildings. That understanding can be leveraged to propose changes in the way the construction of tall buildings can be organized to achieve shorter and less costly projects.

Keywords: Mass construction, Lean construction, Production flow, Production system design, Tall buildings.

[1] Associate Professor, Faculty of Civil and Env. Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel Phone/Fax +972-4-8293190, e-mail: cvsacks@techunix.technion.ac.il

[2] Graduate Student, Faculty of Civil and Env. Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel, e-mail: rebeccap@tx.technion.ac.il

Introduction

Fig. 1 shows the average rates of construction, in terms of number of floors and square meters built per year of construction, for the world's 100 tallest buildings built from 1929 to 2008 (CTBUH 2008; Skyscraper 2008). Among these buildings, the Empire State Building represents an international record in terms of the pace of construction. While the chart does not account for factors such as safety, quality or design complexity, the time required for construction of tall buildings, whether measured per floor or per unit area built, appears to have increased consistently through most of the 20th century. Yet throughout the period improvements in construction technologies were introduced that increased productivity (Eastman et al. 2008).

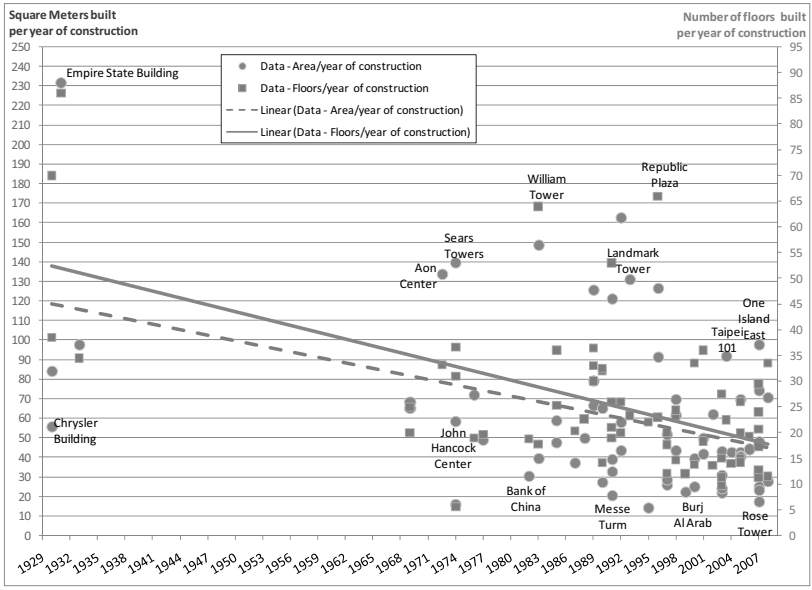


Fig. 1: Construction pace (in floors and area built per year) of the world's 100 tallest buildings built from 1929 to 2008.

There are numerous possible reasons for this seeming contradiction. The most apparent is the increasing number of building systems and their complexity. Whereas the Empire State Building had elevator systems, electrical installations, plumbing, heating and ventilating (Willis and Friedman 1998), all modern buildings also have sprinklers, climate control, fire alarms, AC, alternative power generation, curtain walls, computer networks, telephony, cable TV, security and other systems. Not only are there more systems, but they are each composed of an increasingly higher number of different components that have to be procured from a much more diverse list of suppliers. However, summing the durations of the consecutive individual tasks

required for the additional systems along the critical path alone cannot explain the difference in project durations.

A second reason might be sought in the prevailing economic conditions. The record set by the Empire State Building was achieved during the Great Depression; labor and equipment were in plentiful supply (at the peak level, some 3,500 workers were employed on site). However, the historic record shows that the same general contractor completed similar buildings before the advent of the Great Depression at similar rates. In 1928 a construction speed record was achieved at 6.5 weeks for erecting a 27 story structure. In the same year, a 35 story building was enclosed in seven months. In 1929 the Bank of Manhattan, a 77-story building, was completed in less than one year from the beginning of the foundations (Tauranac 1995).

A third reason is the variation and reliability of the design information. Where a building's systems are complex and there is variation between floor types and individual floors, the task of design integration and coordination between systems is extremely difficult. Where design changes are made through the construction phase the information reliability is reduced further. The reduction in scope of design services, which has developed in parallel with reduced fees, also contributes to less robust design. The results are errors, rework, and interruptions to production flow.

We hypothesize that another significant reason can be found in the production system itself, particularly in the ways in which labor resources are applied. As buildings have themselves become more technologically complex, so have the networks of subcontracting that characterize their supply chains become more extensive, and even trade subcontracts often run several layers deep. Construction management has become focused on contract management and the allocation of risk, largely ignoring production management (Koskela and Howell 2002). With weak design and management of the resulting production systems, the participants can, consciously or unconsciously, accumulate buffers of time, work in process (WIP) and materials. This can be thought of as a 'laissez-faire' production management strategy, in which each trade team is left to determine its own micro-level strategy. The default approach for trade teams performing unit-price subcontracted work is to strive to accumulate buffers of work in order to ensure high local productivity, by expanding early into all available work spaces (Sacks and Harel 2006). This 'WIP accumulation' strategy works against production flow (Hopp and Spearman 1996).

The goal of this research was to explore the impact of information reliability and of the production management strategy on the outcomes for tall office/commercial building construction. The measures for comparison are cycle times, overall crew productivity and construction duration. The research method was to compare different strategies using a discrete event simulation model. This tool is common in construction research (Martinez and Ioannou 1999; Sacks et al. 2007; Tommelein 1998). In this case, simulation enables clean comparison of specific changes in strategies and degrees of design information reliability in isolation from the economic environment and building complexity factors mentioned above.

Empire State Building in the Context of Construction Systems

A detailed study of the production system used in the Empire State Building led the authors to propose the term 'mass construction' to describe the production system that was employed (Partouche et al. 2008). We define mass construction as a building production system characterized by the following features:

1. multiple uniform and repeated spaces or modules
2. work flow planned using TAKT time,
3. industrial supply chain management,
4. monitoring and control of production rates,
5. carefully designed logistic systems to deliver materials,
6. standardized work,
7. minimal variety of parts,
8. careful control of tolerances between parts.

All of these features were present in the design and in the production system of the Empire State Building. In addition, in the case of Empire State, design was conducted collaboratively with co-location of all designers in a short and concentrated design phase. Although modern tall office buildings have multiple repeated spaces, uniformity cannot be taken for granted across all floors and thus standardized work and minimal variety of parts are also not necessarily common features. Variety and complexity in the product are one of the reasons for the development of lean construction, which aims to provide client-determined value while still maintaining the benefits of flow. Lean construction can be seen as a progression not simply from craft and industrialized construction, but also from mass construction. Fig. 2 shows lean construction as derived from the three other classifications (craft, industrialized and mass construction). It inherits concepts from all three, as well as from lean production.

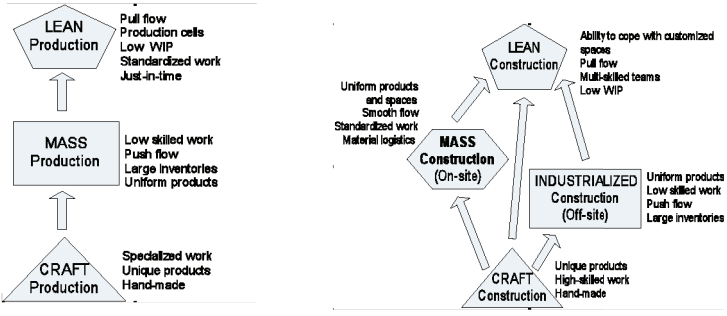


Fig. 2. Evolution of production systems (at left) and of construction systems (at right).

Simulating WIP Accumulation vs. WIP Reduction

Among other ideas drawn from lean production, lean construction proposes minimizing WIP and improving design information quality as ways to improve flow (Eastman et al. 2008; Tommelein 1998). Where building systems are complex, as they are in any modern high-rise tower building, coordination between the systems is difficult because their design and production detailing is carried out by numerous different people. Co-location of detailers together with intensive use of building information modeling and integration tools has been shown to be highly effective in reducing design and coordination errors (Eastman et al. 2008; Khanzode et al. 2005). In this paper, however, we focus on tests of the impact of the first strategy – reduced WIP.

A detailed simulation model of the construction process for typical office/commercial use high-rise buildings was compiled using ProModel discrete event simulation software (ProModel 2007). The model can be parametrically adjusted to simulate construction of buildings of any number of floors, floor sizes and floor compositions. It provides eight different types of spaces from which a building can be composed: five horizontal space types (basement/parking floors, entrance floors, typical office floors, lobby spaces on each floor and technical roof space) and three vertical (elevator and technical shafts in the core and facades). These spaces themselves are the 'product entities' that flow through the simulation activities. The number of spaces of each type can be set to represent different buildings.

The construction trades modeled include excavation and shoring works, foundations, reinforced concrete structural work and a wide variety of building systems and finishing activities. All in all 116 distinct types of activities are modeled. The durations for the activities are stochastic, varying according to triangular distributions defined by minimum, most common and maximum durations. The variations in the durations collectively represent variation caused by unreliable and erroneous design information, lack of availability of materials or equipment and other factors not modeled directly. The system explicitly considers the availability of workers before the start of each activity: an activity can only begin if more than a preset minimum of workers are available, and its duration is set according to the number of workers actually assigned. The durations are also corrected to account for the learning curve as each team learns the best ways to perform each floor, using an expression of the form:

$$\text{Corrected duration} = \text{Base duration}\left(\frac{\text{Maximum crew size}}{\#\text{ workers available}}\right)\left(1+\frac{\text{Learning curve factor}}{\#\text{ repetitions}}\right)$$

The model's primary purpose was to enable experimentation with different management strategies, such as the 'WIP accumulation' strategy introduced above or the 'WIP minimization' strategy defined below, the impact of design and other errors, and resource constraints. Both strategies are also compared to the default management strategy imposed by the software that trends towards the processing of the entity as soon as it arrives in the location. Different priorities can be assigned to activities of any given trade to implement different production planning strategies (activities with higher priority receive workers before activities with lower priority).

The need for rework is modeled using rates of probability for errors occurring, coupled with rework activities that have different durations and resource requirements depending on the severity of the error, which is determined by a percentage tailored for each trade type. The sources of rework may be from design deficiencies, mistakes made during work execution, or both. An example of one section of the simulation is shown in Fig. 3.

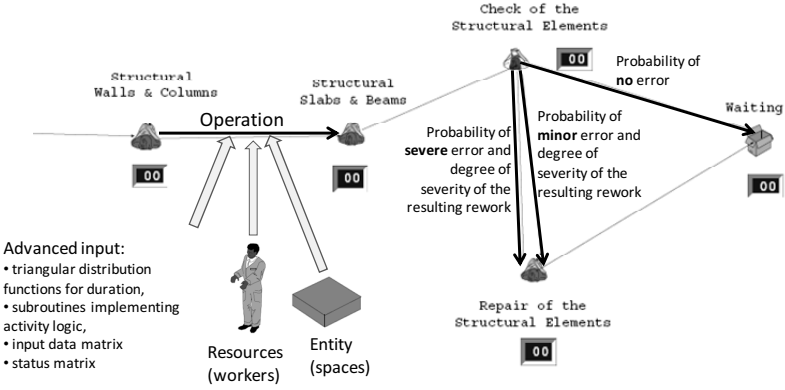


Fig. 3. Typical branching of space flows to model rates of error probability and rework severity.

All of the data for the model was collected through a six-month series of fortnightly meetings with a team of senior engineers at a large construction management practice that specializes in buildings of this type. The collaboration also included site visits at a number of its projects. The typical design and construction process was mapped in detail and the duration and resource requirements for each activity, and their variation, were recorded.

Simulation Results

For the phase of the research reported here, three alternative management strategies were tested using the simulation model:

A) *WIP accumulation:* This is a strategy common for subcontractor trade teams in less stable projects. Their productivity and cash flows are best served by occupying spaces as they become available and allowing WIP to accumulate, to ensure full occupation of their resources – local optimization. This could also be called a 'push' strategy, where trades are encouraged to begin work wherever possible as soon as possible.

B) *No explicit strategy:* In this case, trade teams have no preference for either opening up new work spaces or completing those already in process.

C) *WIP reduction:* This implies that teams place higher priority on completing work in any spaces already begun over starting work in newly available spaces. This could also be called a 'pull' strategy, and it is the opposite of the WIP accumulation or 'push' strategy.

Fig. 4 (a) to (c) shows the results of the simulation for all three strategies from a model of the construction of a building with five basement parking floors (5,000 m2 each), two entrance floors, and 21 typical office floors with lobbies and elevator shafts. Each office floor was 1,500 m2.

The major difference between WIP accumulation (strategy A) and WIP reduction (C) that can be seen clearly in Fig. 4 and in the data is in the cycle time required for the finishing works in each of the lobby areas. The finishing works for each floor are spread out over time in Fig. 4 (a), requiring an average of 92 days, but are closely clustered in Fig. 4 (c), requiring an average of only 50 days. Fig. 4 (b) represents the middle ground between the two strategies; it could be argued that this represents projects where managers resist subcontractors' tendency to open up work as much as possible, but are either not aware of, or unable to achieve a full WIP reduction policy.

The WIP for each case can be assessed by counting the number of floors in which work has begun but has not been completed along any vertical line, representing a specific point in time. As predicted by Little's Law, WIP is high where cycle times are long and low where cycle times are short. Note also that the sequence of work is not always the expected progression up from floor to floor as would generally be prescribed by a project Gantt chart. Instead, work flow is influenced by the variations in durations introduced by design or execution errors, design changes, and information and material flows. Where work in a space is not mature for execution at the expected time because of conditions not fully satisfied, it is pursued elsewhere (this is only possible where a production management technique, such as Last Planner, is used to overcome the lack of predictability of work sequence and where supply chains can react flexibly to prepare out-of-sequence work).

Table 1. Selected results for each of the strategies A to C (the number of workers made available for each trade was the same for all.)

Strategy	Average Project Duration (months), *calculated on 20 simulations*	Resources		Work flow			
		Maximum number of workers needed	Labor Capacity Utilization (%)	Floor Cycle Time for the finishes (days)			
				Minimum	Average	Maximum	*Std. Dev.*
A	29.9	101	90.6%	53	92	181	*37%*
B	28.7	98	89.9%	40	53	74	*18%*
C	29.8	95	90.0%	37	50	76	*17%*

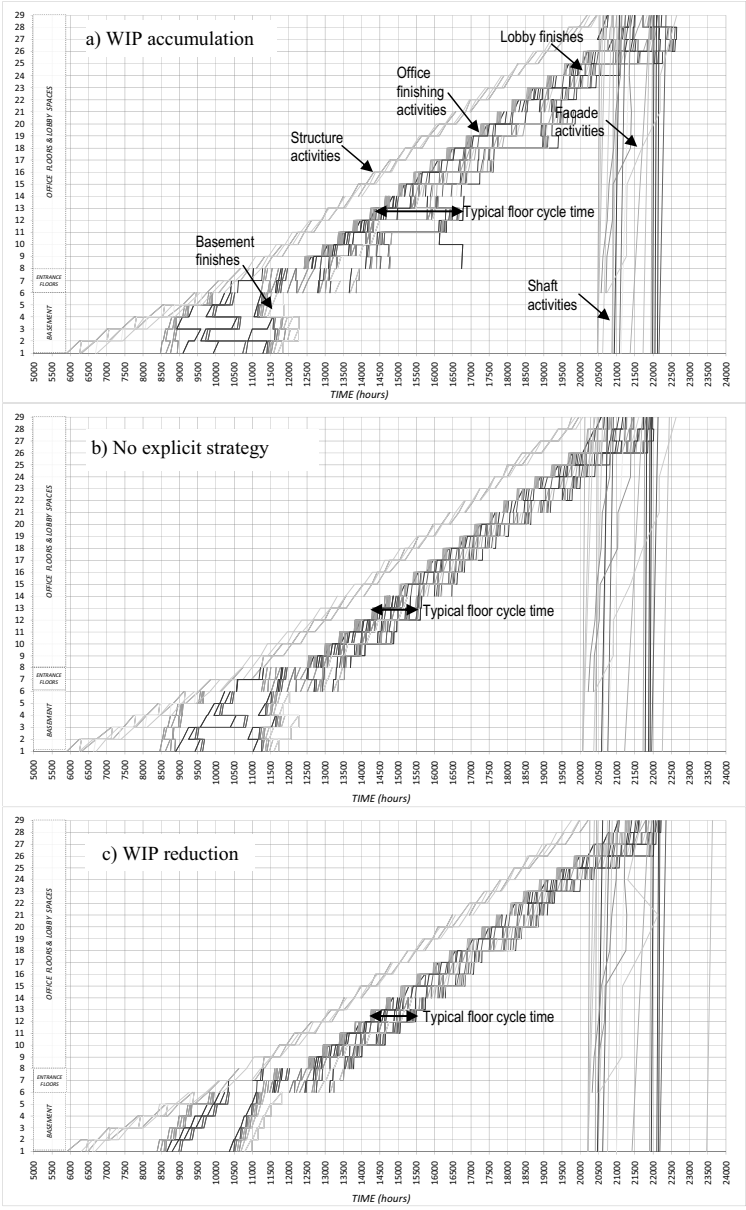


Fig. 4. Line of balance charts showing work progress for each of the three cases A to C.

Conclusions

The slowing pace of construction of modern high-rise office and commercial buildings can be attributed in part to the increasing complexity of their designs and their systems. The number of subcontractors and suppliers in projects, and the organizational depth in terms layers of subcontracts, have also grown. However, and perhaps as a result, construction management appears to have surrendered responsibility for the fine-grained design and operation of project production systems on site and instead allow trade teams to optimize their work. Trade teams each optimizing their own performance does not lead to optimized projects.

The significant differences in the project outcomes resulting from WIP accumulation vs. WIP reduction strategies underline the importance of a good understanding of the production system behavior of projects of this kind. It appears that their construction could be improved if managers were better versed in the 'physics' of construction production systems. In buildings that are highly uniform, as the Empire State Building was, mass construction, with predetermined progress of trades from floor to floor using fairly uniform production rates and carefully set buffers can work well. But where buildings are more complex and variation in design and production rates cannot be removed, as in the case of modern buildings, project schedules that pre-determine the sequence of progression of trades from space to space result in long cycle times and long project durations. This is exacerbated where trade subcontractors are allowed to determine their own progression through a building and accumulate buffers of WIP.

The work reported here is part of ongoing research that is exploring additional aspects of the construction management systems for tall office/commercial buildings. Study of the relationships between the degree of variation in error rates, the sizes of work teams and project durations is of particular interest, because it can provide direct measures of the value of investment in applying WIP minimization strategies and design coordination using BIM, as well as other strategies. Plots that compare cycle time for floors to the degree of capacity utilization can be easily generated for different labor configurations. The eventual goal is to compile a set of recommendations for construction management of tall buildings.

References

CTBUH. (2008). "Tall Building Database." Council for Tall Buildings and Urban Habitat, Chicago, IL.

Eastman, C. M., Teicholz, P., Sacks, R., and Liston, K. (2008). *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators*, John Wiley and Sons, Hoboken, NJ.

Hopp, W. J., and Spearman, M. L. (1996). *Factory Physics*, IRWIN, Chicago.

Khanzode, A., Fischer, M., and Reed, D. (2005). "Case Study of the Implementation of the Lean Project Delivery System (LPDS) using Virtual Building Technologies on a Large Healthcare Project." *13th Conference of the International Group for Lean Construction*, Sydney, Australia, 153-160.

Koskela, L., and Howell, G. (2002). "The underlying theory of project management is obsolete." *PMI Research Conference*, 293-302.

Martinez, J. C., and Ioannou, P. G. (1999). "General Purpose Systems for Effective Construction Simulation." *Journal of Construction Engineering and Management, ASCE*, 125(4), 265-276.

Partouche, R., Sacks, R., and Bertelsen, S. (2008). "Craft construction, mass construction, lean construction: lessons from the empire state building." *Proceedings of the 16th Annual Conference of the International Group for Lean Construction IGLC16*, Manchester, UK.

ProModel. (2007). "ProModel." ProModel Corporation, Orem UT.

Sacks, R., Esquenazi, A., and Goldin, M. (2007). "LEAPCON: Simulation of Lean Construction of High-Rise Apartment Buildings." *Journal of Construction Engineering and Management*, 133(7), 529-539.

Sacks, R., and Harel, M. (2006). "An economic game theory model of subcontractor resource allocation behavior." *Construction Management & Economics*, 24(8), 869-881.

Skyscraper. (2008). "SkyscraperPage.com." Skyscraper Source Media, Victoria BC, Canada.

Tauranac, J. (1995). *The Empire State Building: The Making of a Landmark*, Scribner, New-York.

Tommelein, I. D. (1998). "Pull-Driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique." *ASCE Journal of Construction Engineering and Management*, 124(4), 279-288.

Willis, C., and Friedman, D. (1998). *Building the Empire State Building*, W. W. Norton & Company, Inc., New York, London.

HOW TO LOWER THE RIVER TO REVEAL THE ROCKS WITHOUT PUTTING A HOLE IN YOUR BOAT

Glenn Ballard[1]

Abstract

Toyota's example has inspired revolutionary changes in the way all manner of goods and services are designed and produced. One of the key features of this new approach is the self-imposition of necessity. Rather than wait for customers or competitors to compel innovation and improvement, In the famous words of Toyota Chief Engineer Ohno, we should 'lower the river to reveal the rocks'; i.e., deliberately reduce the buffers of time, capacity, inventory and financial contingency that are currently necessary to absorb variation and uncertainty, in order to reveal where the production system needs to be changed.

This paper explores the application of Ohno's advice in the construction industry. Examples of successful implementation are provided, and methods are proposed to reduce the risk of putting a hole in your commercial boat.

Key words

Buffer, capacity, contingency, innovation, inventory, schedule buffers, stretch goals.

Introduction

Toyota's outstanding capability is the capability of reinventing itself, not in response to changes in its environment, but rather in anticipation of such changes, so that it becomes an environmental force itself.

It does this by systematically stressing the systems through which it designs and makes motor vehicles; by periodically reducing the buffers of inventory, capacity, time and money that absorb waste-causing variation and accommodate constraints that would otherwise cause the system to fail. This reveals where improvement is needed and was expressed in Engineer Ohno's advice to "Lower the river to reveal the rocks" (Ohno, 1988). But how can that be done in design and construction? What can

[1] Project Production Systems Laboratory, Engineering & Project Management Program, Department of Civil & Environmental Engineering, University of California, Berkeley. ballard@ce.berkeley.edu

be done to stress project production systems in order to reveal and act on opportunities for improving performance? How can necessity be self-imposed without 'putting a hole in your boat'?

The paper is divided into the following sections. First, key terms are defined and the relationships among them explained. Examples are then provided of selected techniques in use: specification of product performance targets in design, restricting storage space to reduce inventory, setting stretch goals in reverse phase scheduling, and setting target costs below that achievable through current best practice. These examples are followed by guidelines for successful self-imposition of necessity; how to lower the river to reveal the rocks without putting a hole in your boat. The last section of the paper presents conclusions and recommendations for future research.

Key Terms: Variation, Constraints and Buffers

Variation can be understood as a difference over time between an target condition and an actual condition. In manufacturing, variation is usually defined in queuing theory terminology in terms of arrival rates and processing durations. Constraints are features of a production system that limit its performance. Variation is one such feature. Buffers are features of production systems that cushion the impact of variation and other constraints. Time, capacity and inventory are the classic buffer types identified in manufacturing. Project production systems add a fourth type, financial contingency.

The greater the variation in a system, the larger buffers must be in order to absorb that variation and allow the system to function with its constraints.

Lowering the river to reveal the rocks: Examples

Three examples of stressing production systems are provided in this section:

1. Reducing previously needed inventory
2. Reducing previously needed time
3. Reducing previously needed money

Suzuki's YETs: Reducing previously needed inventory

Suzuki was the chief engineer for development of Toyota's Lexus (Liker, 2004). He challenged the product development team by demanding previously incompatible product features (see Figure 1). For example, reduction of noise generated from the vehicle itself had previously been achieved principally through using mass to absorb vibration. By demanding that the Lexus be both "super quiet" yet "light weight", Suzuki forced the power train engineers to attack the source of noise, engine vibration. This led to an engine built to much tighter tolerances than had previously been thought possible, and to a lightweight yet quiet automobile.

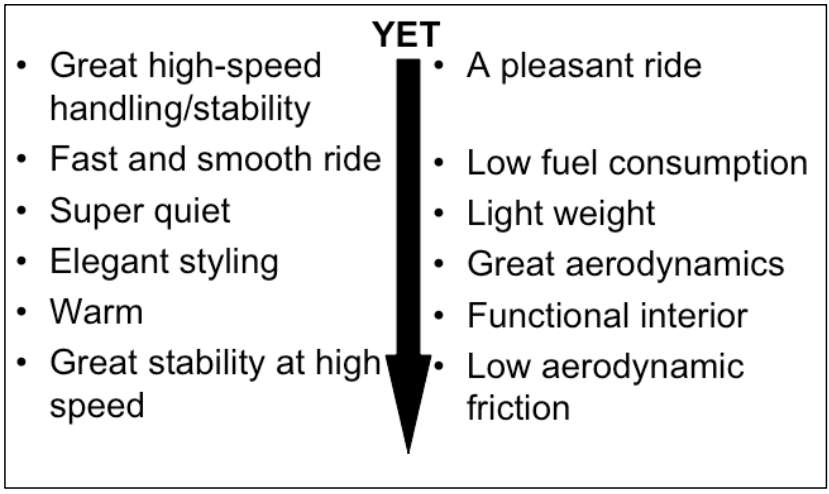


Figure 1: Suzuki's YETs

This is an example of reducing an inventory buffer, the set of traditional design solutions, to promote innovation. Material inventories can also be reduced to promote innovation; e.g., restricting lay down space on a construction site to promote just-in-time deliveries, and the reduction in variation and increased synchronization of interdependent activities necessary to enable such deliveries.

Reverse phase scheduling: Delaying the start date

Reverse phase scheduling is a form of collaborative planning in which a team of people develops a plan and schedule for doing work for which they are responsible (Ballard & Howell, 2003). The name comes from the practice of planning backward from a target milestone[2] , typically using stickies on a wall as shown in Figure 2. Delaying the start date reduces the time available for performing the work. Doing so can promote innovation in the way work is structured and in the clarity of expectations and needs between those who provide (performers) and those who receive (requestors) information and materials from one another in that phase of work.

[2] Figure 2 is extracted from a movie provided by Alan Mossman.



Figure 2: Reverse Phase Scheduling

Attempting to find ways to reduce the amount of time required to perform a task, its performer asks his requestors to specify exactly what they need, their conditions of satisfaction. This often reveals that the task can be divided and consequently its duration reduced. Two questions from performer to requestor are key: 1) "What exactly do you need from me in order to do your task?" and 2) "Is there anything I can do that would allow you to reduce the time you need to do your task?" Of course, the requestor should also take care to carefully specify what they need, and should not assume that they must receive only what they have received in the past, but rather explore what is possible.

Example: In the early design phase of a hospital project, a structural engineer asked engineers from other disciplines to identify the penetrations through floor slabs. The providers could not figure out how to provide such detailed information at that early stage of design development, so returned to the structural engineer and asked for clarification. The structural engineer explained that he only needed penetrations larger than 1-meter square! (Love, 2008)

Example: An electrical engineer realized that she could reduce the duration of her task if a provider were to give her more detailed and better-organized equipment

information. She made that request and was told, "Sure, I can do that. I didn't know you wanted it." [3]

Participants are asked to provide average task durations and avoid padding individual tasks. Planning and replanning continue until there is a sufficient schedule buffer, as shown in Figure 3, equal to or greater than the sum of likely variations in task durations. After the schedule buffer is allocated to individual tasks, the phase plan will extend from start to end date. The reverse phase scheduling process will have produced a reduction in phase duration and a plan more likely to be achieved.

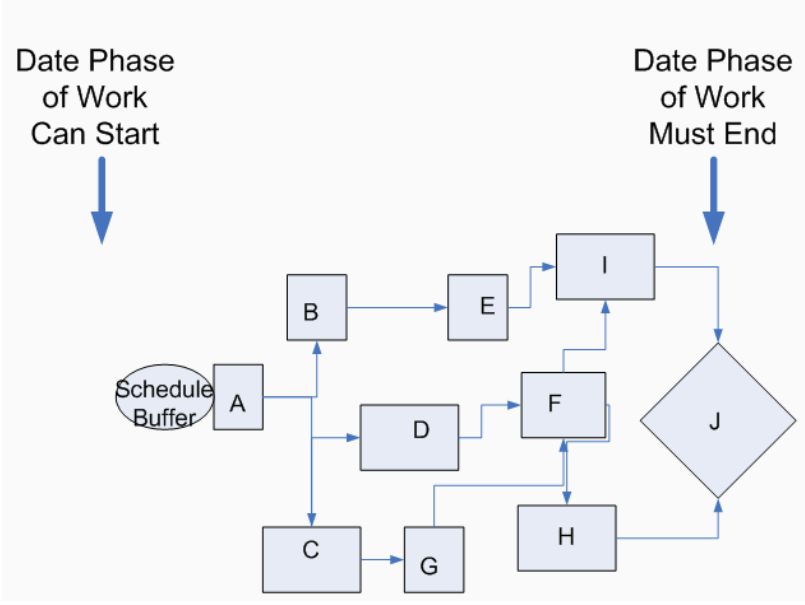


Figure 3: Delaying the start date

Target Costing[4]

What a client is able and willing to spend to get what they need to achieve their goals is the allowable cost for a project. The determinants of allowable cost always include capital availability and ability to repay/recover. These are minimum requirements. Some clients also include stretch goals in their initial statement of Allowable Cost, in an effort to improve profitability or some other performance metric.

[3] Personal communication from Gregory A. Howell
[4] This section is taken in large part from Ballard (2006) and Ballard (2008)

Allowable Cost: what a client is able and willing to spend to get what they need to achieve their goals

The allowable cost may be adjusted to match expected cost, or reduce the gap between allowable and expected, so long as the minimum requirements are met; namely, fitness for purpose, capital availability and ability to repay/recover. Incorporating targets in the allowable cost is more common for clients working with preferred providers over a series of projects, and is standard practice in product development (Cooper & Slagmulder, 1997 and 1998). The first publication of which this author is aware on the application of this product development practice in the construction industry was Nicolini et al., 2000, and the first successful application was reported in Ballard & Reiser, 2004. Cost planning in the quantity surveyor tradition has strong similarities and shares a key distinction; namely, designing to cost versus costing a design (Langston, 2002). The practice of designing to cost was developed in the 1980s in the U.S. defense industry (Michaels and Wood, 1989). However, the practice did not include key elements of target costing. Absent were determination of cost target from allowable cost, and setting stretch goals to drive innovation, Designing to cost does not appear to have had any impact on similar practices in other sectors.

Allowable Cost ≥ Expected Cost ≥ Target Cost

The Expected Cost is the forecast or estimated cost of the project; the product of conceptual estimating prior to design having been produced. It is based on benchmarking against similar facilities or some type of cost model (Pennanen and Ballard, 2008). If the expected cost is greater than the allowable cost, the project does not meet the client's business case and the project should either be abandoned or the business case revised.

The Target Cost is what the team commits to deliver. It cannot exceed expected or allowable cost, and may be set lower than expected cost in order to spur innovation beyond current best practice, depending on the extent to which achieving the expected cost already challenges current best practice.

Shawano Clinic

Shawano Clinic is an outpatient facility with unusual imaging, and hence diagnostic, capabilities. Thedacare, the parent organization, is widely recognized as a leader in the implementation of lean methods to healthcare operations. Boldt Construction, a long time builder of Thedacare facilities, is a leader in lean project delivery. The two organizations agreed to work together to extend Thedacare's lean initiatives to its

capital facilities program. Shawano Clinic was their first 'experiment' (Toussaint, 2006).

The target cost was embedded in the client's allowable cost. Figure 4 shows how the expected cost changed over time in relation to the target cost. Ultimately the target cost was achieved, along with a return to the client of unused contingency and funding of client value-adding scope additions without increasing the budget.

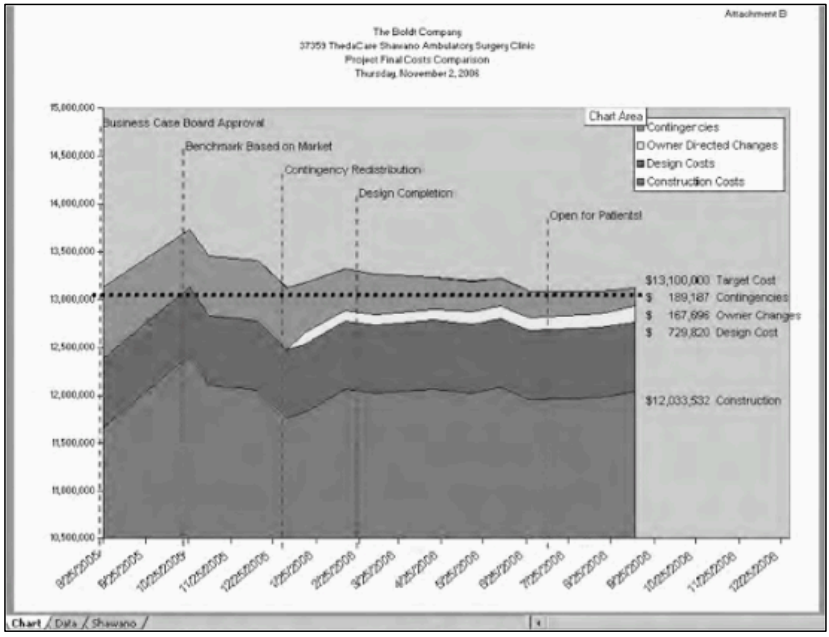


Figure 4: Shawano Clinic

Expressed in percentage terms, the target cost (construction budget) was set 3.6% below the current best practice benchmark; the actual cost was 14.6% below target, and 17.6% below the benchmark. Most of the released funds were used to provide value-adding scope, primarily for imaging capability, with the remainder returned to the client. In addition, the project was completed 3.5 months ahead of schedule, generating 70 additional days of clinic revenue for the owner, amounting to nearly $1 million.

Thedacare now sets an annual cost reduction target for all its new facilities and has successfully hit those targets in each of the two years since Shawano Clinic was completed.

How to Avoid Putting a Hole in your Boat

It is perhaps not surprising that setting stretch goals can improve performance, but these stretch goals reduce buffers previously needed for successful performance. How can this be done without undue risk of failure?

One strategy is to maintain a back door, a line of action with acceptable results, though not innovative and record breaking. This is standard practice in set based design, the generation and exploration of design options, with selection made at the last responsible moment. Since there is some risk that an option will not be developed and selected in the available time, an acceptable option is identified and made ready in case of need (Ward et al., 1995). This strategy should be used whenever possible.

When the first strategy cannot be pursued, and when failure can be tolerated, an alternative is to make a calculated bet, based upon knowledge and experience, that process or product designs can be improved and targets can be achieved. This is similar to the first approach, but in this case some degree of innovation is confidently predicted, as opposed to falling back on a standard solution. Breakthrough innovation is not precluded, but organizational management is confident that some degree of improvement is achievable.

When the first and second strategies are not viable (there is sufficient risk of failure that it is prudent to somehow offset that risk), a third strategy is to choose circumstances in which failure can be absorbed by a different type of buffer. For example, the time allowed for producing a deliverable may deliberately be set below the previous best, with overtime (a capacity buffer) held in reserve should the target not be achievable.

Conclusion and Recommendations for Future Research

Self-imposing necessity by reducing previously needed buffers has been shown to result in innovation and improved performance. Strategies have been proposed for doing such experiments without exposing an organization to undue commercial risk.

Documentation of additional cases is needed to assure that the experiments caused the results. In addition, the proposed strategies need to be tested and improved.

References

Ballard, Glenn and Gregory A. Howell (2003). "An Update on Last Planner". *Proceedings of the 11th annual conference of the International Group for Lean Construction,* Blacksburg, Virginia, August, 2003.

Ballard, Glenn and Paul Reiser (2004). "The St. Olaf College Fieldhouse Project: A Case Study in Designing to Target Cost". *Proceedings of the 12th annual conference of the International Group for Lean Construction,* Elsinore, Denmark, August, 2004.

Ballard, Glenn (2007). *How to lower the river to reveal the rocks.* A workshop conducted for the Lean Construction Institute of Denmark, Copenhagen, April 9, 2007. (Slides available upon request to author)

Ballard, Glenn (2008). "The Lean Project Delivery System: an Update". *Lean Construction Journal,* 2008.

Cooper, Robin & Regine Slagmulder (1997). *Target Costing and Value Engineering.* Productivity Press, Portland OR. 379 p.

Cooper, Robin & Regine Slagmulder (1999). *Supply Chain Development for the Lean Enterprise: Interorganizational Cost Management.* Productivity Press, Portland, OR. 510 p.

Hopp, Wallace and Mark Spearman (2000). *Factory Physics, 2nd edition.* McGraw-Hill, New York, NY. 698 p.

Langston, Craig (2002). "A New Era in Cost Planning". Ch. 5 in *Design and Construction: Building in Value* (see Best and DeValence), p.59-74.

Liker, Jeffrey (2004). *The Toyota Way.* McGraw-Hill, New York, NY. 330 p.

Love, Jay (2008). "Target Value Design on the Cathedral Hill Hospital Project". 2008 Annual Conference, Project Production Systems Laboratory, University of California, Berkeley.

Michaels, Jack. V. and William P. Wood, (1989). *Design to Cost.* John Wiley & Sons, New York, NY. 413 p.

Nicolini, D. & C. Tompkins & R. Holti & A. Oldman & M. Smalley (2000). "Can Target Costing and Whole Life Costing be applied in the Construction Industry?" Evidence from Two Case Studies. *British Journal of Management*, Vol. 11.

Ohno, Taiichi (1988). *Toyota Production System.* Productivity Press, Portland, OR.

Pennanen, Ari and Glenn Ballard (2008). "Determining Expected Cost in the Target Costing Process". *Proceedings of the 16th annual conference of the International Group for Lean Construction,* Manchester, U.K., July 16-18, 2008. Pp. 589-600.

Toussaint, Susan (2006). ThedaCare Shawano Ambulatory Care Center: Lean Continuous Improvement Implementation. Boldt Construction Company, November 3, 2006.

Ward, Allen, Jeffrey K. Liker, John J. Cristiano, and Durward K. Sobek II (1995). "The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster". *Sloan Management Review,* Spring 1995, pp. 43-61

OVERCOMING THE HURDLE OF FIRST COST: ACTION RESEARCH IN TARGET COSTING

Glenn Ballard[1*] and Zofia K. Rybkowski[2]

[1] Research Director, Project Production Systems Laboratory, http://p2sl.berkeley.edu/
Adjunct Associate Professor, Department of Civil and Environmental Engineering
214 McLaughlin Hall, University of California, Berkeley, CA 94720-1712
Phone +1 510/530-1743, ballard@ce.berkeley.edu

[2] PhD Candidate, Program in Engineering and Project Management
Department of Civil and Environmental Engineering, 215-A McLaughlin Hall
University of California, Berkeley, CA 94720-1712
Phone +1 510/684-5729, cezkr@berkeley.edu

ABSTRACT

Advocates of sustainable and evidence-based design initiatives argue that building owners can secure favorable internal rates of return when full life cycle building costs are considered. While the argument has merit, these decision-makers express concern about overcoming the hurdle of first cost. To reduce first cost, a number of lean construction practitioners are exploring a planning and design process called target costing. Target costing in construction is a collaborative cost management process that relies on business plan validation to determine what is to be delivered and what the client is willing and able to pay for a project—before establishing the allowable cost. When warranted, a target cost may be set even lower than the allowable cost in order to spur innovation. Once a target cost has been established, the project is collaboratively designed to that target cost. This case study examines the target costing techniques used during the design of an 850,000 square foot (approximately 79,000 square meters) medical center. Qualitative and quantitative outcomes are explored, as well as implications for future projects.

INTRODUCTION

A number of building designers argue that higher quality facilities can lead to long-term cost savings, an assertion that is especially developing momentum among sustainable design communities, as well as among those active in the evidence-based design (EBD) movement. Long term cost savings are calculated using a technique known as Life Cycle Cost Analysis (LCCA). The methodology can be applied when periodic savings from reduced use of energy, water or operation and maintenance

costs (in the case of sustainable design) or medicinal or legal costs, for example (in the case of EBD), result in a calculation of positive net present value (NPV) (Boussabaine and Kirkham 2004; Bull 1993; Evans et al. 1998; Ive 2006; Kirk and Dell'Isola 1995). Such attempts to bolster the quality of decision-making have merit; it makes intuitive sense that improved facility quality can lead to reduced need for facility maintenance and replacement over time. However, skeptics argue a number of hurdles must be overcome in order to construct a higher quality building. For example, the pay-now-save-later expectation of LCCA makes it limited in its applicability because building owners wishing to construct a higher quality facility are still constrained by their ability to finance the project, a reality with which they must contend, irrespective of long-term benefits. In other words, *first cost*—or the capital investment cost that is expended on a facility when it is constructed—often becomes a significant challenge that trumps positive NPV calculations (Ashworth 1993; Cole and Sterner 2000; Moore 2001).

The constraint of first cost must therefore be addressed if LCCA is ever to become a viable tool for capital budgeters to use. Leaders of lean construction have suggested that first cost can be made more manageable if building design teams apply principles of target costing during the design process (Ballard and Reiser 2004; Macomber et al. 2008; Nicolini et al. 2000).

Target Costing

According to Cooper and Slagmulder (1997), "target costing is a disciplined process for determining and realizing a total cost at which a proposed product with specified functionality *must* be produced to generate the desired profitability at its anticipated selling price in the future." In traditional product pricing, the price of a product is established by adding a profit markup to the cost required to produce the product. The problem with this method is there is no guarantee that buyers will be willing to pay the asking price. The process of target costing, by contrast, engages a reverse strategy; the market price is *first* established by determining how much buyers might be willing to pay (using focus group research, for example). A desired profit is then subtracted to give product designers the cost to which they must design the product:

Target cost = Target Price (revenues) – Target Margin (Clifton et al. 2004)

The word "must" is emphasized in the definition of target costing, suggesting that, if the product cannot be designed and produced at the required cost, the project must be abandoned (Clifton et al. 2004). This stipulation is the only way to ensure that the product will ultimately be profitable.

Assuring the economic validity of construction projects is much needed. Cost overruns are commonplace and the traditional practice of costing a design rather than designing to cost often leads to cost cutting measures, such as late stage value engineering and a scramble to reduce specifications, quality and profit (Nicolini et al. 2000). The system sets suppliers and service providers against the owner, removing any incentive to streamline costs early on. In fact, cost reduction measures are typically introduced so late in the design process that they have led to diminished functionality, giving value engineering a dubious reputation in the industry.

By contrast, target costing begins with a business plan, as well as business plan validation. In combination, these project definition stages help owners identify what they are able and willing to pay for their proposed facility. The process of target costing is performed early using cross-functional teams, where the owner, service providers and suppliers function collaboratively (Ballard 2006; Ballard 2008; Ballard and Reiser 2004; Clifton et al. 2004; Nicolini et al. 2000). Focusing on collaboration and long-standing relationships, team members work creatively to value engineer individual subsystems, with the target cost and program as its ultimate goal (Ahuja and Walsh 1983; Barrie and Paulson 1992; Cooper and Slagmulder 1997; Fisk 2003; Nicolini et al. 2000).

Again, it is crucial that target costing takes place throughout the development of a project's design, when ability to impact cost is greatest, as has been suggested by a number of architecture, engineering and construction professionals (MSA 2004; Paulson 1976). This enables cost savings without sacrificing functionality to the same extent that occurs during late stage value engineering.

Target Costing in Construction

Target costing in construction has been "broadened to include additional design criteria beyond cost, including time, work scheduling, buildability and similar issues." (Ballard and Reiser 2004; Lichtig 2005). A pioneering paper by Nicolini et al (2000) bridged the gap between target costing for product design and target costing for building design. Unfortunately, the case study they reported was unsuccessful. The first successful application of target costing in construction appears to have been the case reported in Ballard and Reiser (2004), in which a college athletic field house was designed and built for a cost per square foot 30% lower and 10 months shorter in project duration, compared to a comparable project on which target costing had not been used.

Target costing in construction applies most readily to developers producing something for sale or lease to others and to clients producing their own means of production (Ballard 2008). The developer estimates the returns from sale or lease of a facility, specifies an acceptable profit margin, then calculates the allowable cost for producing the facility. Clients producing facilities for their own use similarly estimate the benefits from the investment (equivalent to revenues), specify an acceptable return, and then calculate the allowable cost (i.e., what they are able and willing to spend to get those benefits). Because of the complexity of buildings and their cost uncertainty, Ballard argues that key design and construction professionals should be engaged by clients in a *business validation* phase. Including a separate building validation phase ensures alignment of ends, means and constraints (Ballard 2008). Again, the target costing process demands that a building which cannot be realized at or below target cost should not be built. By involving the key members of the project team, designers and builders, in business plan validation, an owner is able to terminate development of an unfeasible project early enough in the process, minimizing loss.

The Project Production Systems Laboratory at the University of California, Berkeley, published a current best practice guide to target costing in November, 2005 (P2SL 2005). The process steps recommended were:

1. The client evaluates the business case and decides whether or not to fund a feasibility study.
2. The feasibility study involves all key members (designers, constructors, and client stakeholders) of the team that will deliver the project if the study findings are positive.
3. The client is an active and permanent member of the project delivery team.
4. The feasibility study produces a detailed budget aligned with scope.
5. All team members understand the business case and stakeholder values.
6. A cardinal rule is agreed upon by all performers: the Target Cost cannot be exceeded.
7. Cost estimating and budgeting is done continuously (i.e. "over-the-shoulder estimating") through intimate collaboration between design professionals and cost modelers.
8. The Last Planner system is used to coordinate the actions of team members.

The next section discusses the methodology used during this action research project. In addition to the P2SL components, the project also introduced a new form of contract, the Integrated Form of Agreement.

METHODOLOGY

The authors chose to document the target costing process of an 850,000 square foot U.S.-based medical center using action research. Because the practice of construction target costing is still developing and because implementation requires participation and exploration by all members of the project team (Greenwood et al. 1993), it was decided that action research was the most appropriate methodology to use for research of this nature. Action research can document a single project, but differs from more familiar case study research in that "the researcher is not an independent observer, but becomes a participant, and the process of change becomes the subject of research" (Benbasat et al. 1987; Westbrook 1995).

As mentioned above, the project adopted an *Integrated Form of Agreement* (IFOA). Construction contracts that subordinate the interests of one party to another or distribute risk unevenly are common in the construction industry and have been blamed for high levels of distrust and litigation. Conversely, when a contract supports risk sharing, as does the IFOA, individual parties identify their own interests with that of the project (Koskela et al. 2006; Lichtig 2006). The IFOA contract also allows money to move across organizational boundaries in search of the optimal life cycle cost investment. Such a contract was utilized throughout the action research project.

The target cost was established during an extensive business planning phase, followed by a four month *business plan validation* phase that included key members of the project design team: architect, engineer, contractor and critical trade partners.

During the entire twelve month of designing to targets, team members physically *co-located* to the same office floor (figure 1). The co-located team included the contractor, as well as representatives from the mechanical, plumbing and electrical (5 days/week), curtain wall, architectural metal panels, shoring, elevator,

drywall, structural steel and concrete trade partners (2-3 days per week). To enhance communication, members from a single company sat in multiple groups; for example, architectural representatives sat in the sustainability, planning, exterior enclosure, interiors, administration and technical architect groups.

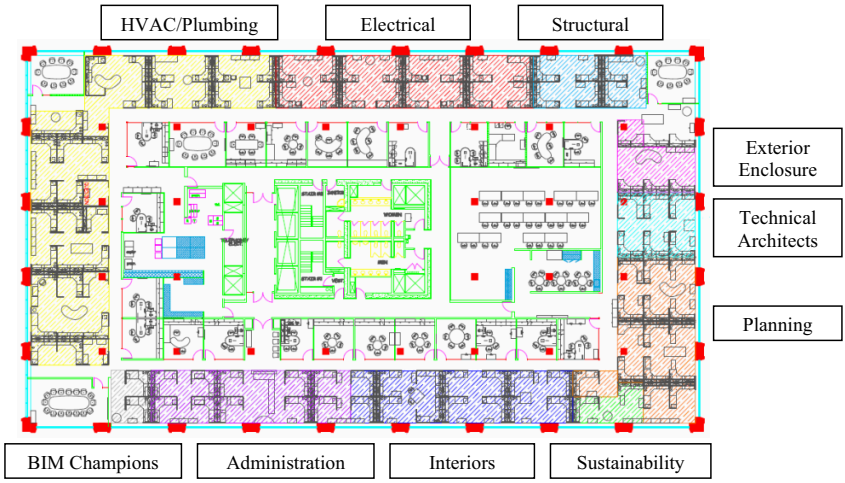


Figure 1. Cluster groups were physically co-located on the same floor.

Trade contractors were referred to as "*trade partners*" to more accurately reflect their role as integral contributors during the preconstruction and construction phases of target costing exercises. All existing team members and trade partners were permitted to interview new members under consideration and were permitted an equal voice during the hiring process.

The target costing process is meeting intensive. The project team met in a *big room* for approximately two hours each meeting, two times per week—once for a target costing exercise and once for a Last Planner exercise (Last Planner™ is a lean project planning and control system (Ballard 2000; Hamzeh et al. 2008)).

Planning and preplanning of individual parts of the project were generally accomplished during *cluster group* and subcommittee meetings. Each cluster group was assigned its own target cost to meet. Value engineering changes recommended by one group were circulated to all others to determine the cost implications on the entire project. Cluster Groups for this project included structural, mechanical, electrical and plumbing, exterior skin (architectural enclosure), interiors, project requirements, site work, and conveying systems. In addition to meeting with the entire project team twice weekly as previously described, Cluster Groups individually met 2-3 hours per week; these meetings were scheduled *not* to overlap, so that team members could attend other Cluster Group meetings, as needed. Representatives

from a single company would inhabit multiple Cluster Groups. Additionally, a *Core Group* met regularly, and included executive representation from the owner, architect, contractor and concrete trade partner.

Because a successful target costing process requires them to engage in practices with which they may not be familiar, team members were continually trained in lean production thinking and met regularly to read and discuss chapters from Jeffrey Liker's *The Toyota Way* (Liker 2004).

To benchmark the team's progress toward its target cost goal, the estimating manager weekly presented a current estimate plot so the entire team could monitor its current position vis-à-vis the target cost (figure 2). To better identify innovation and cost savings on a regular basis, material escalations were updated every 6 months and labor escalations every 12 months. Target costing goals were established for each building subsystem to motivate each Cluster Group to brainstorm innovative and unique cost saving opportunities using its own methods. For example, although the structural engineering group used building information modeling (BIM) to regularly update its estimates, the architecture group used 2D electronic estimating methods.

Set-based design is a process in which design alternatives are defined and communicated between all disciplines, and choosing a single alternative is done at the last responsible moment. This occurs at each level of design development; from concept to detailed design (Parrish et al. 2008a; b). The process reduces the waste that accompanies negative iteration—iteration that does not add value to the design. Individual members of the project team used A-3 sized sheets of paper to document and post—for all to see and evaluate—design alternatives they recommended the owner consider adopting.

Although the project maintained a central intranet site with current drawings, updated drawing sets were regularly printed and posted on designated walls at the project office to reduce the waste and confusion that sometimes occurs when individual team members print their own sets.

To ensure a spirit of continual improvement, a *plus/delta* exercise was used following meetings. Plus/delta is a process advocated by the Lean Construction Institute. A flip chart is divided into two columns: a "+" sign heads the left column and a "Δ" sign heads that on the right. Unlike the more familiar category of "-", "Δ" represents "opportunity for change or improvement." The distinction is important because it diverts team attention away from blame-finding or finger pointing and focuses it on it instead on opportunities for continual improvement—a fundamental tenet of lean.

RESULTS

Results from the target costing process for the case study medical facility are shown in figure 2. Note that progress toward the target cost was gradual, but steady, trending down over time, in contrast to the more typical increase in cost estimates as drawings increase in complexity.

During the initial twelve months design development (9/07-07/08), the team reduced its estimate from an initial anticipated total cost of over $970 million by $85 million (the final goal is a reduction of more than $90 million). To achieve this reduction, the project team generated design alternatives that were thoroughly tested

before incorporation into the cost estimate. According to the project estimator, physical co-location of the project team and the twice per week big room meetings brought the greatest benefit to the target costing exercise. This communication is said to have greatly saved time associated with traditional design-bid-build contractual communication.

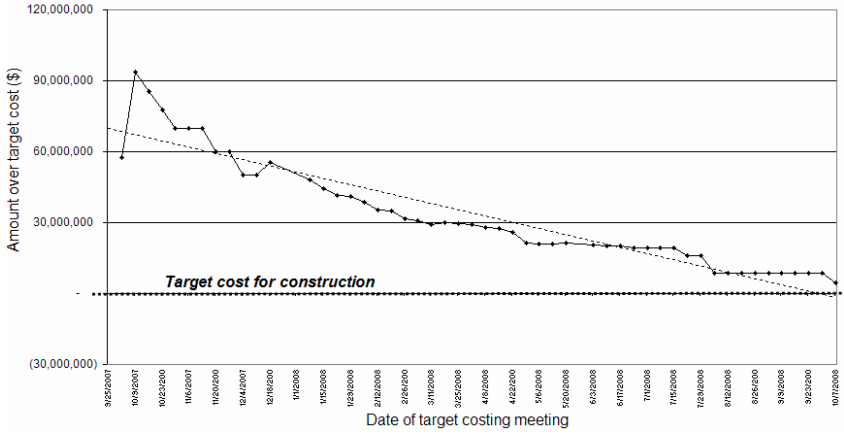


Figure 2. Target costing progression over development of project. Vertical axis represents the remaining gap between the current estimate and the target cost.

Some examples of design innovations that helped reduce expected cost:

- Changed building mass to accommodate program fit
- Modified elevator design
- Increased efficiency of plumbing, HVAC, elevator
- Increased efficiency of structure, switching parking framing from concrete to steel
- Redesigned switchgear
- Modified exterior skin design

DISCUSSION

Quantifying the impact of construction target costing is still in its early days. Quantification usually demands controlled scientific experimentation, where confounding variables are eliminated by holding all variables constant but one (Bernard 2000). However, the complexity of construction processes renders more traditional research methods impractical. Action research methodology is suited to case study situations in which multiple variables impact a process and researchers effect change. In this project, researchers helped facilitate the experimental target costing process.

Target costing is of special interest to these authors in the context of life cycle cost analysis (LCCA). LCCA tools help owners determine payback periods or engage in cost-benefit analysis when making decisions about whether or not to invest in an environmentally sustainable building system or when contemplating the inclusion of Evidence-Based Design interventions in a medical facility. While the results of LCCA might recommend investment in a sustainable energy system (given long term annual energy savings), for example, many owners are put in the position of not being able to afford the requisite capital—or "first"—cost. Early work on target costing case studies has been promising. It is hoped that additional action research experiments will build on work currently being done.

CONCLUSION

Construction target costing offers an opportunity to substantially reduce first cost without compromising the required functionality of a facility. Used in combination with lean principles and the Last Planner System of project management, preliminary results show that an integrated project delivery team for an 850,000 square foot California-based medical facility has been able to successfully achieve a target cost 14% below market, reducing its initial cost estimate by 9% by incorporating design innovations.

ACKNOWLEDGMENTS

Research for this paper was in part supported by gifts made to the Project Production Systems Laboratory (http://p2sl.berkeley.edu/). All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the Project Production Systems Laboratory.

REFERENCES

Ahuja, H. N., and Walsh, M. A., eds. (1983). *Successful methods in cost engineering*, Wiley, New York.

Ashworth, A. (1993). "How life cycle costing could have improved existing costing." In: *Life Cycle Costing for Construction*, J. W. Bull, ed., Blackie Academic & Professional, London.

Ballard, G. (2006). "Rethinking project definition in terms of target costing." *Proceedings IGLC-14*, Santiago, Chile, 77-89.

Ballard, G. (2008). "The lean project delivery system: an update." 1-19. www.leanconstructionjournal.org

Ballard, G., and Reiser, P. (2004). "The St. Olaf College Fieldhouse Project: a Case Study in Designing to Target Cost." *12th Annual Conference of the International Group for Lean Construction*, Elsinor, Denmark, 234-249.

Ballard, H. G. (2000). "The Last Planner System of Production Control," The University of Birmingham, Birmingham, UK.

Barrie, D. S., and Paulson, B. C. (1992). *Professional Construction Management: including CM, Design-Construct, and General Contracting*, McGraw-Hill, Inc., New York.

Benbasat, I., Goldstein, D. K., and Mead, M. (1987). "The case research strategy in studies of information systems." *MIS Quarterly*, 369-386.

Bernard, H. R. (2000). *Social Research Methods: Qualitative and Quantitative Approaches*, Sage Publications, Inc., Thousand Oaks.

Boussabaine, A., and Kirkham, R. (2004). *Whole Life-Cycle Costing*, Blackwell Publishing, Bodmin, Cornwall.

Bull, J. W. (1993). *Life Cycle Costing for Construction*, Blackie Academic & Professional, London.

Clifton, M. B., Bird, H. M. B., Albano, R. E., and Townsend, W. P. (2004). *Target Costing: Market-Driven Product Design*, Marcel Dekker, Inc., New York.

Cole, R. J., and Sterner, E. (2000). "Reconciling theory and practice of life-cycle costing." *Building Research & Information*, 28(5/6), 368-375.

Cooper, R., and Slagmulder, R. (1997). *Target Costing and Value Engineering*, Productivity Press, Portland, UK.

Evans, R., Haryott, R., Haste, N., and Jones, A. (1998). "The long term costs of owning and using buildings." Royal Academy of Engineering, London.

Fisk, E. R. (2003). *Construction Project Administration*, Prentice Hall, Upper Saddle River, N.J.

Greenwood, D. J., Whyte, W. F., and Harkavy, I. (1993). "Participatory action research as a process and as a goal." *Human Relations*, 46, 175-191.

Hamzeh, F. R., Ballard, G., and Tommelein, I. D. (2008). "Improving Construction Work Flow--the Connective Role of Lookahead Planning." *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*, Manchester, UK, 635-646.

Ive, G. (2006). "Re-examining the costs and value ratios of owning and occupying buildings." *Building Research & Information*, 34(3), 230-245.

Kirk, S. J., and Dell'Isola, A. J. (1995). *Life Cycle Costing for Design Professionals*, McGraw-Hill, Inc., New York.

Koskela, L., Howell, G., and Lichtig, W. (2006). "Contracts and production." *CIB W92 Symposium on Sustainability and Value through Construction Procurement*, Salford, UK, 332-229.

Lichtig, W. A. (2005). "Ten key decisions to a successful construction project." *American Bar Association Forum on the Construction Industry*, Toronto, Canada, 1-26.

Lichtig, W. A. (2006). "The Integrated Agreement for Lean Project Delivery." *Construction Lawyer*, 26(3).

Liker, J. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill, New York.

Macomber, H., Howell, G., and Barberio, J. (2008). "Target-Value Design: Nine Foundational Practices for Delivering Surprising Client Value." <http://www.aia.org/nwsltr_pm.cfm?pagename=pm_a_112007_targetvaluedesign> (July 30, 2008).

Moore, R. (2001). "Management side of engineering: payback method--too simple and too expensive." *Plant Engineering*.

MSA. (2004). "MacLeamy Curve." <http://www.msa-ipd.com/MacleamyCurve.pdf> (July 30, 2008).

Nicolini, D., Tomkins, C., Holti, R., Oldman, A., and Smalley, M. (2000). "Can Target Costing and Whole Life Costing be applied to the Construction Industry? Evidence from Two Case Studies." *British Journal of Management*, 11, 303-324.

P2SL. (2005). "P2SL Report on the Current Benchmark in Target Costing." Project Production Systems Laboratory, University of California, Berkeley. p2sl.berkeley.edu

Parrish, K., Wong, J.-M., Tommelein, I. D., and Stojadinovic, B. (2008a). "Set-based design: case study on innovative hospital design." *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*, Manchester, UK, 413-423.

Parrish, K., Wong, J.-M., Tommelein, I. D., and Stojadinovic, B. (2008b). "Value propositions for set-based design of reinforced concrete structures." *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*, Manchester, UK, 495-506.

Paulson, B. C., Jr. (1976). "Designing to reduce construction costs." *Journal of the Construction Division, ASCE,*, 102(CO4).

Westbrook, R. (1995). "Action research: a new paradigm for research in production and operations management." *International Journal of Operations & Productions Management*, 15(12), 6-20.

STRUCTURAL DESIGN ITERATION: THE APPLICATION OF DSM TO SEISMIC RETROFIT

Stan J. Tuholski[1] and Iris D. Tommelein[2]

ABSTRACT

Iteration in design or re-design is commonplace within architectural, engineering, and construction (AEC) projects. Positive iteration is often required to optimize design solutions around competing objectives. This runs counter to the misconception shared by many engineers that iteration is negative and linearity in design is preferable and achievable through adequate pre-planning. We have identified a void in the practical application and theoretical development of design theory within the structural engineering community, particularly in methodologies that address iteration in design. This void points at a lack of understanding that contributes to project performance deficiencies as characterized by cost over-runs and sub-optimal design, among others. This paper presents a seismic retrofit case study for the purpose of developing a greater understanding of the role of iteration in design. The design structure matrix (DSM) work planning tool is used to optimize the sequence of design activities in order to limit the required impacts of necessary iteration allowing for efficient information flows. The implementation of DSM on this project had two valuable effects: (1) the optimized matrix correctly identified the dependency network underlying the primary design problem as evident by the alignment of observed iterative activities and the derived block, and (2) the DSM provided a common framework for discussing iterative tasks and planning collaborative design efforts within the multi-disciplinary team.

KEYWORDS

Design Structure Matrix, Iteration, Re-design, Structural Engineering Methodology

[1] PhD Candidate, Civil and Envir. Engrg. Department, 407 McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, Phone 925/423-6493, tuholski1@llnl.gov,

[2] Professor, Civil and Envir. Engrg. Department, and Director, Project Production Systems Laboratory (http://p2sl.berkeley.edu/), 215-A McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, Phone 510/643-8678, FAX 510/643-8919, tommelein@ce.berkeley.edu.

INTRODUCTION

"Work structuring" is the effort to develop a project's process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts (Ballard 1999, Tsao et al. 2000). Work structuring (aka. work planning in the design community) in an AEC design process includes identifying necessary design tasks, participants, sequences, hand-offs, and work products. Closely related to work planning is the concept of design iteration. This paper explores the concept of design iteration on a seismic retrofit project, and then focuses on the development of strong-back column details that became central to the design development. It details how the Design Structure Matrix (DSM) modeling tool is used to predict activity loops and categorize the nature of iterative activities.

ITERATION IN DESIGN

The concept of iteration in design is closely tied to design theory methodologies and processes. Where design theory is referenced in civil engineering texts, point-to-point methods are most prevalent. Within point-to-point methods, successive linear iteration or decomposition are common means by which optimization is achieved (e.g., Stephenson and Callander 1974). An alternate non-linear conceptualization characterizes design as a "wicked problem" (Rittel and Webber 1973), describing the challenges of dynamic design problems. The theory of wicked problems suggests simple, static solutions or approaches to complex projects are unlikely to succeed. The only successful solutions are those that recognize the inherent non-linearity of systems and allow for extensive iteration, feedback, and delay. In other words, successful management solutions must recognize non-linear iteration in design.

Ballard (2000) describes iteration in design as both *positive* (value adding) and *negative* (rework). He proposes several (12) means of increasing value to all production system members while eliminating wasteful efforts. One suggestion is to apply DSM to AEC design planning. DSM is a method to highlight iteration in design, allowing for a more efficient structuring and sequencing of work (Browning 2001). Mechanical engineering researchers commonly refer to iteration as "redesign" and have pursued DSM and related methodologies with the goal of understanding the underlying structure of design problems. Chen et al. (2005), for example, use domain mapping matrices (DMM) to describe the structural composition of *primary* and *major* redesign. Primary redesign is defined as iteration where design variables/parameters are altered to achieve enhanced performance levels. In major redesign the design model itself is modified to improve the results.

DESIGN STRUCTURE MATRIX (DSM)

DSM is a representation and analysis tool for system modeling, especially for the purposes of decomposition and integration (Steward 1981). Project based DSM is a dynamic form of DSM characterized by the mapping of dependency relationships within process domains. The goal of project based DSM is to gain insight into optimal activity sequencing, realize overall process efficiencies through work planning, and minimize unnecessary rework (Browning 2001).

The DSM modeling process requires three basic steps. The first two generate the process representation matrix and the third is analytical, involving matrix manipulation. Step one decomposes a design project into a process with discrete activities, identifying the required inputs, outputs, and information dependencies. Step two arranges activities sequentially in a square matrix with identical row and column identifiers. The marked dependencies read as, "The activity in row *i*, depends on the activity in column *j*." Step 3, referred to as triangularization or sequencing, involves analysis and manipulation of the assembled matrix. The activities located below and to the left of the diagonal are sequential and feed-forward information. The activities located above and to the right of the diagonal are out-of-sequence and require activity with iteration and information feedback. Groups of activities, bounded by iterative tasks are referred to as blocks. Work within blocks may need to be performed in an iterative manner. DSM was chosen for application to the following seismic retrofit design because of the inherent interdependence between structural elements, mechanical/electrical/plumbing/architectural impacts, and cost.

CASE STUDY

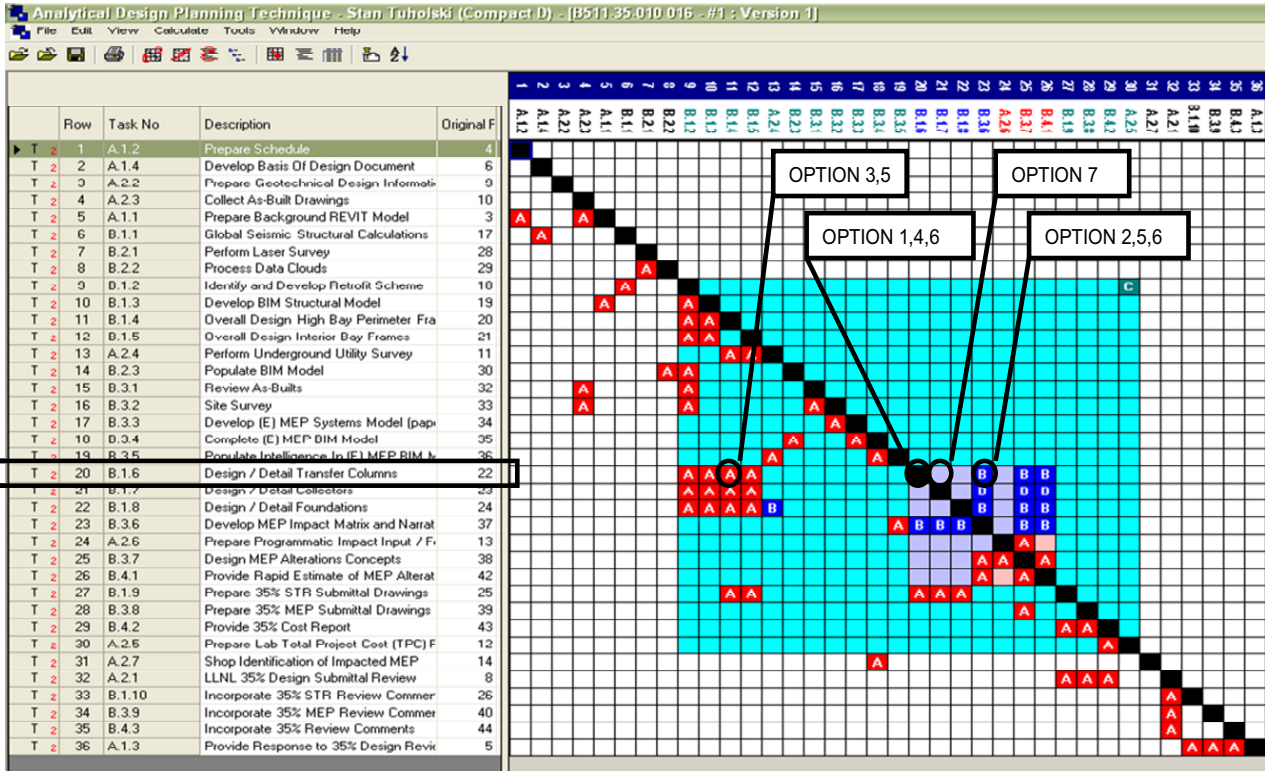
Building 511 (B511) was built in 1942 and served as a Navy airplane assembly hanger throughout WWII. Following several modifications, B511 now houses Plant Engineering, which supports infrastructure maintenance across Lawrence Livermore National Laboratory (LLNL). The original 13.7 m (45 ft) high bay structure, with a footprint of 79.3 m by 61 m (260 ft by 200 ft), was timber framed with long span wood trusses. Wood-framed low bay portions of the building were subsequently built. This case study reviews the design development of a seismic retrofit scheme consisting of concentric steel braces on shallow mat footings with associated steel collectors. Building information modeling (BIM) techniques, including laser scanning and Revit modeling (Autodesk 2008) were used to capture existing conditions and explore interactions with new structural elements. The intent of the design is to achieve the ASCE 41 life-safety objective while limiting expensive "collateral" impacts to mechanical, electrical, and plumbing (MEP) systems.

GENERAL ITERATION

The design services request for proposal required the subcontractor to collaboratively implement DSM methodologies during work planning. LLNL obtained permission from Adept Management Ltd. to experiment with DSM software version 7.3.2532.

Tuholski (2008) describes the DSM implementation methodology. The design team, including LLNL and consultants, categorized dependencies by strength in descending order from A to C and set DSM algorithms to optimize the sequence around the type A and B only (Figure 1). Through DSM implementation, the team predicted and anticipated iteration involving the central design problem; interaction between strong-back column details and MEP impacts. Other, more peripheral forms of iteration were observed, namely:

BIM Coordinate System: The project team deliberated three times on the insertion point and coordination system for the mechanical and structural models within Revit. The cause of the iteration involved differing origins of data. The mechanical model



	Row	Task No	Description	Original F
T 2	1	A.1.2	Prepare Schedule	4
T 2	2	A.1.4	Develop Basis Of Design Document	6
T 2	3	A.2.2	Prepare Geotechnical Design Informati	9
T 2	4	A.2.3	Collect As-Built Drawings	10
T 2	5	A.1.1	Prepare Background REVIT Model	3
T 2	6	B.1.1	Global Seismic Structural Calculations	17
T 2	7	B.2.1	Perform Laser Survey	28
T 2	8	B.2.2	Process Data Clouds	29
T 2	9	B.1.2	Identify and Develop Retrofit Scheme	10
T 2	10	B.1.3	Develop BIM Structural Model	19
T 2	11	B.1.4	Overall Design High Bay Perimeter Fra	20
T 2	12	B.1.5	Overall Design Interior Bay Frames	21
T 2	13	A.2.4	Perform Underground Utility Survey	11
T 2	14	B.2.3	Populate BIM Model	30
T 2	15	B.3.1	Review As-Builts	32
T 2	16	B.3.2	Site Survey	33
T 2	17	B.3.3	Develop (E) MEP Systems Model (pap	34
T 2	18	B.3.4	Complete (E) MEP BIM Model	35
T 2	19	B.3.5	Populate Intelligence In (E) MEP BIM M	36
T 2	20	B.1.6	Design / Detail Transfer Columns	22
T 2	21	B.1.7	Design / Detail Collectors	23
T 2	22	B.1.8	Design / Detail Foundations	24
T 2	23	B.3.6	Develop MEP Impact Matrix and Narrat	37
T 2	24	A.2.6	Prepare Programmatic Impact Input / F	13
T 2	25	B.3.7	Design MEP Alterations Concepts	38
T 2	26	B.4.1	Provide Rapid Estimate of MEP Alterat	42
T 2	27	B.1.9	Prepare 35% STR Submittal Drawings	25
T 2	28	B.3.8	Prepare 35% MEP Submittal Drawings	39
T 2	29	B.4.2	Provide 35% Cost Report	43
T 2	30	A.2.5	Prepare Lab Total Project Cost (TPC) F	12
T 2	31	A.2.7	Shop Identification of Impacted MEP	14
T 2	32	A.2.1	LLNL 35% Design Submittal Review	8
T 2	33	B.1.10	Incorporate 35% STR Review Commer	26
T 2	34	B.3.9	Incorporate 35% MEP Review Commer	40
T 2	35	B.4.3	Incorporate 35% Review Comments	44
T 2	36	A.1.3	Provide Response to 35% Design Revi	5

Figure 1: Design Activity DSM

was based on a laser scanned point cloud representation of the infrastructure which was accurate to 2.5 mm (1/10 in). The structural model was based on original structural drawings and did not take into account tolerance in construction or deflection under applied loads. The final solution involved a compromise, allowing insertion of the structure to minimize deviation from the as-built condition. The team considered this form of iteration as negative.

Information Hand-off Between Laser Scanners and Mechanical Engineer: The content and format of information exchange between the laser scanners and mechanical engineer took at least five attempts to clarify. One cause of this iteration was misunderstandings surrounding the technical capabilities of the laser scan conversion to a 3-D CAD file. Another cause was misunderstandings surrounding expectations of the intelligent information embedded with the CAD file. All this iteration was considered negative as it expended significant unexpected meeting time. The root cause of this negative iteration was a lack of technical understanding or experience. It would be expected that this precise form of iteration would not occur on future projects. However, it is quite likely that iteration caused by technical uncertainties that are new could arise in a similar manner.

Schedule Development and DSM Refinement: The team produced four schedules and twelve DSM matrices prior to reaching final agreement. This iteration was approximately half due to the learning curve associated with a trial DSM implementation and half project specific process optimization. The iteration was classified as positive, however the team suggested the DSM iteration should be reduced on future projects due to lessons learned.

STRONG-BACK PROBLEM DESCRIPTION

The team considered seven (7) detailed concepts of the strong-back column design. The strong-back column was a critical element of the steel braced frame system in both directions. Each detailed option was driven by a dependency associated with unique design activities. The transverse frames were located in the center of the high bay and braced both low and high-by roofs. Horizontal seismic loads were transferred to the high bay roof by means of collectors supplementing the existing roof trusses and a strong-back steel column introduced adjacent to the existing wood column. Figure 2 depicts the Revit model with new (N) and existing components. In the longitudinal direction, the frames were located at the intersection of the low and high bays. Collectors at the low and high bays, respectively, transferred horizontal seismic loads in this direction. Longitudinal seismic braced frames were inserted between strong-back columns.

DESIGN CONSIDERATIONS

Structural Seismic Resistance in the Transverse Direction: In the transverse direction, the primary function of the strong-back column is to transfer seismic loads from the low bay roof to the high bay roof. Flexural strength and stability along with collector continuity are important design considerations. Optimal steel shapes from most to least efficient are wide flange column with strong axis bending,

miscellaneous channel bolted to the side of the column, steel plates bolted to the side of the column, and wide flange column with weak axis bending. For shapes susceptible to lateral-torsional buckling, torsional bracing off of the existing structure is required. It is beneficial to have the column close to the existing structure or additional strength is required to compensate for the lack of bracing.

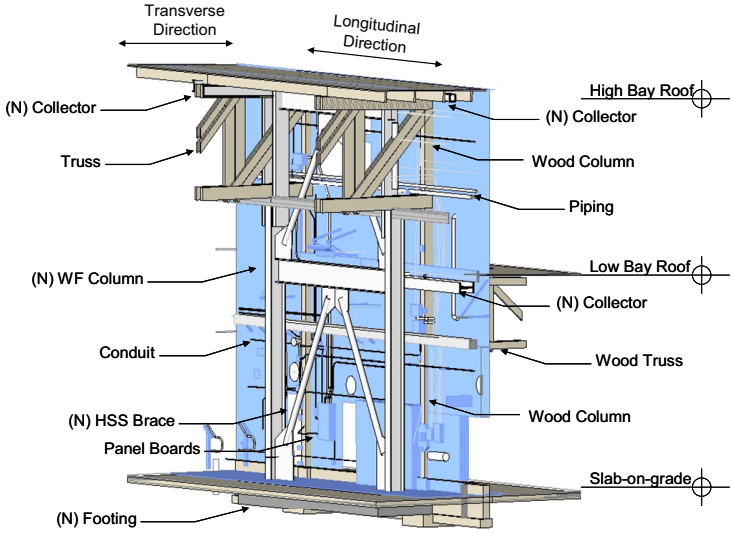


Figure 2: Revit Model Isometric at Strong-back and Longitudinal Braced Frame

Structural Seismic Resistance in the Longitudinal Direction: In this direction, the primary function of the strong-back columns is to resist compression and tension loads at seismic braced frames. The frames brace the high bay and low bay roofs and are located typically every third bay, however a few are located in adjacent bays. The strong-back columns at the braced frames must be coordinated with the collector elements that drag and deliver seismic loads at both roof levels. Axial strength and stability, brace/column detailing geometry, and collector interface arrangement are important design considerations for the columns at the longitudinal frames.



Figure 3: Photo at Future Strong-back and Longitudinal Braced Frame Bay

Mechanical, Electrical, Plumbing (MEP): The primary goal of this project is structural in nature so it is necessary to relocate MEP systems in conflict with the new structural elements. Due to the critical support functions provided to the Lab by this facility, the facility must remain operational during construction. This notwithstanding, design consideration for MEP elements is to limit "collateral" impacts to the extent possible. Electrical conflicts include wall-mounted distribution panels and conduit runs. The conduits were primarily attached to the face of existing columns. Mechanical and plumbing conflicts include hot and chilled water, steam piping, and compressed air lines. Structural solutions that are not attached to the existing wood column face are optimal from a MEP piping and conduit perspective. Structural solutions that avoid panel boards mounted on the wall face are optimal from the electrical perspective.

Architectural: The architectural design goal is to limit impacts to architectural elements and functions due to new structural elements. Architectural design considerations include interruption of wall mounted cabinetry and avoidance of emergency exit doors. Additionally, a floor pathway immediately adjacent this column line allows for material movement around the shop. Pathway function is best maintained by locating the new columns as tightly as possible to the exiting structure.

OBSERVATIONS OF OPTION DEVELOPMENT

The team developed seven options for the strong-back column details. The first six options were developed up to and including 35% design. Option 7 was carried through to the final construction documents. Each option was developed in response to an identified deficiency and was requested by the responsible discipline for that activity. Observed Options 1, 2, 4, 6, and 7 were driven by detail related activities within the type A and B dependent block identified by the DSM in Figure 1. These options were typically *refinements* on previous suggestions. The activities driving Options 3 and 5 were outside the primary loop and constituted greater systematic changes. These options were considered mid-course in the development process which suggests they were both iterative and non-linear in nature. It was observed that each round of iteration was triggered by a pull from a sub-optimal dependency or activity. The value of using DSM, as illustrated, was that it isolated a block of activities with the majority of dependent links. In other words, the optimized sequence was validated because the re-work was isolated in a tight 'knot' or block. Additionally, designers were aware of the tendency for re-work in these areas and were able to plan the interactions accordingly. These plans included holding co-located field design sessions and allowing for the transfer of partial batch sizes of specific information.

Option 1 - W14 Wide Flange Column Reinforcement: The structural engineers first prepared this option as part of a pre-design scoping effort, as it offered the most direct and traditional solution for this seismic deficiency. They were very experienced with this form of retrofit and therefore more confident than novices would be in exploring alternate design solutions. A W14 steel wide flange column was face-mounted to the existing column. This was optimal from the structural perspective because the steel column was in strong axis bending and directly attached to the existing wood column by intermittent brackets. This solution was sub-optimal

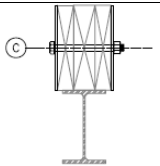
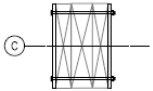
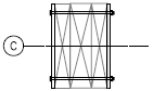
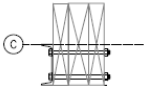
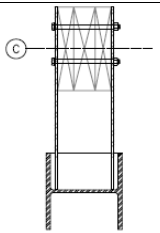
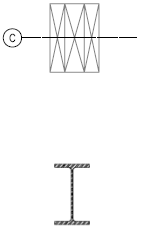
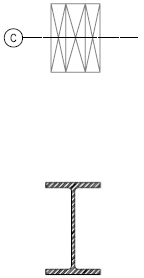
	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Typical Plan Detail at Existing Wood Column with Steel Reinforcement							
Description	W14 Wide Flange Column	Sandwich Plate	Sandwich Plate Adjusted	Channel	W14 Column Shored Truss	W14x53 Column	W18x119 Column
Existing Column Offset	Offset 0 cm (face-mount)	Inset (along side)	Inset (along side)	Inset (along side)	Offset 31 cm (12 in)	Offset 36 cm (14 in)	Offset 46 cm (18 in)
Comment	Baseline pre-design Concept	Proposed after first integrated team site-walk	Structural enhancement of Option 2	Structural enhancement of Option 3	Structural	35% Design Detail	100% Design Detail
Concept Motivation	Optimize strong-back strengthening	Avoid MEP impacts at column face	Optimize flexural strength of strong-back transfer column	Optimize configuration at longitudinal braced frame column	Optimize longitudinal braced frame configuration and reduce MEP impacts	Further reduce MEP impacts and eliminate truss shoring by passing truss with channels	Increase offset to allow W18 collector to pass between transfer column and existing column
Requesting Discipline: Activity Pull	Structural: Design/Detail Transfer Columns	MEP: Develop MEP Impacts Narrative	Structural: Overall Design High Bay Frames	Structural: Design/Detail Transfer Columns	Structural/MEP: Overall Design High Bay Frames & Develop MEP Impacts Narrative	Structural/MEP: Design/Detail Transfer Cols & Develop MEP Impacts Narrative	Structural: Design/Detail Collectors

Table 1: Evolution of Strong-back Transfer Column Design

for MEP impacts because the column interrupted the electrical conduit and piping. Architecturally speaking, this solution balanced intrusion on the walk-way with cabinet and door interferences.

Option 2 - Sandwich Plate Reinforcement: This option was driven by mechanical engineering requirements to reduce piping and conduit impacts. The solution was sub-optimal structurally because plates are less efficient that the wide flanged column, but optimal MEP-wise and architecturally, due to reduced impacts.

Option 3 - Sandwich Plate Reinforcement (Adjusted): This option was suggested by structural engineers to address the inefficiencies of the plates in bending. Plate sizes were upsized at the typical condition and a wide flanged column was added where longitudinal braces occurred. From an MEP and architectural perspective, this solution was similar to Option 2 and structurally it was improved. Structural engineers however became aware of a new concern, detailing column and brace details at adjacent longitudinal frame bays required cost prohibitive detailing.

Option 4 - Channel Reinforcement: Option 4 was developed in parallel with Option 3. It substituted a steel channel alongside the wood column for less efficient plates. This solution was more efficient structurally at the typical condition, however it did not address inefficiencies at adjacent longitudinal bays.

Option 5 - W14 Column Reinforcement Shored Truss: This option was developed to address detailing concerns at adjacent longitudinal seismic frames. The steel column was rotated to its weak axis for primary bending and offset 31 cm (12 in) from the wood column face. This adjustment balanced the efficiency of detailing the frame columns with reduced efficiency of the strong-back in bending due to the rotated shape and intermittent bracing. This solution was balanced from an MEP and architectural perspective. By offsetting the column, the majority of piping and conduit conflicts were avoided and door/cabinet conflicts were reduced. The offset column did intrude into the architectural access isle to a greater degree. The greatest shortcoming of this detail was the interruption and shoring of the existing truss. This detail was set aside because shoring and re-support were considered prohibitively expensive.

Option 6 - W14x53 Column: Option 6 was developed by structural engineers in an effort to capture the benefits of Option 5 without shoring the truss. The wide flange column was rotated to allow for the welding of steel channels to the column at the high bay roof truss. This allowed the strong-back column to pass the truss without the need for shoring. Intermittent attachment brackets were increased in frequency to maintain the stability of the wide flanged column. The wide flanged column off-set was increased to further reduce impacts to conduit and piping. This increased the intrusion slightly on the architectural access isle.

Option 7 - W18x119: This option represented a refinement of Option 6 by upsizing the column depth and weight to eliminate the need for intermittent bracing. The offset off the column was increased to 46 cm (18”) to facilitate collector detailing at the low bay roof. The interaction between strong-back column detailing and collector detailing was not previously identified by the design team and was not represented in the DSM. Option 7 represented the 100% construction documents detail. It was balanced from a structural standpoint. The column was offset to avoid the existing

truss and collector, however, the column was upsized in weight due to the reduction in stabilizing connection points.

CONCLUSIONS

This seismic design case study enabled the team to develop greater understanding of iteration in design. Several instances of iteration were observed, including examples of both positive and negative iteration. The central design feature of this project involved the development of steel strong-back columns. Seven rounds of design iteration were observed, each providing various benefits and penalties with respect to structural, MEP, and architectural design considerations. Detail development was driven by the iterative activities required to address deficient or sub-optimal aspects of the design. The implementation of DSM on this project had two valuable effects: (1) the DSM (Figure 1) correctly identified the dependency network underlying the primary design problem, and (2) the DSM provided a common framework for discussing the required design iteration within the multi-disciplinary team. In other words, the team was able to overcome negative connotations surrounding iteration and focus on the value benefits delivered to the owner. The process of design development appeared to be non-linear both in the DSM as well as observed in practice. Ultimately, the final solution represented a collection of sub-optimal considerations across competing design objectives; column off-set location, depth/weight, and interaction with seismic collectors and frames all were balanced with impacts on MEP and architectural features.

REFERENCES

Autodesk (2008). Autodesk website, http://usa.autodesk.com, visited on Sept. 1.

Ballard, G. (1999). "Work Structuring." *White Paper-5* (unpublished), Lean Constr. Inst., Ketchum, ID, available at http://www.leanconstruction.org/.

Ballard, G. (2000). "Positive vs Negative Iteration in Design". *Proc. 8th Ann. Conf. of the Intl. Group for Lean Constr. (IGLC 8)*, Brighton, UK.

Browning, T. (2001). "Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions". *IEEE Transactions on Engineering Management,* 48 (3) 292-306.

Chen, L. and Li, S. (2005). "Towards Rapid Redesign – Decomposition Patterns for Large-scale and Complex Redesign Problems". *Proceedings of IDET/CIE 2005,* ASME Int'l. Design Engrg. Technical Conf., Long Beach, CA.

Rittel, H. and Webber, M. (1973). "Dilemmas in a General Theory of Planning." *Policy Sciences.* Fourth Edition, Elsevier Sci. Pub., Amsterdam, pp. 155-159.

Stephenson, J. and Callander R. (1974). *Engineering Design.* John Wiley and Sons, Australasia Pty Limited, Perth, Australia.

Steward, D. (1981). "The Design Structure System: A Method for Managing the Design of Complex Systems". *IEEE Transactions on Engrg. Mgmt.,* 28 (3) 71-74.

Tsao, C.Y., Tommelein, I.D., Swanlund, E., and Howell, G.A. (2000). "Case Study for Work Structuring: Installation of Metal Door Frames." *Proc. 8th Ann. Conf. of the Intl. Group for Lean Constr.*, Brighton, U.K.

Tuholski, S. (2008). *Transformation, Flow, and Value Constellations in AEC Projects.* A Doctoral Dissertation Submitted to the Faculty of Civil and Environmental Engineering at the University of California, Berkeley, December.

FROM LEAN TO GREEN CONSTRUCTION: A NATURAL EXTENSION

Isabelina Nahmens, Ph.D.[1]

[1]Assistant Professor, Dept. of Construction Management & Industrial Engineering, Louisiana State University, 3128 Patrick F. Taylor Building, Baton Rouge, LA 70803-6419, e-mail: nahmens@lsu.edu

Abstract

One of the focuses of Lean construction is waste elimination from the construction processes, while creating a culture within the company of continuous improvement. Similarly the focus of Green construction is on the removal of waste from the construction process and in addition it adds an environmental dimension to lean construction. Lean and green construction share a common goal, to eliminate as much waste as possible. Therefore, not producing waste is both the most efficient and cost effective approach to sustainability. Current industry practice shows that lean construction is already the dominant paradigm in factory built home manufacturing, yet its impact on the environment is less understood. This paper uses a case study approach which demonstrates that a natural byproduct of applying lean techniques is the reduction of waste which overlaps with one of the key objective of green building. This case study presents the application of lean production in the wall/partition department of a HUD-code home plant which resulted in a 10% reduction of raw material- reducing wallboard damaged during the construction stage. This paper compares material wastes before and after a Kaizen event performed in the wall/partition department. Lessons learned from this case study are discussed and used to proposed guidelines to integrate lean methodology and green building. Findings from this research will contribute to a better understanding of the applicability of lean strategies in the housing industry and its impact on the environment.

Introduction

The construction industry is one of the biggest contributors to pollution and waste (through its life cycle) (Horvath 2004). As reported by the Environmental Protection Agency (2004), in the U.S., buildings account for 39 percent of total energy use, 12 percent of the total water consumption, 68 percent of total electricity consumption and 38 percent of the carbon dioxide emissions. The construction activities and the built environment have an enormous impact on the natural environment, human health and overall economy. Green building practices can reduce the impact of

construction on the environment and human health. Green building practices can be introduced at any stage in construction, from design to deconstruction. Ideally, the impact of the built environment should be addressed on a life cycle basis, from the origins of the building material, through the manufacture and installation of these materials, to their eventual demolition of the building. Each stage in this life cycle raises questions of sustainability. Considering that construction waste comprises 40 percent of landfill material (Allen and Iano 2004), it is imperative that builders learn to build in a sustainable manner. Green building principles are a good starting point, by guiding builders to realize the kinds of waste that are generated during the construction stage and how to reduce them.

Due to the vast environmental impact of the built environment, the construction industry has a major potential to advance sustainability practices. Combining lean and green building may be one approach to sustainable construction by focusing on waste reduction that not only results in reduced environmental impact but also increases the bottom line by reducing costs. The U.S. Environmental Protection Agency (EPA 2003) found that the implementation of lean strategies produces an operational and cultural environment that is highly conducive to waste minimization and pollution prevention. Although, lean strategies as originally documented by Womack and Jones (1996) do not explicitly incorporate environmental performance metrics, lean production may have a significant positive impact on the environment due to its focus on minimization of resource usage. Current empirical evidence of this link is sparse and has yet to characterize the nature of this relationship. This paper uses a case study example where a HUD-code home manufacturer implemented lean, to explore the impact on the environment, as measured by waste reduction, after the improvement implementation.

HUD code homebuilding is an industrialized approach to homebuilding, which relocates many field operations to a more controlled factory environment. HUD code homes are composed of three-dimensional sections that are typically 95% finished when they leave the factory (Carlson 1991), then transported to site, lifted and placed by crane. Due to their production method, HUD code homes produce less waste because of reduced construction time, and less time needed on a site which means less damage to the home site and surrounding environment (Wortman 2007). This paper addresses the construction stage and explores ways to operationalize green building through lean construction strategies for factory-build home manufacturers. More specifically, explores waste reduction strategies in their production operations resulting from lean implementation.

Overview of Sustainable and Green Building

Sustainable, green and terms alike have become common and part of everyday dialogue among all parties of the construction supply chain- including supplier, factory producers, builders and clients. However, despite the growing use of these terms their definition is in some cases inaccurate and poorly understood. The most widely accepted definition of sustainable construction is from the Bruntland Commission's report, Our Common Future (Bruntland 1987) which defines it as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". In a building context, this definition can

be applied as: "*a building that can be produced and continue to be operated over the long term without adversely affecting the natural environment necessary to support human activities in the future"* (Building Science 2006). In order to fulfill this definition, the entire supply chain needs radical changes, not only from a material perspective but also from a production method perspective. Current construction methods are very far from producing truly sustainable buildings, however moving towards those goals is possible.

Considering how far the construction industry is from building a truly sustainable building, a practical definition of green building is one that is more sustainable than current practices (Building Science 2006). EPA (2008) describes green building as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle. Green building relates to sustainable development, as it promotes building practices that conserve energy and water resources, preserve open spaces through brownfield development, and are accessible to public transportation (EPA 2008).

Integration of Lean and Green Building

The lean production system has its origins in the automobile manufacturer industry with the Toyota Production System (Ohno 1988). Lean means getting the right things, to the right place, at the right time, in the right quantity while minimizing waste and being flexible and open to change (Womack 2005). The overriding goal of a lean production is to deliver value to all stakeholders- internal and external customers; and to eliminate waste- all activities that do not add value. Lean production is based on five fundamental principles: 1) identify what the customer values, 2) identify the value stream and challenge all wasted steps, 3) produce the product when the customer wants it and, once started, keep the product flowing continuously through the value stream, 4) introduce pull between all steps where continuous flow is impossible, and 5) manage toward perfection (Womack and Jones, 1996). In Construction the application of the lean production model stems from a discussion of Koskela's work (1993), which emphasized the importance of the production process flow, as well as aspects related to converting inputs into finished products as an important element to the creation of value over the life of the project.

Kaizen, typically referred to as an event, is an intensive and focused approach to process improvement. This lean method seeks operational perfection by eliminating waste – non-value added activities from the perspective of the customer. Green building can be operationalized by using a Kaizen approach and focusing on environmental performance of the production processes. Conducting a Kaizen event helps to eliminate waste by empowering employees with the responsibility, time, and tools to uncover areas for improvement and to support change. This type of activity is team based and involves employees from different levels of the organization. Traditionally, the purpose of the Kaizen event is to continuously improve and install a lean culture in the company through the use of lean principles and tools. A typical framework for executing a Kaizen event is shown in Figure 1.

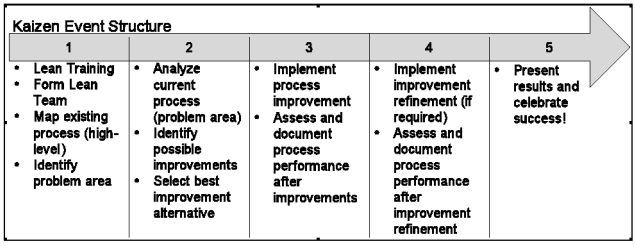


Figure 1. Typical Kaizen Event Structure (modified from Chatterjee 2008)

A Kaizen event provides focus on a process or an operation and helps to identify value and waste. The seven wastes that are evaluated and removed during these events are: defects (activities involving repair or rework), overproduction (activities involved in producing too much at a particular point in time), transportation (activities involving unnecessary movement of materials) , waiting (occurs when an operator is ready for the next operation, but must remain idle until previous step is taken by someone else), inventory (any inventory that is not directly required to fulfill current customer orders), motion (any unnecessary steps taken by employees and equipment) and processing (any extra operation or activity in the manufacturing process) (Ohno 1988).

There is evidence in the literature and industry practice that waste reduction is achieved through lean implementations, in particular material waste (Womack and Jones 1996; Salem and Zimmer 2005; Nahmens 2007; Nahmens and Mullens 2009). Further, evidence of the natural connection between lean and green building was stated by EPA. The EPA (2003) found that lean produces an operational and cultural environment that is highly conducive to waste minimization and pollution prevention, and that lean provides an excellent platform for environmental management tools such life cycle assessment and design for environment.

Methodology

This paper uses a case study approach which demonstrates that a natural byproduct of applying lean techniques is the reduction of waste which overlaps with one of the key objective of green building. The methodology use for this case study entailed observation and interviews, from which the following data was gathered: 1) company's background, 2) lean implementation approach, 3) results obtained, and 4) effect of lean implementation on waste reduction. The primary purpose of this case study was to develop an understanding of how the implementation of lean principles through a kaizen event, without focusing the event on green building objectives, resulted in significant material waste reduction. Then, lessons learned were used to proposed guidelines to integrate lean methodology and green building.

Case Study Findings: lean results and impact on waste reduction

This section summarizes finding from the case study.

1) Company's background- the targeted manufacturer for this case study was a HUD-code housing plant that initiated lean production efforts in 2006. Since this plant was new to lean concepts, the implementation was focused on a particular

department- the wall build department. This manufacturer specializes on HUD-code homes, by offering 47 different models in configurations of single, double or triple wides. Floor plans range from 737 to 2,458 square feet, 2 to 6 bedrooms and 1 to 3 bathrooms. This company offers limited customization by allowing customers to choose from a predetermined set of options (e.g. six wallpaper styles, three Formica countertop colors, three shingle colors, three carpet colors, four exterior vinyl siding colors, two vinyl trim colors and six shutter colors). This strategy increases the variety of required inventory of raw material on the line.

2) Lean implementation approach- before performing the kaizen event, three managers, including the plant manager, participated in a one week lean training off-site. The training covered basic lean concepts and techniques including workplace organization (5S), takt time, continuous flow, pull/kanban replenishment, cellular manufacturing, value stream mapping, process observation analysis, waste discovery, cycle time/bottleneck analysis, line balancing/production leveling, standard work, visual control, kaizen events, etc. The material in this training was tailored to the industrialized housing industry and addressed the challenges of implementing lean in the industry. The intensive training equipped managers with the knowledge to identify waste, to develop new lean approaches to reduce waste, and to implement and sustain change. Then, managers trained workers at the plant, as needed for each kaizen event.

The focus area for the kaizen event was the wall build department which includes the interior walls (partitions) and end walls production. The assembly of walls takes place on four framing tables (three for partition walls and one for end walls). The assembly process includes building the wall frame and installing vinyl covered drywall board (referred to as wallboard). The six different wallpaper styles offered is accomplished by staging six different piles of wallboards on the wall build area. All the framing components and wallboards used are pre-cut to size by supporting workstations in the area. The initial layout of the wall build area is shown in a spaghetti diagram in Figure 2, the wallboard staging areas are highlighted (both raw and pre-cut wallboard).

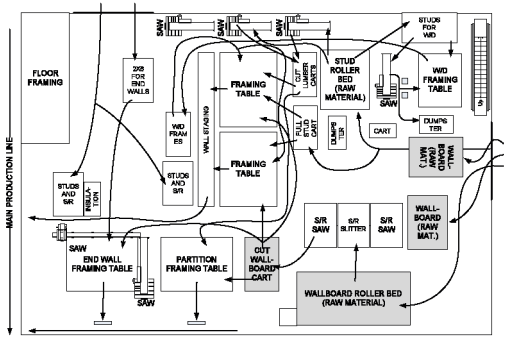


Figure 2. Initial Layout of the Wall Build Area

Identification of Waste. After initial data collection and observations the lean team concluded that the wall build department was a bottleneck to the main line flow and restricted overall plant capacity. The identified source for this issue was the incapability of the wall build area to consistently keep pace with the main production line or takt time (the takt time on the main line was 48 minutes, while the cycle time of the wall build department was 65 minutes). The takt time is a representation of customer demand. The lean team also observed various forms of waste, including labor, equipment and material, in the wall build process. Most of the waste identified was due to the poor layout, which affected the overall performance of the production system, in particular the activities in the wall build department. As evidence from Figure 2, flows within the build area went in every direction, many were lengthy, and they often crossed other flows, creating congestion.

Process Description. This case study focused in the activities related to the wallboard, because results from lean implementation showed great potential for material waste reduction. Before the kaizen event, material handlers delivered the raw material by loading the bundles of wallboard onto the roller bed or on the floor. Workers in charge of prepping the raw material (e.g. supporting activities) retrieved the wallboard from the bundles staged on the roller bed or on the floor nearby. They carried the wallboard to one of two saws or to a slitter. The jig table of the saw/slitter was set at the specified size and wallboard was cut to size, labeled by hand, and placed in an adjacent staging cart. Workers on the framing tables selected a panel to build, obtained the drawing and retrieved framing components from the staging cart. After framing the wall, they then retrieved the pre-cut wallboard from the staging cart, positioned it on the frame and attached it to the frame using an adhesive gun and staples. The completed panels were then staged upright adjacent to the tables awaiting transport to the line, sometimes blocking the access to the wallboard roller bed (Figure 3). Completed walls were moved to the line by two methods, depending on location of the framing table. Panels staged next to the lower tables were transported by bridge crane, while panels staged next to the central tables were dragged along the floor by hand. The second method increased the chances of damaging the installed wallboard.



Figure 3. Wallboard Roller Bed Blocked by a Finished Wall

Key Waste Drivers. The overriding issue with the wallboard activities was the poor layout of the wall build area and improper staging equipment. Although, the area had a wallboard roller bed, which was the designated area to properly stage the raw wallboards, it was not fully used because of limited accessibility. The rollers on the roller bed were designed to pull material from the ends and not from the sides as required by the current layout. In addition to the orientation of the rollers, the second level on the roller bed made the retrieving of the raw material awkward (since required workers to pull material over their heads). Because of these limitations, material handlers often staged bundles of wallboard on the floor in any open space. Further congesting and blocking path ways in the area and increasing chances for material damages. The staging area for the pre-cut wallboard was close to two framing tables, but further form the other two and framers had to travel longer distances and maneuver with load through other workstations to retrieve materials. This situation increased the chances of damaging wallboards. Before conducting the Kaizen event, workers were not aware about how much wallboard was been wasted due to improper staging or awkward maneuvers through the poor layout. This fact was discovered during the Kaizen event.

The Solution. The objective of the wall build-Kaizen event was to rearrange the layout to improve process flow as shown in Figure 4. Some of the layout changes accomplished in the Kaizen event included (Nahmens and Mullens 2009):

- The two central framing tables were moved and aligned with the lower two tables, allowing finished walls to be staged so that they were accessible by the bridge crane that was used to deliver finished walls to the main line and reducing the potential damage of installed wallboard.
- The stud cutting activity was rearranged to achieve a straight-line flow. The lumber storage rack was relocated on the upper wall to provide in-line flow for the material handler during delivery. Two chop saws were turned 90 degrees and relocated directly below the storage racks. New pre-cut component staging bins were located directly adjacent to the framing tables (each bin can hold studs for up to ten panels). Sawyers place cut components directly in the bins, eliminating the need for framers to leave their tables to obtain components.
- Wallboard cutting was rearranged to smooth flow. Raw material was staged in a new rack that held six different colors of wallboard, two different sizes per color. The new rack is easy to replenish from the front and puts less strain on cutters as they pull material and transport it to the cutting tables (e.g. pulling over their heads). The saws/slitter was relocated away from the traffic path, facilitating wallboard handling. A dumpster was placed immediately behind the saws/slitter for scrap. Next to the saws/slitter a staging area for the cut wallboards was designated.
- Half of an existing mezzanine, used for insulation storage, was moved to open up floor space for the improved layout.

- Process documentation was improved for cutting wood components and jigs were provided to simplify cutting and improve quality.
- A new procedure and labeling system was developed to organize pre-cut materials in the wood staging bins at the framing tables. The procedure allows everyone in the area to visually monitor production performance at each table.
- Area supervision was trained to monitor the status of each table and the main production line and manage activities in the area to minimize disruptions to main line flow.

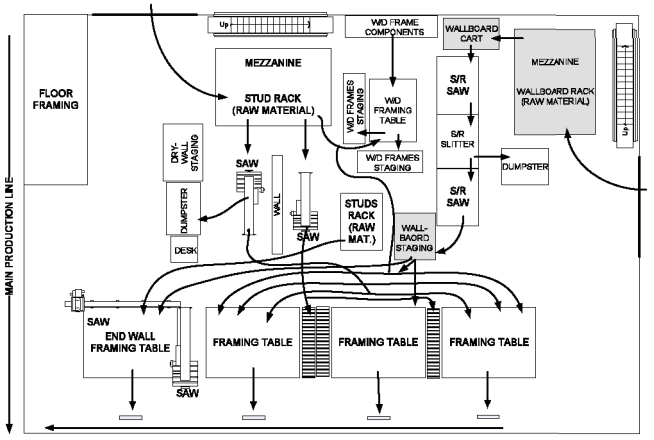


Figure 4. Improved Layout of Wall Build Area (after Kaizen Event)

3) Lean implementation results- the kaizen event improved the overall wall build department's efficiency allowing the on time delivery to the main production line while reducing the workforce from 9 to 6.5 people (labor waste), and reducing space required for the operation by 12% (equipment waste) and reducing wallboard damaged by 10% (material waste). The plant invested $25,786 in labor and materials for the kaizen event, which paid for itself in less than four months as annual labor savings amounted to $73,000.
4) Effects of lean implementation on waste reduction- although the focus of the Kaizen event was not the reduction of resource consumption in the production of walls. A by-product of this lean implementation was an impressive reduction of 10% of wallboard (previously being wasted due to improper staging or awkward maneuvers through the poor layout). Thus, improving the process flow in the wall build department, made this process more resource-efficient throughout the construction stage. The use of proper stating material and the layout improvement prevents raw material damage. In the original layout, finished walls were exposed to potential damage when hand carried to the main line through a cluttered and undefined traffic path. In the improved process, the wallboard defect rate was reduced by enforcing the use of racks to stage the boards and the use of the crane to convey finished walls. The case study results suggested that good concepts for

lean (e.g., efficient continuous flow, effective pull system, workload leveling, defect-free processes, standard tasks, good visual controls, and reliable technology) were also good concepts for material waste reduction. As a whole, the implementation of lean strategies were shown to increase efficiency and reduce variability of building operations, concurrently resulting in material waste reduction a key objective of green construction.

Guidelines: Lean and Green Building

Findings from the case study are summarized in the following set of guidelines to integrate lean construction methodology and green building, while minimizing material waste.

1) Move related equipment and materials closer together. Utilize straight line, L or U-shaped flows, to encourage efficient movement of people and materials. From a lean perspective, this reduces travel waste such as excessive travel time, and congestion delay. From a green building perspective, it reduces the possibilities of related damage of raw material, work in process and completed components. This strategy can be used in all the departments across the plant.
2) Designate and label each area within the production floor, forcing the material handler to stack bundles of raw material in the designated rack or staging area, since there is no unused space - all space is assigned to other activities or designated as traffic paths. From a lean perspective, this facilitates the process flow, standardizes the process and generates a lean culture among workers. From a green building perspective, ensures sustainability of the green improvement gains in the process related to waste reduction from the kaizen event, and minimizes wasted spaces.
3) Use proper staging equipment that has easy access to replenish and retrieve material from, putting less strain on workers. From a lean perspective, proper stating equipment makes the process more efficient. From a green building perspective, reduces the possibilities of damage of material due to awkward maneuvers (e.g. pulling over their heads or against rollers) thus reducing rework waste.

Conclusions

The transition to a sustainable society is not a trivial problem but rather a complex endeavor. The construction process and the built environment represents a challenge in this transition, which is likely to intensify given the increasing trends in population and the aging infrastructures around the world. This paper explores the applicability of lean strategies in the housing industry aiming to reduce material waste and encouraging resource efficient processes. In general, there are some benefits to be realized from the use of some lean principles as an approach to lessen the environmental impact of construction activities. These results reflect the similarities of both green building and lean production as far as their goal to reach resource efficient operations- reducing waste. Environmental factors should be an integral part of how business is conducted, not an afterthought or an add-in. Work processes are inherently environmentally friendly or hazardous for the environment according to the environmental hazards present in each step required to complete the construction

process. By carefully planning processes to minimize environmental impact, building processes can be made greener. In order to transition to a true sustainable society, requires designers and builders to understand the problem and modify their construction processes and business strategies. Only in this way current building process can be improve, and our society can head towards a sustainable future.

References

Allen, E. and Iano, J. (2004). "Fundamentals of Building Construction, Materials and Methods". Fourth Edition, Publisher John Wiley & Sons Inc, New York, NY.

Bruntland, G. (1987). "Our Common Future: The World Commission on Environment and Development". Oxford, Oxford University Press.

Building Science (2006). "BSD-005: Green Building and Sustainability", last updated 2006/10/27. Retrieved August 21, 2008, from BuildingScience.com

Carlson, D.(1991). "Automated Builder: Dictionary/Encyclopedia of Industrialized Housing". Automated Builder Magazine, Publications Division, CMN Associates, Inc., Carpinteria, CA.

Chatterjee, B. (2008). "Applying Lean Kaizen: A catalyst for organization change". Pharmaceutical Processing. Feb2008, Vol. 23 Issue 2, p10-14.

Horvath, A. (2004). "Construction Materials and the Environment". Annual Review of Environment and Resources. Vol. 29, pp. 181-204.

Koskela, L. (1993). "Lean production in construction". Proceedings of the 10th ISARC, Houston, Texas, May 24-26, 47-54.

Nahmens, I. (2007). "Mass customization strategies and their relationship to lean production in the homebuilding industry". Unpublished doctoral dissertation, University of Central Florida.

Nahmens, I. and Mullens, M. (2009). "The Impact of Product Choice on Lean homebuilding" Construction Innovation Journal, January 2009, Volume 9, Issue 1.

Ohno, T. (1988). "Toyota Production System", Productivity Press.

Salem, O. and Zimmer, E. (2005). "Application of lean manufacturing principles to construction". Lean Construction Journal, Volume 2, Number 2.

U.S. Environmental Protection Agency (2003)."Lean Manufacturing and Environment. http://www.epa.gov/lean/performance/index.htm (Last updated on Tuesday, March 4th, 2008).

U.S. Environmental Protection Agency (2004). "Buildings and the Environment: A Statistical Summary Compiled by: U.S. Environmental Protection Agency Green Building Workgroup". December 20, 2004.

U.S. Environmental Protection Agency (2008). "Lean in Government Starter Kit". Last updated on Wednesday, April 16th, 2008. http://www.epa.gov/lean/toolkit/LeanGovtKitFinal.pdf (Retrieved August 21, 2008).

Womack, J.P. (2005). "Lean Consumption". Harvard Business Review, March 2005.

Womack, J.P. and Jones, D.T. (1996). "Lean Thinking: Banish Waste and Create Wealth in Your Corporation". Simon & Shuster: New York, NY.

Wortman, R. (2007). "Modular Homes Lead Industry Green Building Efforts". Ezine Articles, submitted October 19, 2007. <http://EzineArticles.com> (Retrieved August 21, 2008).

PROGRESS MONITORING OF CONSTRUCTION PROJECTS USING NEURAL NETWORKS PATTERN RECOGNITION

Ashraf Elazouni[1] and Osama Abdel-Wahhab[2]

Abstract

The traditional monitoring practice involves collecting actual quantity data, and comparing against a benchmark which represents the relevant planned data. The encountered well-known problem in monitoring is that the quality of the collected data is often subjected to great variation due to the variation in the reporting skills as well as the willingness to record data accurately. A potential technique to circumvent this problem is to conduct the comparison against multiple possible outcomes rather than a single-valued benchmark. The main objective of this research is to utilize the Pattern Recognition (PR) techniques to classify the work planned at specified cut-off dates during the planning stage and use the classification to monitor and evaluate the progress during the construction stage. The PR technique generalizes a virtual benchmark to represent the whole project based on multiple possible outcomes generated at a given cut-off date. The generalization feature offers a potential tool to overcome the problem of variation in the quality of data collected. Patterns are constructed to encode work of the project at different cut-off dates. Finally, the PR concept and technique proved its robustness to monitor and evaluate progress of construction projects based on the technique of Critical Path Method (CPM).

Introduction

Time management is a basic function of the system of construction project management. Time management constitutes project planning and project control. A project plan is devised to provide time guidance for the expeditious accomplishment of the project. During the construction phase of the project, project management controls site operations by establishing a progress monitoring and information feedback procedures. Current practices of progress monitoring and evaluation involve the use of the superintendent's daily site reports and the project manager's monthly progress reports to describe the quantities of completed activities. Project monitoring

[1]Ashraf Elazouni, Construction Eng and Management Dept., King Fahd University of Petroleum & Minerals, P.O. Box 346, Dhahran 31261, Saudi Arabia, Ph. +966 03-860-3312, Fax +966 03-860-4019, e-mail: elazouni@kfupm.edu.sa.

[2]Osama Abdel-Wahhab, Electrical Eng. Dept, University of Hail, P.O. Box 2440, Hail, Saudi Arabia. Ph. +966 06-531-0082(Ext. 120), e-mail: osama@uoh.edu.sa.

involves the determination of work quantities put into place and the feedback of this information in a format suitable for direct comparison with the plan. Project monitoring is performed at regular intervals and at a predetermined cut-off dates. Based on the fed back data, the whole situation of the project is analyzed and consequently corrective actions are suggested to expedite lagging activities.

One objective of this research is to design and construct patterns that are being mapped to CPM schedules to describe the work planned during the planning stage as well as the work accomplished during construction stage. Patterns lend themselves well for manipulation by computer programs. The second objective is to employ the neural network pattern recognition techniques to; classify the work planned at the predetermined cut-off dates during the planning stage using multiple possible patterns; and recognize the week that corresponds to the input patterns which represents the actual work accomplishments at a given cut-off dates during the construction stage.

Previous research

Several studies were reported in the literature related to computer-aided techniques that can be used for viewing site conditions and progress monitoring of construction projects. Hiroshi and Nobuoh (1993) described a filing system of construction pictures and its integration with a database. Abeid et. al. (2003) described the development and implementation of an automated real-time monitoring system for construction project programmed in a Delphi Environment. Riley and Whitesides (1999) conducted a study that assessed the feasibility, potentialities and best application for the implementation of digital image photography in the building design and construction process. Kubicki et al. (2004) focused on the use of building construction digital imagery as a computer-aided communication tool for improving coordination between the different actors involved in progress monitoring. Abd Majid et. al. (2004) discussed the development of a conceptual integrated model that acts as a tool to monitor and evaluate the physical progress of a construction project at periodic intervals. The model integrates the 2D digital images captured from small-detail concrete structural elements at construction sites, the as-built AutoCAD drawings of these elements, and the standard scheduling tools such as Microsoft Project. Memon et. al. (2005) discussed a Digitalizing Construction Monitoring (DCM) model which integrates 3D CAD drawings and digital images to document as-built construction schedules.

Other studies were recently reported in the literature related to techniques that could be used for progress monitoring and evaluating performance of construction projects. Barraza et. al. (2000) used a stochastic S-curve as an alternative to using the deterministic S-curve technique. Stochastic S-curves provide probability distributions for expected cost and duration for a given percentage of work completed. Monitoring project performance is performed by comparing the most likely budget and duration values, obtained from respective probability distributions for actual progress, with the project's actual data and cumulative cost. Cheng and Chen (2002) reported a study that focuses on developing an automated schedule monitoring system for precast

building construction. The system, which is called ArcSched, is composed of a Geographic Information System (GIS) integrated with a database management system. Through systematic monitoring of the construction process and representation of the erection progress in graphics and colors, the scheduled components for erection are repetitively tracked. Construction progress is monitored through identifying the differences between the planned schedule and the real-time schedule. Nassar et. al. (2005) presented a statistical approach, namely Weibull analysis, that can be used in conjunction with the Earned Value Method to evaluate stochastically the schedule performance of construction projects. Poku and Arditi (2006) developed a system called PMS-GIS (Progress Monitoring System with Geographical Information System) to represent construction progress not only in terms of a CPM schedule but also in terms of a graphical representation of the construction that is synchronized with the work schedule.

It became obvious by surveying the previous research that, utilizing pattern recognition concept and techniques in monitoring and evaluating the progress of construction projects is a novel approach in project management. Recently, Elazouni and Abdel-Wahhab (2007) developed a methodology to monitor the number of off-site produced (OSP) units of concrete structures using pattern recognition technique. Due to numerous inevitable factors, the number of off-site produced (OSP) units of concrete structures being erected a day is generally not fixed but varies appreciably. The methodology utilizes PR to classify the work accomplishments achieved at predetermined cut-off dates. During planning stage, a number of patterns are prepared at the cut-off dates and used to train the Neural Network (NN). Thus, the evaluation of the completed work at a certain cut-off date is performed by benchmarking against multiple possible outcomes which is more meaningful than benchmarking against only a single outcome. During construction stage, a pattern is prepared to describe the work accomplishment at a given cut-off date and entered to the trained NN. The NN will declare a date for the input pattern. Comparing the declared date to the actual cut-off date of the input pattern will indicate the status of progress. The results were such that the developed NN could recognize patterns with an error rate of only 3.6%. The study proved that the concept and technique of PR offers a very effective and robust approach to monitor and evaluate the progress of construction projects.

Methodology

During the planning phase of the project, cut-off dates separating periods at which the project will be regularly monitored during construction are specified. Normally, a monitoring period, typically a week, is determined when there is a need to describe a new stage of the project marked by the addition of an appreciable amount of work relative to the previous monitoring period. Patterns are designed and used to describe the work accomplishments of the particular project. A pattern is basically a matrix with appropriate numbers of rows and columns which can be used conveniently to map the CPM schedule of the project. The project work accomplishments at any time can be represented by filling in the appropriate cells of the schemes with 0-1 entries. As time goes on, the number of cells with entries of ones increases to indicate the extra work.

During the planning stage of the project, a number of patterns are generated for the project by assigning different start times of the project activities. The start times are selected randomly within the range of the early and late start times taking activities' sequence in consideration. Then, the completed patterns are curtailed at the cut-off dates to produce as many patterns as the number of the cut-off dates. The variation between the generated patterns at a given cut-off date is basically due to the selected values of the start times. The set of patterns at a given cut-off date represent possible outcomes of the actual accomplishment at this particular cut-off date. The sets of patterns at all the cut-off dates along with the corresponding weeks constitute the input patterns to the NN pattern recognition model. Some of the generated patterns are used for training the NN and the remaining patterns are kept for testing the trained NN.

During the construction stage of the project, the project monitoring is pursued regularly at the same cut-off dates specified during the planning stage. At any desired cut-off date, a pattern is prepared to describe the actual work accomplishments. This involves determining the actual start times of activities and measuring the work accomplishments already put into place up to the cut-off date. This pattern which represents the status of the project at the particular cut-off date is introduced as an input pattern to the trained NN model. The trained NN model will declare the week that this input pattern tends to converge to its patterns. Comparing the date of the declared week to the cut-off date of the input pattern will indicate whether the actual progress is ahead or behind. Thus, the pattern recognition technique automatically implements the task of project monitoring and evaluation. A detailed implementation of the outlined methodology is demonstrated in the application section below.

Application

Figures 1 and 2 show the CPM network and the corresponding pattern respectively of an example project of 25 activities. The pattern in figure 2 is basically a matrix of 25 rows and 32 columns to indicate the numbers of activities and working days respectively. The appropriate cells of the matrix are filled in with "one" entries knowing the start times and durations of the activities. The remaining cells of the matrix are filled in with "zero" entries. Thus, the matrix filled with 0-1 entries in figure 2 constitutes a pattern that represents the CPM schedule of the whole project and can be manipulated by computer programs. The cut-off dates of 5-day interval are indicated in heavy vertical lines in Figure 2. Patterns at a given cut-off date can be easily produced by curtailing the right-hand part of the pattern in figure 2.

Similarly, additional patterns can be constructed at each cut-off date. The patterns are generated by randomly assigning values to the activities' start times within the range of the early start and late start values maintaining the sequence of activities. Figure 3 shows ten additional patterns of the CPM network at 32 days with shaded areas indicating cells with entries of "ones". Confining the start times of activities to a value between the early and late start times ensures that these patterns represent multiple possible patterns which will lead to the same project duration.

Thus, the variation between the generated patterns at a given cut-off date is basically due to the variation of the start times of the activities. Ten patterns at a given cut-off date can be produced by curtailing the right-hand side of the patterns. The sets of random patterns at all the specified cut-off dates along with the corresponding weeks constitute the input to feed to the NN pattern recognition model.

Implementation

The NN was trained using the algorithm developed by Abdel-Wahhab and Sid-Ahmed (1997). This algorithm proved to be faster and more stable than other algorithms presented in the literature. The set of data for training and testing the NN patterns constitutes 7 cut-off dates each has 10 random patterns with a total of 70 patterns representing the input patterns. Associated with each input pattern there exits an output pattern of a vector of 7 entries indicating entry of "one" for the cut-off date

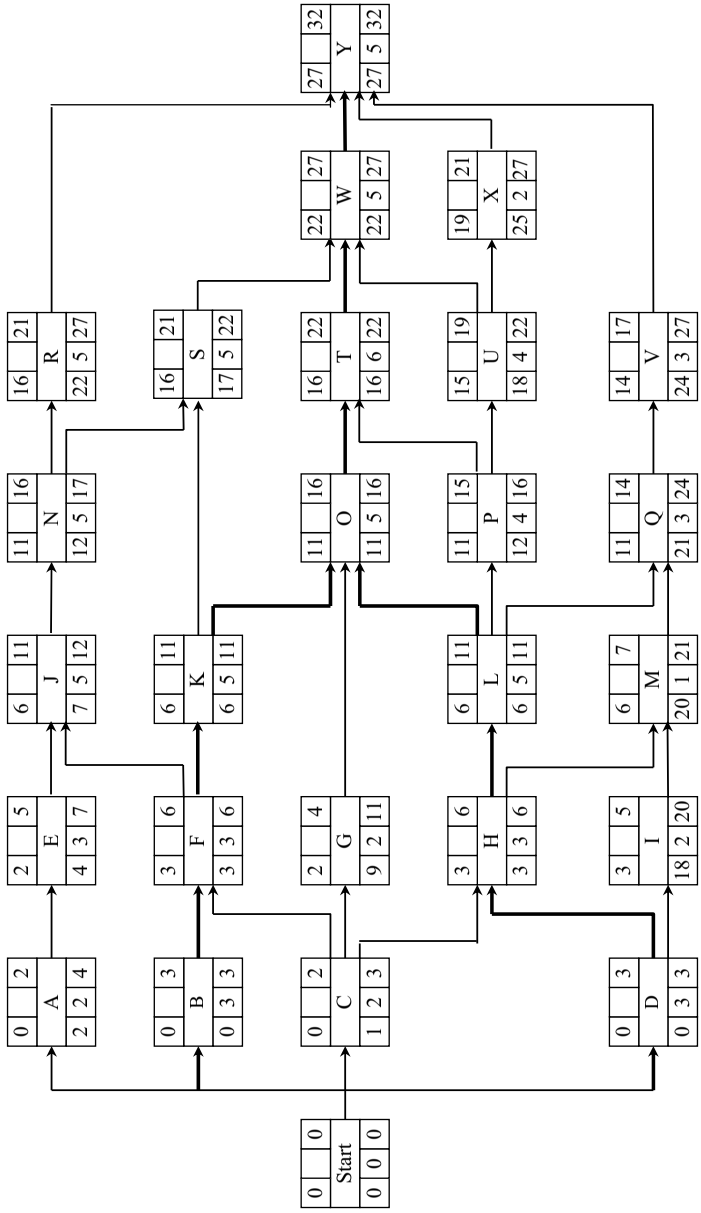


Figure 1: CPM network of an example project of 25 activities.

Days►	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Activity▼	Week 1					Week 2					Week 3					Week 4					Week 5					Week 6					Week 7	
A	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
U	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
X	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1

Figure 2: Pattern of the example project of 25 activities.

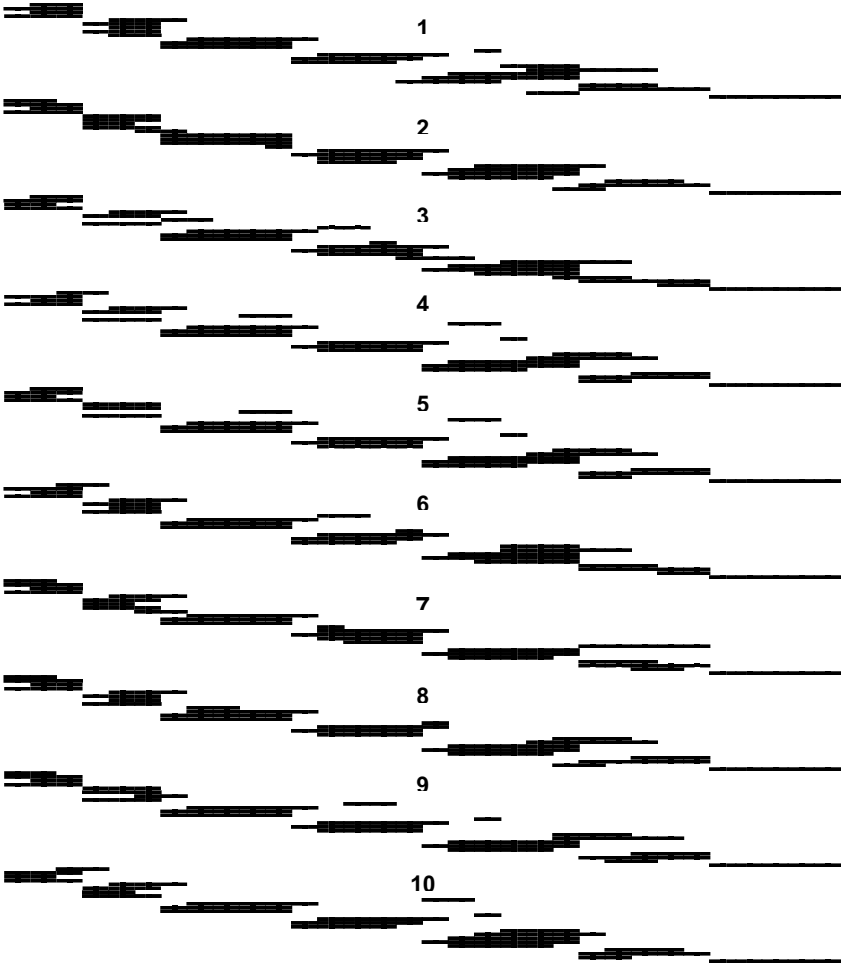


Figure 3: Ten additional patterns of the example project at 32 days.

of the pattern and "zero" for the entries of the other 6 weeks. The input pattern to the NN is a vector 800 elements representing entries of 32 columns and 25 rows and the output represents a vector of seven elements of the project cut-off dates.

The NN was configured by changing the number of hidden layers and the number of neurons in each hidden layer. It was observed that the best performance

was obtained at a configuration of one hidden layer containing ten neurons. The NN was trained on pattern groups 1 to 7. The 7 training data were split further into two pattern groups, the first 5 pattern groups and the remaining 2 pattern groups. The individual patterns of the 5 pattern groups were used for updating the network weights and biases and were entered randomly to the neural network. The remaining 2 pattern groups were used for validation purpose. The validation process is a stopping criterion such that when the recognition error increases, the training session is stopped, and the weights and biases at the minimum value of error are returned. This method, which is called cross validation, gives the ability to monitor the generalization performance of the network and prevent the network from over-fitting the training data.

The trained NN was tested using pattern groups 8 to 10 which were not introduced to the NN during the training session. When a particular test pattern is entered to the trained network, the recognized cut-off date is the one exhibiting the highest output among the seven cut-off dates. The results are presented in Table 1 which indicates that the patterns of pattern groups 8 till 10 were all recognized correctly. Generally, the NN could correctly recognize 21 members out of 21 with absolutely no recognition error. This result indicates that the proposed PR approach proved its effectiveness as a progress monitoring and evaluation technique for construction projects.

Table 1: Pattern recognitions of the three test pattern groups.

Cut-off date	Test Patterns		
	Pattern 8	**Pattern 9**	**Pattern 10**
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7

Benefits of using PR technique

The collection of actual data in construction sites is prone to high degree of imprecision. Russell and Fayek (1994) noted that the issue of detection in the field contains a large extent of uncertainty and inconsistency. They imputed this problem to the considerable variance in levels of education and experience as well as attitudes toward recording daily site information by field personnel. Personnel responsible for recording daily site information range from experienced and educated engineers who are willing to accurately document work progress and productivity to inexperienced and uneducated personnel who struggle hard to document daily site information. Russell and Fayek (1994) noted that the attitude of personnel is either to align

themselves with the field or the office. Those who are pro-field personnel tend to avoid paperwork. In addition, the detection of work progress by general contractor's personnel can be biased against the subcontractors.

Another problematic attitude of field personnel is to conceal the slow progress of some activities to appear in good shape. Knowing that the actual data will be compared directly against planned data on an activity-by-activity basis, the personnel reporting actual progress tends to covert the bad performance of stumbling activities by generously reporting the actual progress. They speculate that the problems are not really serious and some remedial actions upon putting in action will definitely speed up progress and produce better results by the subsequent cut-off date. Another reason to conceal slow progress is that being evaluated on an activity-by-activity basis and not on the holistic project performance, the bad performance of stumbling activities will camouflage the outstanding performance they accomplished in some other activities. All these problems result in a great deal of variation in the quality of information collected in the field.

The process of traditional monitoring which compares the actual collected data of individual activities against single-valued benchmarks often results in great variation in the quality of data collected due to reporting skills as well as willingness to record accurately. The generalization feature that the NN brings about offers a potential environment to overcome this problem. The PR technique generalizes a virtual benchmark to represent the whole project based on multiple possible outcomes generated at each cut-off date. The merits that the generalized benchmark offers include: The effect of the imprecision in data collection, which happens due to either the lack of experience or the nature of the work which makes it difficult to figure out the accurate amount of completed work, on the evaluation of the status of activities and the whole project is significantly diminished; The impetus for personnel to inaccurately report data on-purpose is entirely negated as actual progress is being evaluated against a virtual benchmark; A fair overall evaluation of the project considering both slow-progressed and well-progressed activities is presented to the field personnel while keeping the single-valued benchmarks of the individual activities exclusively to project managers to analyze situations and make decisions.

Conclusions

The objective of this study was to investigate the utilization of the concept and technique of pattern recognition to monitor and evaluate progress of the CPM schedules. The results were such that the NN could correctly recognize 21 members out of 21 with no recognition error. This result indicates that the concept and technique of pattern recognition proved effectiveness and robustness to monitor and evaluate the progress of construction projects.

Acknowlegment

This research was funded by Fast Track research grant No. SB080011. The authors would like to thank King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia, for providing various facilities necessary to conduct this research.

References

Abd Majid, M. Z., Memon, Z. A., and Mustaffar, M. (2004). "Conceptual Digital Monitoring Model for Evaluating the Progress of Work." Proc., CONVR 2004: Conference on Construction Applications of Virtual Reality, Lisbon, Portugal.161-166.

Abdel-Wahhab, O., and Sid-Ahmed, M. A. (1997). "A New Scheme for Training Feed-Forward Neural Networks." Pattern Recognition, 30(3), 519-524.

Abeid, J., Allouche, E., Arditi, D., and Hayman, M. (2003). "PHOTO-NET II: A Computer Based Monitoring System Applied to Project Management." Automation in Construction, 12(5), 603-616.

Barraza, G. A., Back, E., and Mata, F. (2000). "Probabilistic Monitoring of Project Performance Using SS-Curves." Journal of Construction Engineering and Management, 126(2), 142-148.

Blismas, N., Pasquire, C., and Gibb, A. (2006). "Benefit Evaluation for Off-site Production in Construction." Construction Management and Economics, 24, 121-130.

Cheng, M. and Chen, J. (2002). "Integrating Barcode and GIS for Monitoring Construction Progress." Automation in Construction, 11(1), 23-33.

Elazouni, A., Abdel-Wahhab, O., (2007). "Progress Monitoring of Erection of Off-Site Produced Units Using Pattern Recognition." Proc., Construction Management and Economics 25 Conference, University of Reading, Reading, UK.

Hiroshi, N., and Nobuoh, H. (1993). "Filing of Construction Photos Linked with Database." Proc., the 5th International Conference on Computing in Civil and Building Engineering, ASCE, Anaheim, California, 718-721.

Kubicki, S., Halin, G., and Bignon, J. C. (2004). "Assistance to Building Construction Coordination by Image." Proc., ECPPM Conference, Istanbul, Turkey.

Memon, Z. A., Abd.Majid, M. Z., and Mustaffar, M. (2005). "An automatic project Progress Monitoring Model by Integrating Auto CAD and Digital Photos." Proc., The International Conference on Computing in Civil Engineering, ASCE, 1605-1617.

Nassar, K. M., Gunnarsson H. G., and Hegab, M. Y. (2005). "Using Weibull Analysis for Evaluation of Cost and Schedule Performance." Journal of Construction Engineering and Management, 131(12), 1257-1262.

Poku, S. E., and Arditi, D. (2006). "Construction Scheduling and Progress Control Using Geographical Information Systems." Journal of Computing in Civil Engineering, 20(5), 351-360.

Riley, D., and Whitesides, J. (1999). "Implementing Digital Image Photography in the Building Industry." Journal of Construction Education, 4(2) 162-174.

Russell, A., and Fayek, A., (1994). "Automated Corective Action Selection Assistant." Journal of Construction Engineering and Management, 120(1), 11-33.

MATERIAL SELECTION IN BUILDING CONSTRUCTION USING OPTIMAL SCORING METHOD (OSM)

Jorge A. Sefair[†], Daniel Castro-Lacouture*, and Andres L. Medaglia[†]

* Building Construction Program, College of Architecture, Georgia Institute of Technology, 280 Ferst Drive, 1st Floor, Atlanta, GA 30332, USA. daniel.castro@coa.gatech.edu
[†]Centro de Optimización y Probabilidad Aplicada (COPA), Departamento de Ingeniería Industrial, Universidad de los Andes, Bogotá D.C., Colombia.
{j-sefair, amedagli}@uniandes.edu.co

Abstract

Trying to choose the best-performance materials is a complex task due to the vast set of alternatives. Likewise, multiple criteria such as environmental impact, design suitability, and cost are often considered by the purchasing agent when evaluating materials. Moreover, it is often the case that these criteria present tradeoffs making the decision's complexity even higher. Thus, considering that buildings have multiple systems with their own material selection process, this paper proposes the application of a systematic and efficient method to support this process. The proposed method ranks candidate materials using multiple criteria, allowing decision makers to easily include their preferences. A computational experiment based on data available in the literature is presented to demonstrate its use in the construction field.

1. Introduction

Material selection is a strategic process in building companies where they choose among a vast set of alternatives the best-performance materials under multiple (conflicting) criteria. It is well known that this process is the most significant topic in a building study (San-Jose et al. 2004), among other reasons, because materials account for a considerable portion of the building total cost (Zavadskas et al. 2005). Moreover, construction materials have a significant impact on the environment, contributing to greenhouse emissions through their exploitation and transportation (Yudelson 2008). Depending on the type of material, the indoor environmental quality of a building can be influenced, thus affecting the health of their occupants (Ries et al. 2006). Materials can also provide safety and are a fundamental part of the building design. As such, mechanical (e.g., specific strength, elasticity modulus), chemical (e.g., corrosion resistance, oxidation resistance), and external properties (e.g., color, texture) have to be considered in the material selection process (Ashby 2000; Farag 2002).

The material selection process is a complex task in which several evaluation criteria are considered (Giudice et al. 2005; Jee and Kang 2000). Those evaluation criteria are often in conflict, meaning that if materials are selected to optimize one criterion that will be at the expense of sacrificing the other criteria (Ashby 2000). Hardly ever one material is the best for all the criteria. Additionally, the number of candidate materials also increases the complexity of the decision process (Jalham 2006). According to Farag (2002), it is estimated that more than 40,000 metallic alloys and a similar number of plastics, ceramics, composites, glasses, and other materials, are available for use. Such a large number of materials requires the use of computational tools that facilitates the material selection process (Fernandez 2004).

The material selection problem has been extensively treated in the literature through many approaches (Charles and Crane 1996). The more extended method is the use of Ashby charts (Ashby 2005) in which two evaluation criteria are plotted in a scatter chart (e.g., density vs. Young's modulus, cost vs. strength). Each region in the chart suggests a family of materials satisfying a given level of each criterion. Although this method is very useful for an initial screening of materials, it may not be easily applied to problems with more than two evaluation criteria (Chan and Tong 2007). Moreover, it is not flexible to include additional criteria to the ones already preestablished in the available charts (Holloway 1998).

The weighted sum method is a common technique also applied to the material selection problem (Farag 2002; Sirisalee et al. 2004; Ashby 2000). Despite its simplicity, this method requires a consensus from the decision makers to determine the more convenient weights, which most of the time is difficult and full of subjectivity.

The outranking methods have also been applied to the material selection problem. Rao and Davim (2008) proposed a combination of the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) with Analytic Hierarchy Process (AHP) to select materials. However, TOPSIS and other outranking methods such as ELECTRE (Vinckle 1999; Shanian and Savadogo 2004) and the AHP method (Saaty 1994), require a huge number of pair-wise comparisons that become those methods impractical to problems with a large number of alternatives and criteria often found in the construction arena.

Another alternative approaches for material selection include the use of multiobjective optimization (Ashby 2000; Ashby 2005), ranking methods (Jee and Kang 2000; Chan and Tong 2007), index-based methods (Holloway 1998; Giudice et al. 2005; Rao 2006; Alexopolus 2007), and other quantitative methods such as cost-benefit analysis (Farag 2002). However, these methods also require a large amount of information, fail to easily elicit decision maker preferences, and do not scale well in large instances often found in a practical setting.

This work applies the Optimal Scoring Method (OSM) (Sefair et al. 2008a; Sefair et al. 2008b), which is an optimization-based approach to rank alternatives. OSM provides a single score that is used to rank materials, according to multiple evaluation criteria. The application of this method allows the user to deal with real-sized problems in which a large number of criteria is used to rank many candidate materials as it is often the case in the construction market. In addition, the OSM allows decision makers to easily incorporate their preferences of the evaluation criteria. To test the

stability of the ranking after changes in the input parameters, we conducted a sensitivity analysis on a data set from the literature.

2. Optimal Scoring Method (OSM)

The method to rank the candidate materials is the Optimal Scoring Method (OSM) (Sefair et al. 2008a; Sefair et al. 2008b). OSM allows decision makers to rank a set of alternatives I by using a set of evaluation criteria J. Additionally, a set of rules R can be expressed to reflect the decision maker's preferences towards the importance of the evaluation criteria. Parameter vectors $\mathbf{l} \triangleq [l_j]$ and $\mathbf{u} \triangleq [u_j]$ specify minimum and maximum bounds on the importance for each evaluation criterion $j \in J$. The matrix of realizations of the evaluation criteria is defined by $\mathbf{D} \triangleq [d_{ij} \in \Re]$ ($i \in I, j \in J$) where d_{ij} refers to the assessment of criteria j for material i. To convert the evaluation criteria to commensurable units, a matrix of normalized values is defined by $\overline{\mathbf{D}} \triangleq [\overline{d}_{ij} \in \Re]$ ($i \in I, j \in J$). OSM computes a vector of dimensionless scores $\mathbf{z} \triangleq [z_i]$ (one score per material) by determining the best weights for each criterion ($\mathbf{w} \triangleq [w_j]$). Those weights (between 0 and 100%) can be interpreted as the relative importance of each criterion. If the weight associated to a given criterion is larger than those assigned to the other criteria, then we say that the given criterion is more important for the decision maker.

OSM is used to maximize the individual score of each material. That is, instead of allocating subjective weights prior to the evaluation, OSM allows materials to achieve the maximum possible score, while satisfying a set of rules over the importance of the criteria. Those rules are provided by the decision maker, reflecting his/her decision preferences. For instance, if criteria A, B, C, D, E, and F are considered for material evaluation, a common rule is that criterion A is more important than criterion B, criterion B is more important than criterion C, and so on. A second rule can state that criterion A is at least twice as important as criterion B. Finally, a third rule can express that the aggregated importance of criteria A, B and C, must be higher than the aggregated importance of criteria D, E, and F.

The OSM framework is shown in Figure 1. The data input module, collects information on candidate materials and its properties. In addition, parameters and rules describing decision maker's preferences are to be specified. In the scoring module the data normalization procedure is conducted, assuring criteria commensurability. Normalized data, parameters and rules feed the optimization procedure where the optimal importance (weight) of each criterion and the optimal score for each material are computed. Optimal scores and weights are used in the analysis module where a post-processing or a sensitivity analysis can be conducted. In the post-processing analysis phase optimal scores are used as input for other quantitative techniques such as clustering, multivariate analysis, linear regression, and data envelopment analysis, to enrich the final decision. On the other hand, a sensitivity analysis unveils the ranking robustness due to variations in the decision maker's preferences. After this analysis, OSM supports the final decision about the more suitable materials.

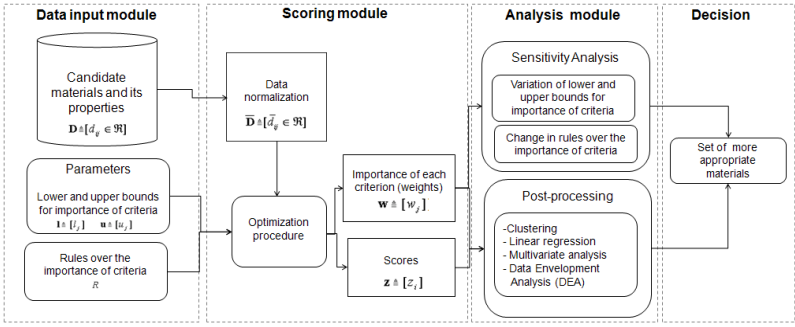


Figure 1. OSM framework

3. Computational experiments

The computational experiment uses a data set with 15 materials and 4 evaluation criteria to select the more appropriate material for a structural component in the form of a hollow cylinder. Table 1 shows the input data as well as the weights used in the weighted sum approach for material selection (Farag, 2002).

Table 1. Candidate materials and assessment for a structural component

Material	Specific strength (*SS*) (MPa)	Specfic Modulus (*SM*) (Gpa)	Corrosion Resistance (*CR*)[a]	Cost Category (*C*)[b]
AISI 1020 (UNS G10200)	35.9	26.9	1	5
AISI 1040 (UNS G10400)	51.3	26.9	1	5
ASTM A242 type 1 (UNS K11510)	42.3	27.2	1	5
AISI 4130 (UNS G41300)	194.9	27.2	4	3
AISI 316 (UNS S31600)	25.6	25.1	4	3
AISI 416 heat treated (UNS S41600)	57.1	28.1	4	3
AISI 431 heat treated (UNA S43100)	71.4	28.1	4	3
AA 6061 T6 (UNS A96061)	101.9	25.8	3	4
AA 2024 T6 (UNS A92024)	141.9	26.1	3	4
AA 2014 T6 (UNS A92014)	148.2	25.8	3	4
AA 7075 T6 (UNS A97075)	180.4	25.9	3	4
Ti-6A1-4V	208.7	27.6	5	1
Epoxy-70% glass fabric	604.8	28	4	2
Epoxy-63% carbon fabric	416.2	66.5	4	1
Epoxy-62% aramid fabric	637.7	27.5	4	1
Weight (w_j)	0.30	0.30	0.15	0.25

Source: Farag (2002)
[a] 5 Excellent, 4 Very good, 3 Good, 2 Fair, 1 Poor
[b] 5 Very inexpensive, 4 Inexpensive, 3 Moderate price, 2 Expensive, 1 Very expensive

To illustrate the use of OSM we assume the decision maker considers the specific strength *(SS)* and the specific modulus *(SM)* as equally important. It is also assumed that *SS* and *SM* criteria are more important than cost (C), which in turn, is more

important than the corrosion resistance criterion (CR). The relative importance (weight) for each evaluation criterion ranges from 0 to 1.

The normalized data and the optimal scores obtained by OSM are shown in Table 2. Given the preferences of the decision maker, the material Epoxy-63% carbon fabric is the more suitable material to build the cylindrical component. In general, Epoxy materials (Epoxy-63% carbon fabric, Epoxy-70% glass fabric, and Epoxy-62% aramid fabric) are ranked first for their good performance concerning specific strength, specific modulus, and corrosion resistance. Nevertheless, they are bad performers in terms of cost because they are very expensive compared to other alternatives.

Table 2. Results of the OSM ranking in the material selection of a structural component

Rank	Material	Specific strength (*SS*) (MPa)[c]	Specfic Modulus (SM) (Gpa)[c]	Corrosion Resistance (*CR*)[a,c]	Cost Category (*C*)[b,c]	Optimal Score (z_i)
1	Epoxy-63% carbon fabric	0.64	1.00	0.75	0.00	0.604
2	Epoxy-70% glass fabric	0.95	0.07	0.75	0.25	0.499
3	Epoxy-62% aramid fabric	1.00	0.06	0.75	0.00	0.449
4	AISI 4130 (UNS G41300)	0.28	0.05	0.75	0.50	0.375
5	AA 7075 T6 (UNS A97075)	0.25	0.02	0.50	0.75	0.366
6	AA 2014 T6 (UNS A92014)	0.20	0.02	0.50	0.75	0.351
7	AA 2024 T6 (UNS A92024)	0.19	0.02	0.50	0.75	0.350
8	AA 6061 T6 (UNS A96061)	0.12	0.02	0.50	0.75	0.331
9	AISI 431 heat treated (UNA S43100)	0.07	0.07	0.75	0.50	0.327
10	AISI 416 heat treated (UNS S41600)	0.05	0.07	0.75	0.50	0.321
11	Ti-6A1-4V	0.30	0.06	1.00	0.00	0.317
12	AISI 316 (UNS S31600)	0.00	0.00	0.75	0.50	0.288
13	AISI 1040 (UNS G10400)	0.04	0.04	0.00	1.00	0.266
14	ASTM A242 type 1 (UNS K11510)	0.03	0.05	0.00	1.00	0.264
15	AISI 1020 (UNS G10200)	0.02	0.04	0.00	1.00	0.260
	OSM Weight (w_j)	0.27	0.27	0.22	0.24	

[a] A larger value indicates better performance
[b] A larger value indicates a less expensive material
[c] Normalized values

The relevance of the cost in the material selection process is evident in real purchasing scenarios and consequently ubiquitous in the literature. For instance, the cost is reconsidered in a second stage for material evaluation in Farag (2002), concluding that the least expensive choice is the best solution among a set of similar alternatives. Moreover, earlier work concentrates in minimizing cost as an objective (Ashby 2000) or considers cost as a decisive factor in the selection process (Chan and Tong 2007; Giudice et al. 2005; Jee and Kang 2000). Hence, as a second phase, we conducted a sensitivity analysis to evaluate the robustness of the ranking after changes in the importance of cost. Being consistent with the results found in the first phase (see Table 2), but in order to explore a broader range of alternatives, the OSM rules were modified, establishing that the importance of the specific strength (*SS*) and

specific modulus (*SM*) should be the same, yet greater than or equal to the importance of the corrosion resistance (*CR*). In addition, the cost (*C*) is considered more important than corrosion resistance (*CR*). Note, however, that no relation among the importance of criteria *SS*, *SM*, and *C* is established, allowing OSM to assign a higher importance to the cost criteria than to specific strength (*SS*) and specific modulus (*SM*).

The sensitivity analysis was conducted by varying the lower bound for the importance of cost and corrosion resistance (l_C and l_{CR}). By doing so, it is possible to show the impact on the material ranking caused by changes in the minimum importance of the corrosion resistance (l_{CR}) and cost (l_C) criteria. Notice that, any variation in parameter l_{CR} will affect the importance of criteria *SS* and *SM*. A gap factor is included, specifying that the importance of criteria *SS, SM,* and *C,* must be at least 10% greater than the importance of criterion *CR*.

Figure 2 shows the results of the sensitivity analysis. The shaded area in the l_{CR}-l_C plane shows the set of possible combinations of parameters l_{CR} and l_C, satisfying the established rules. For values of l_{CR} between 0.18 and 0.23 and all possible values of l_C, the material Epoxy-63% carbon fabric has the higher score. In the point labeled as A, the parameter l_{CR} takes the value of 0.21 and l_C takes the value of 0.30. The optimal weights provided by OSM under this scenario are $w^*_{CR} = 0.21$, $w^*_{SS} = 0.23$, $w^*_C = 0.32$, and $w^*_{SM} = 0.23$, producing a score of 0.53 for material Epoxy-63% carbon fabric. Likewise, for values of l_{CR} between 0.16 and 0.18, the best ranked material is AA 7075 T6 (UNS A97075); whereas for values of l_{CR} below 0.16 the best material is AISI 1040 (UNS G10400). For those scenarios where the value of l_{CR} is set to zero and regardless of the (possible) values of l_C, materials AISI 1040 (UNS G10400), AISI 1020 (UNS G10200), and ASTM A242 type 1 (UNS K11510) are ranked in the first place with the same score.

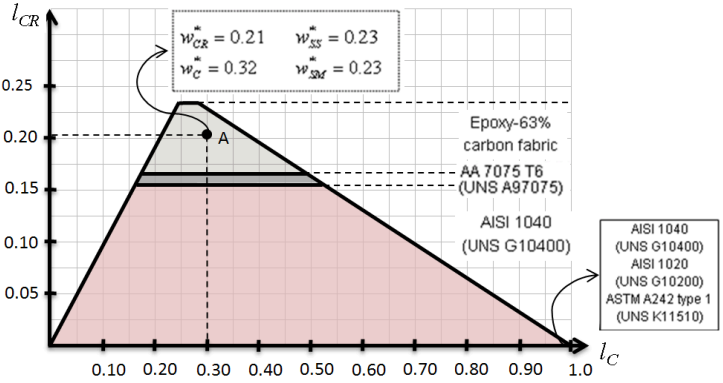


Figure 2. Results of the sensitivity analysis varying importance lower bounds

In conclusion, the results in Figure 2 confirm the expected behavior concerning the ranking of the candidate materials. If the value of parameter l_{CR} increases, then the importance of criterion *CR* increases as well as the importance of criteria *SS* and *SM*. Thus, the best ranked materials are those with good performance in these criteria. In fact, material Epoxy-63% carbon fabric exhibits the highest specific strength (SS). Similarly, when the value of parameter l_C increases, materials with the lower cost are ranked in the first places. For instance, when l_C tends to be 1 then less expensive materials emerge as better alternatives.

4. Concluding remarks

The material selection process is a complex task in the area of building construction given the large number of available materials. In addition, the current construction tendencies require the inclusion of a broader scope of evaluation criteria beyond the traditional ones, such as environmental impact, indoor environmental quality, distance to the supplier, socioeconomic characteristics of the supplier region, among others, increasing even more the complexity of the material selection process.

The proposed application of the optimal scoring method (OSM) provides a single score that can be used to rank materials. Moreover, OSM provides the user with a ranking of materials even in situations where a large number of materials and evaluation criteria are considered. Other alternative techniques require an overwhelming process for data preparation and preference elicitation, while OSM requires a reduced set of input parameters and is computationally efficient (i.e., few seconds for hundreds of materials).

OSM also allows decision makers to easily incorporate their preferences towards the importance of the evaluation criteria through the use of parameters and rules, avoiding pairwise comparisons between materials. Moreover, through OSM decision makers can quickly evaluate the impact on the optimal ranking due to changes in their preferences.

OSM can be combined with other methodologies to consider a broader scope of facts affecting the material selection. Techniques such as clustering analysis, linear regression or multivariate analysis can use the score generated by OSM as input for further analysis.

Finally, the OSM proved to be an easy-to-understand tool that can be applied not only to the material selection problem, but also to other situations in building construction such as material supplier ranking and delivery system ranking, among others.

References

Alexopolus ND. Generation of quality maps to support material selection by exploiting the quality indices concept of cast aluminum alloys. Materials & Design 2007; 28(2):534-543.

Ashby MF. Multi-objective optimization in material design and selection. Acta Materialia 2000; 48(1):359-369.

Ashby MF. Materials Selection in Mechanical Design. 3rd Edition. Elsevier; 2005.

Chan JWK, Tong TKL. Multi-criteria material selections and end-of-life product strategy: Grey relational analysis approach. Materials & Design 2007; 28(5):1539-1546.

Charles J, Crane F. Selection and use of engineering materials. London: Butterworth-Heinemann; 1996.

Farag M. Quantitative methods of materials selection. In: Kutz M (editor). Handbook of materials selection. New York: Wiley; 2002.

Fernandez J. From kaolin to Kevlar: Emerging materials for inventing new architecture. Journal of Architectural Education 2004; 58(1):54-65.

Giudice F, La-Rosa G, Risitano A. Materials selection in the life-cycle design process: a method to integrate mechanical and environmental performances in optimal choice. Materials & Design 2005; 26(1):9-20.

Holloway L. Materials selection for optimal environmental impact in mechanical design. Materials & Design 1998; 19(4):133-143.

Jalham IS. Decision-making integrated information technology (IIT) approach for material selection. International Journal of Computer Applications in Technology 2006; 25(1):65-71.

Jee DH, Kang KJ. A method for optimal material selection aided with decision making theory. Materials & Design 2000; 21(3):199-206.

Rao RV. A material selection model using graph theory and matrix approach. Materials Science and Engineering: A 2006; 431(1-2):248-255.

Rao RV, Davim JP. A decision-making framework model for material selection using a combined multiple attribute decision-making method. The International Journal of Advanced Manufacturing Technology 2008; 35(7-8): 751-760.

Ries R, Bilec M, Gokhan NM, Needy KL. The economic benefits of green buildings: A comprehensive case study. The Engineering Economist 2006; 51(3):259-295.

Saaty TL. Fundamentals of decision making and priority theory with the AHP. Pittsburgh: RWS Publications; 1994.

Sefair JA, Medaglia AL, Cohen M-d. Método de puntaje óptimo (MPO). Working Paper. Departamento de Ingeniería Industrial, Universidad de los Andes, Bogotá, Colombia. 2008a.

Sefair, JA, Medaglia, AL Cohen, M-d. Optimal scoring method: an approximation to ranking with multiple criteria. Talk given at the IIE Annual Conference and Expo, Vancouver, Canada, 2008b.

Shanian A, Savadogo O. A material selection model based on the concept of multiple attribute decision making. Materials & Design 2004; 27(4):329-337.

Sirisalee P, Ashby MF, Parks GT, Clarkson PJ. Multi-criteria material selection in engineering design. Advanced Engineering Materials 2004; 6(1-2):84-92.

Vinckle P. Outranking approach. In: Gal T, Sterwart T, Hanne T (editors). Multicriteria decision making: advances in MCDM models, algorithms, theory, and applications. Boston: Kluwer Academic Publishers; 1999.

Yudelson, J. The green building revolution. Washington, D.C.: Island Press; 2008.

Zavadskas EK, Kaklauskas A, Banaitis, A, Trinkunas V. System for real time support in construction materials selection. International Journal of Strategic Property Management 2005; 9(2):99-109.

DEVELOPMENT OF PROJECT LEVEL ENGINEERING PRODUCTIVITY BENCHMARKING INDEX

Pin-Chao Liao [1], Stephen R. Thomas [2], William J. O'Brien [3], Stephen P. Mulva [4], and Jiukun Dai [5]

[1] University of Texas at Austin, Department of Civil, Architectural, and Environmental Engineering, University Station, C1752, Austin, Texas 78712; PH (512) 232-3051; FAX (512) 499-8101; e-mail: binchao@mail.utexas.edu
[2] Construction Industry Institute, 3925 West Braker Lane (R4500) Austin, Texas 78759-5316; e-mail: sthomas@mail.utexas.edu
[3] University of Texas at Austin, Department of Civil, Architectural, and Environmental Engineering, University Station, C1752, Austin, Texas 78712; e-mail: wjob@mail.utexas.edu
[4] Construction Industry Institute, 3925 West Braker Lane (R4500) Austin, Texas 78759-5316; e-mail: stephen.mulva@engr.utexas.edu
[5] Construction Industry Institute, 3925 West Braker Lane (R4500) Austin, Texas 78759-5316; e-mail: jiukun.dai@engr.utexas.edu

Abstract
Since 2002, the Construction Industry Institute (CII) has been working to develop a standardized Engineering Productivity Metric System (EPMS) for benchmarking purpose. In this system, engineering productivity is defined as a ratio of direct engineering work hours to the engineering outputs as measured by Issued for Construction (IFC) quantities. The EPMS consists of six major engineering disciplines with a number of underlying metrics. Engineering productivity can be accordingly benchmarked at any of these levels; however, there is a lack of project-level engineering productivity. The challenge is that IFC quantities are measured with different units and thus are difficult to roll up to the project level. To overcome this barrier, this study examines three approaches for aggregating engineering productivity metrics to the project level based on 112 heavy industrial projects. The selected project level engineering productivity measurement best summarizes the underlying engineering productivity metrics and provides a macro view of engineering performance. It allows owners and engineering organizations to benchmark engineering productivity at the project level. It also lays the foundation for future engineering productivity analysis and research.

Introduction

Productivity presents how efficiently the major resources are used to produce the outputs. Improving productivity usually leads to competitive advantage and more profit. Therefore, extensive research has been conducted to improve productivity in the construction industry. However, most productivity research has focused on construction productivity and engineering productivity has been rarely studied.

CII undertook the development of the Engineering Productivity Metrics System (EPMS) to support productivity benchmarking and research. The EPMS consists of engineering productivity metrics defined as a ratio of direct work hours to Issued for Construction (IFC) quantities, and productivity data is collected at the discipline level and below. However, there is a lack of a project level engineering productivity measurement (PLEPM) to summarize an overall status of engineering productivity of the discipline or lower level. It's primarily because IFC quantities of the different disciplines are measured by different units. For example, concrete quantity is measured by cubic yard, and structural steel is measured by ton. Accordingly, this paper presents the efforts to develop a PLEPM for benchmarking as requested consistently by the industry.

Background

Engineering productivity is defined as a ratio of input to output. The inputs of engineering may be clearly defined but measuring the outputs is elusive (Sacks and Barak 2008).

Therefore, various engineering productivity measurements have been used in previous research. For example, Thomas (1999) measured engineering productivity using hours per drawing, and Song et al (2003) used hours per designed element (a column or beam) to measure engineering productivity. CII (2001) utilized hours per engineered quantity (e.g. ton of steel or linear foot of pipe) to measure engineering productivity and explored influence factors such as engineering input quality and complexity. The analyses were only based on piping engineering because of data availability. Nevertheless, CII (2001) enumerated several advantages of quantity-based engineering productivity measures: (1) it is directly tied to the engineering activity; (2) it is less subject to manipulation; (3) both the inputs and outputs are already tracked in most current engineering environments; (4) it measures engineering and construction productivity on the same basis; and (5) it focuses attention on the final product rather than intermediate product.

Based on extensive literature review and industry inputs, CII benchmarking program defines engineering productivity metrics as a ratio of direct engineering work hours to IFC quantities in the EPMS (Kim 2007). To reduce the data collection effort and to provide flexibility for engineering productivity benchmarking, the EPMS is organized into a hierarchical structure as shown in Figure 1. Engineering productivity data (both work hours and IFC quantities) can be collected and compared at the major category, sub-category, or element level. In this hierarchy, engineering productivity metrics can be rolled up from the element or sub-category level up to the discipline level, such as total concrete, total steel, and total piping. The EPMS was validated through initial data collection and

preliminary analysis (Kim 2007). However, since the launch of the system, there has been an increasing demand from the industry for a PLEPM which provides managers a macro-view of engineering productivity. Furthermore, the lack of PLEPM inhibited understanding of engineering productivity because the effects of best practices, project performance and engineering productivity are not be able to quantified. Thus, development of PLEPM is imperative.

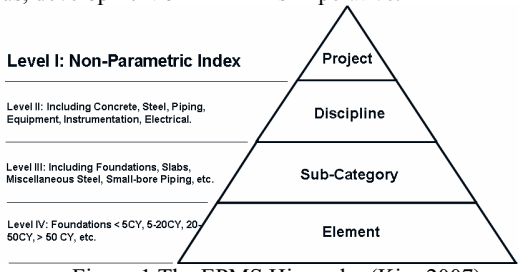


Figure 1 The EPMS Hierarchy (Kim 2007)

The construction industry uses a number of indices to summarize project performance. For example, safety performance can be measured by the Total Recordable Incident Rate (TRIR) and Days Away, Restricted and Transferred Rate (DART). A number of approaches have been used to develop productivity summary indices.

The first approach is based on the Earned-value concept which compares actual performance to expected performance. For example, CII (2004) proposed an engineering productivity measurement model as a ratio of actual work hours to predicted work hours. However, this approach is likely unreliable due to the large standard error of the estimated hours (Kim 2007). Ellis Jr. and Lee (2006) defined a project-level productivity (PLP) index using total work hours divided by equivalent work units (EWU) to monitor multi-discipline daily labor productivity. However, this approach normalized installed quantities without considering their variances. Another approach standardizes underlying metrics and then aggregates them. As to metric standardization, Maloney et al. (1995) transformed variables with different scales into the range of 0 to 1 in order to make comparison across the variables. Furthermore, the z statistic (z-score) is another common method to standardize variables with the consideration of both sample mean and standard deviation (Agresti and Finlay 1999). As to metric aggregation, the weighted-sum of underlying metrics is a common method addressed in previous studies. Ibbs (2005) defined the end-of-project productivity index as change-impacted and change-unimpacted periods weighted by their work hours.

The EPMS Database

CII benchmarking is a member service and traditionally CII members are primarily associated with heavy industry. Therefore, CII's engineering productivity dataset is heavy industry oriented. In the engineering productivity dataset, 112 heavy industrial projects were collected from 2002 to 2007. Figure 2 summarizes the distribution of these projects by various characteristics including respondent type,

project type, project nature, and project size. By respondent type, contractors submitted 82% of the projects. By project type, process projects such as chemical manufacturing facilities or oil refining plants dominate the database. Addition and modernization projects account for 80% and large (>$5MM) projects are approximately 61% of the database.

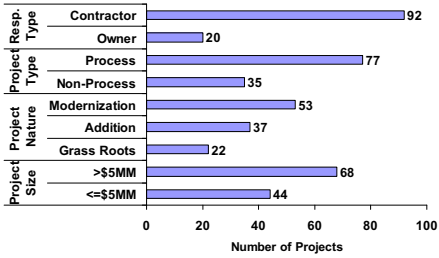


Figure 2 Projects with Engineering Productivity Data by Characteristics

Methodology

Three approaches, the Earned-value method, Z-score method, and Max-min method are examined to construct the PLEPM. Then the developed indices are evaluated regarding how well the indices summarize the underlying metrics.

The Earned-value Method

This method calculates an engineering productivity index as a ratio of total actual work hours to total earned (predicted) work hours for all underling metrics. Predicted hours are equal to norm values for engineering activities multiplied by the IFC quantities. A simplified example with only concrete and steel disciplines is presented in Table 1 to demonstrate the process.

Table 1 Development Process using the Earned-value Method

Disciplines	Work Hours (1)	Quantity (2)	Engineering Productivity (EP)	Average EP for all projects (3)	Baseline work hours (4)
Concrete	3800	8140 (CY)	0.47	4.54 (Hr/CY)	36956
Steel	12800	1650 (Ton)	7.76	9.31 (Hr/Ton)	15362
				Productivity Index EVp (5)	0.32
Calculations	(4)=(2)*(3) (5)=Σ(1)/Σ(4)				

An index value less than one indicates better productivity, since the engineering work took fewer hours than the baseline. Accordingly, for the p^{th} project, the project level engineering productivity index (EV_p) can be calculated with the Earned-value method as Equation 1:

$$EV_p = \frac{\sum_{i=1}^{n}\left(WH_{pi}\right)}{\sum_{i=1}^{n}\left(\overline{P_i} \times Qty_{pi}\right)} \qquad \text{Equation 1}$$

Where

WH_{pi} = the direct work-hours of the i^{th} underlying metric of the p^{th} project

$\overline{P_i}$ = average engineering productivity of the i^{th} underlying metric

Qty_{pi} = the IFC quantity of the i^{th} underlying metric in p^{th} project

The Z-score Method

To improve the normality of the metric distributions, this approach begins by transforming raw engineering productivity metrics with a natural logarithm function before converting them into their z-scores because previous research has verified that productivity metrics are non-normally distributed (Zener 1968). Shapiro-Wilk test results showed that CII engineering productivity metrics in raw scale are non-normal distributed ($p < 0.05$) whereas transformed metrics are normal distributed ($p > 0.05$). Next, the transformed engineering productivity metrics are standardized to z-scores. Lastly, all the standardized underlying engineering productivity metrics are weighted by the work hours to rolled up to a PLEPM. The following example in Table 2 illuminates the index development process using the Z-score method.

The index will range from -3 to 3. A negative value of the Z_p index indicates engineering productivity is better than average. Given the i^{th} underlying engineering productivity metric of the p^{th} project (EP_{pi}), EP'_{pi} represents its natural logarithm transformation. Next, a standardized z-score, Z_{pi}, is shown in Equation 2:

$$Z_{pi} = \frac{EP'_{pi} - \overline{EP'_i}}{\sigma_{EP'_i}} \qquad \text{Equation 2}$$

where

Z_{pi} = z-score of the i^{th} engineering productivity metric in the p^{th} project.

$\overline{EP'_i}$ = mean of natural logarithm transformed engineering productivity of the *i*th underlying metric.

$\sigma_{EP'_i}$ = standard deviation of natural logarithm transformed engineering productivity of the *i*th underlying metric.

Table 2 Development Process using the Z-score Method

Disciplines	Work Hours (1)	IFC Quantity	EP (2)	Transformed EP (3)	Average Transformed EP for all projects (4)	Standard Deviation of Transformed EP for all projects (5)	Z score (6)
Concrete	3800	8140	0.4	-0.76	0.64	1.41	-0.99
Steel	1280	1650	7.7	2.05	1.91	0.85	0.16
						Productivity Index Zp (7)	-0.10
Calculati	(3)=ln(2)						

ons	(6)=[(3)-(4)]/(5) (7)=[Σ Product of (1)*(6)]/[Σ(1)]

Finally, standardized underlying metrics can be aggregated using their work hours as the weights to represent engineering productivity at the project level:

$$Z_p = \frac{\sum_{i=1}^{n}(WH_{pi} \times Z_{pi})}{\sum_{i=1}^{n} WH_{pi}} \quad \text{Equation 3}$$

Where

WH_{pi} = the direct work-hours of the i^{th} underlying metric of the p^{th} project

The Max-min Method

This method standardizes the engineering productivity metrics by using the Max-min approach and then weights the underlying metrics by their work hours. Table 3 demonstrates an example for index construction using the Max-min method for concrete and steel engineering productivity.

Table 3 Development Process using the Max-min Method

Disciplines	Hours (1)	Quantity	EP (2)	Min. EP (3)	Max. EP (4)	Weighted Score (5)
Concrete	3800	8140	0.47	0.1	10	14080
Steel	12800	1650	7.76	2	25	320422
Productivity Index Mp (6)						20%
Calculations	(5)=[(2)-(3)]/[(4)-(3)]*(1)*100% (6)=[Σ(5)]/[Σ(1)]					

The index will ranges from 0% to 100%. The smaller the index value the better productivity, since it is closer to the project with best engineering productivity. Therefore, for a given p^{th} project, EP_{pi} represents engineering productivity of the i^{th} underlying metric and N_{pi} represents its normalized score:

$$N_{pi} = \frac{EP_{pi} - Min(EP_i)}{Max(EP_i) - Min(EP_i)} \times 100\% \quad \text{Equation 4}$$

Next, a work-hour-weighted average of all underlying normalized metrics of the p^{th} project, M_p, can be calculated as:

$$M_p = \frac{\sum_{i=1}^{n}\left(WH_{pi} \times N_{pi}\right)}{\sum_{i=1}^{n} WH_{pi}} \quad \text{Equation 5}$$

Where

WH_{pi} = the direct work-hours of the i^{th} underlying metric of the p^{th} project

Index Evaluation

Finally, these three approaches should be evaluated regarding how well the underlying metrics are presented. In order to achieve meaningful benchmarking results, the projects should be benchmarked with the most comparable ones with similar characteristics such as similar project size or project nature. Therefore, when evaluating the three approaches, projects were also grouped by their characteristics: Project size (<$5 Million vs. >$5 Million), project type (process vs. non-process), project nature (grassroots, addition, and modernization), work involvement (engineering only vs. engineering and construction), contract type (lump sum vs. cost reimbursable), and project priority (schedule driven vs. non-schedule driven).

The first step is for each project to calculate the percentile for all underlying engineering productivity metrics and the PLEPM in each project characteristic subgroup. Then under each subgroup, a project has a weighted average percentile which is equal to the percentile of underlying metrics weighted by their work hours. The next step is to calculate absolute difference, PD, between the percentile of PLEPM and the weighted average percentile. PD calculation is demonstrated as in equation 6. The lower the PD, the better the index represents its underlying metrics.

$$PD_p = \left| \frac{\sum_{i=1}^{n} (WH_{pi} \times Pt_{pi})}{\sum_{i=1}^{i=n} WH_{pi}} - Pt_{pPLEPM} \right|$$

Equation 6

PD_P = the percentile difference between PLEPM and weighted average of underlying metrics of the p^{th} project

WH_{pi} = the direct work hours of i^{th} underlying metrics of the p^{th} project

Pt_{pi} = the percentile of i^{th} underlying metrics of the p^{th} project

Pt_{pPLEPM} = the percentile of the PLEPM of the p^{th} project

A simplified example illustrates how PD of a grassroots project is derived using only two underlying metrics, concrete and steel. First, extract all grassroots projects from the entire database. Considering all grassroots projects, this project's engineering productivity percentiles for concrete, steel, and the PLEPM are calculated as x%, y%, and z% respectively. Second, PD is calculated as in Equation 7:

$$PD = \left| \frac{H_{Concrete} \times x\% + H_{Steel} \times y\%}{H_{Concrete} + H_{Steel}} - z\% \right| \qquad \text{Equation 7}$$

Finally for each project characteristic, the $\overline{PD}$ can be calculated as the average of all projects with the examined characteristic. Results are shown in Table 4. Regardless of project characteristics, $\overline{PD}$ of the Z-score index is consistently better than the Earned-value and Max-min indices, with a difference of 0.98% and 2.56% on average respectively. These outcomes suggest that the Z-score method is the best candidate to produce the PLEPM.

Table 4 Average PD of Project Index by Characteristics

Approaches	Project Size N=112	Project Type N=112	Project Nature N=112	Work Involvement N=107	Contract Type N=65	Project Priority N=79	Average PD
Earned-value	9.91	10.21	9.80	9.38	11.06	10.28	10.10
Z-score	8.27*	9.55*	9.34*	8.56*	9.70*	9.28*	9.12*
Max-min	10.15	12.19	11.84	11.18	13.05	11.70	11.68

*The best among the three approaches

Conclusions and Path forward

Using EPMS to benchmark engineering productivity provides meaningful insight on how engineering is performed at different levels of details and helps project managers to recognize the potential improvement. On the other hand, it's also important to provide a macro-view of engineering productivity. However, due to different units of engineering productivity metrics, it's difficult to aggregate engineering productivity to the project level. This study examined three approaches to construct a PLEPM for benchmarking purpose. The results suggest that the Z-score method is superior to the other approaches because the index best represents their underlying metrics. However, it is also noted that Z-score method may have the deficiency in that it's hard for industry practitioners to interpret the index value.

A reliable PLEPM using the Z-score method opens new opportunities for engineering productivity benchmarking. The index can be used to analyze effects on engineering productivity from the use of best practices, such as front-end planning, constructability or change management at the project level. Nevertheless, based on the inputs from the industry, it's also critical to use the index to track the trend of engineering productivity.

References

Agresti, A., and Finlay, B. (1999). *Statistical methods for the social sciences*, Prentice Hall, Inc., Upper Saddle River, NJ, 07458.

Construction Industry Institute (CII). (2001). "Engineering productivity measurement." *RR156-11*, Construction Industry Institute, The University of Texas at Austin, Austin, TX.

Construction Industry Institute (CII). (2004). "Engineering productivity measurements II." *RR192-11*, Construction Industry Institute, The University of Texas at Austin, Austin, TX.

Ellis Jr, R. D., and Lee, S.-H. (2006). "Measuring project level productivity on transportation projects." *Journal of Construction Engineering and Management*, 132(3), 314-320.

Ibbs, W. (2005). "Impact of change's timing on labor productivity." *Journal of Construction Engineering and Management*, 131(11), 1219-1223.

Kim, I. (2007). "Development and implementation of an engineering productivity measurement system (EPMS) for benchmarking," Ph.D. Dissertation, The University of Texas at Austin, Austin, TX.

Maloney, W. F., and McFillen, J. M. (1995). "Job characteristics: Union-nonunion differences." *Journal of construction engineering and management*, 121(1), 43-54.

Sacks, R., and Barak, R. (2008). "Impact of three-dimensional parametric modeling of buildings on productivity in structural engineering practice." *Automation in Construction*, 17(4), 439-449.

Song, L., Allouche, M., and Abourizk, S. (2003). "Measuring and Estimating Steel Drafting Productivity." Honolulu, HI., United States, 67-75.

Thomas, R. (1999). "Conceptual Model for measuring productivity of design and engineering." *Journal of Construction Engineering and Management*, 5(1), 1-7.

Zener, C. (1968). "An analysis of scientific productivity." *Proceedings of the National Academy of Sciences of the United States of America*, 1078-1081.

A FRAMEWORK FOR INTEGRATING ELITIST GA AND PROJECT MANAGEMENT TOOL

Jin-Lee Kim[1], M. ASCE and Ralph D. Ellis, Jr. [2], M. ASCE

ABSTRACT

A construction schedule generated by most commercial project management software packages does not guarantee its optimality when the resources are limited. Project scheduling software revealed the limitation because they employ the simple priority rules for generating a precedence and resource feasible schedule, even though they provide the schedules in a reasonable amount of time regardless of the size of project.

This paper proposes a framework for integrating Elitist Genetic Algorithm (EGA) and a project management tool for construction resource-constrained project scheduling as an add-in function. The integration framework aims to help project planners to compare the scheduling results generated from the existing project management software packages such as Primavera Project Planner and MS Project with those obtained from EGA. A case example based on a commercial warehouse project is introduced to show the possibility of implementing the function through the integration of data structure.

KEY WORDS

Resource, Scheduling, Project management, Commercial software packages, Optimization.

INTRODUCTION

Project planning plays a significant role of defining project goals and objectives, setting out the deadlines for project completion, and developing contingency plans on potential risks. Project management tools are essential to reduce the potential incidence, especially, in the area of specification, estimation, monitoring, and control. Many project managers are willing to invest a variety of project management tools for the reason mentioned above. In contrast with strong reasons for the use of project

[1] Assistant Professor, Ph.D., P.E., Dept. of Engineering Technology, 108 Wilson Hall, Missouri Western State Univ., 4525 Downs Dr., St. Joseph, MO 64507; PH (816) 271-5821; FAX (816) 271-5983; e-mail: jkim@missouriwestern.edu

[2] Associate Professor, Ph.D., P.E., Dept of Civil & Coastal Engineering, Univ. of Florida, 365 Weil Hall, Gainesville, FL 32611; PH (352) 392-9537 x1485; FAX (352)/392-7983; e-mail: relli@ufl.edu

management tools, the majority of project management literatures argue that looking for the best procedure for resolving resource conflicts is useless in practice since it does not impact on planned project duration (Herroelen 2004; Herroelen and Leus 2005). However, the project scheduling problems, which generally include resource-constrained project scheduling, resource leveling, and time-cost trade-off analysis, have been interesting and challenging subjects of extensive research for several decades in the optimization study area in order to put them in practical application. Construction resource-constrained project scheduling problem considered in this paper attracts more attentions from the researchers in that it is concerned with assigning limited resources into activities over time optimally.

Over the years, a variety of project scheduling software packages have been developed and put to use in project management practice. Among them, Primavera Project Planner (P5) and Microsoft Project are the two most popular and widely used tools in practice. Note that a newly updated version is P6, but we used P5 here. Many commercial software packages have a limitation for the capabilities for scheduling projects under resource constraints optimally because they rely on the use of simple priority rules for generating a precedence and resource feasible schedule. Some of the priority rules they embody, for instance, include total float, early start, early finish, late start, late finish, etc. (Primavera 2005, see pages 305-308). Kolisch (1999) presented interesting experiment results that Primavera Project Planner delivered the best resource-constrained project scheduling performance out of seven commercial software packages on 160 test instances in a multi-project environment, and that the scheduling performance of commercial software decreases with increasing number of activities, increasing number of requested resource types, and with decreasing resource capacity. Despite many efforts to deliver the practical use of the software, there is a gap between the theory on the optimality of resource-constrained project scheduling and the practice on managing projects successfully using the theory.

As an attempt to make the gap close, we explore here the possibility to develop a project scheduling add-in function, which searches for a near-optimal and/or optimal solution as well as enables project planners to compare the scheduling results for better decision on their planned schedule. Therefore, the objective of this paper is to propose a framework for integrating Elitist Genetic Algorithm (EGA) and a project management tool for construction resource-constrained project scheduling as an add-in function. The integration framework aims to enable project planners to compare the scheduling results generated from the P5 with those obtained from the Elitist genetic algorithm (Kim and Ellis 2008) that can produce optimal solutions for a project up to 60-activity and near-optimal solutions for a project up to 120-activity. A case study based on a commercial warehouse project is introduced to show the possibility of implementing the function through the integration of data structure.

The following section briefly introduces the Elitist Genetic Algorithm (EGA) to search for a near-optimal and/or optimal solution to the construction resource-constrained project scheduling problem, followed by the review for resource leveling functions of project scheduling software, Primavera Project Planner (P5) considered here. The possibility to compare the scheduling results generated from the P5 with those obtained from the EGA is discussed. This paper then presents the coke bunker

construction project as a case example problem to show the implementation of the add-in function, following by a concluding remark.

ELITIST GENETIC ALGORITHM FOR RESOURCE SCHEDULING

This section introduces the Elitist Genetic Algorithm (EGA) for an optimal solution to the resource-constrained project scheduling problem of construction project networks, comparing its performance to the schedules obtained from well known heuristic methods. EGA makes a use of four genetic algorithm operators such as selection by elitism, roulette wheel selection, one-point crossover, and uniform mutation. Figure 1 shows the operation of EGA. The project specific schedule data and the algorithm parameters are prepared at the very beginning of the operation. The operators and their functions include (1) the random number generator for producing an initial population and examining the precedence feasible individuals, (2) the serial schedule generation scheme for calculating a fitness value of each individual, (3) the elitist roulette wheel selection operator for selecting a parent individual for the next generation while copying the best chromosome to the new population, (4) the one-point crossover operator for exchanging parent string segments and recombining them to produce two resulting offspring individuals, and finally (5) the uniform mutation operator for playing a role of random local search which searches regardless of the direction of learning to obtain the better solution (Kim and Ellis 2008).

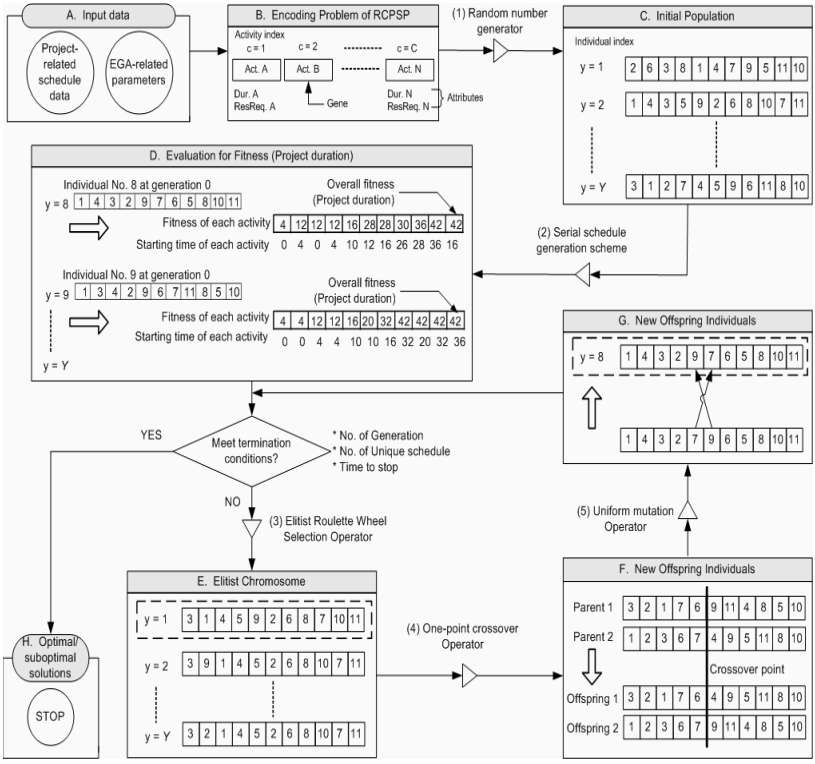


Figure 1: Operation of Elitist Genetic Algorithm (After Kim and Ellis 2008)

In order to show competitiveness of the algorithm performance, we compared the scheduling results produced from EGA with those obtained from the well-known optimality and lower-bound heuristic approaches. Three instance sets obtained from the PSPLIB (Kolisch and Sprecher 1996) are used in this experiment. The projects in these instance sets consist of 30, 60, and 120 activities, respectively. Each set has been generated using a full factorial design of parameters, which determine the characteristics of the resource and precedence constraints. For each problem size, a problem instance has four renewable resources. A set of 30-activity (J30), 60-activity (J60), and 120-activity (J120) problem instances consists of 480, 480, and 600 instances, respectively. There are 1560 instances in total. The sets J30 and J60 consist of 480 problem instances, while the set J120 consists of 600 problem instances. The overall performance of EGA is shown by the means of finding the best fitness value, which can be considered a near-optimal and/or optimal solution to the resource-constrained project scheduling problem.

We compared the performance of EGA with well-known optimal and/or lower-bound solutions obtained from PSPLIB (Kolisch and Sprecher 1996) by comparing average fitness values, average percent deviations, and average CPU runtime in

second for 1560 problem instance sets. The population size, crossover and mutation rates were set to 100, 0.5, and 0.03 for this test, respectively to attempt to obtain better solutions using large populations. The algorithm terminated with the number of generation of 100 (Population size x Generation No. = 100 x 100 = 10,000 trials). Table 1 shows the performance of EGA for solving 480, 480, and 600 instances of J30, J60, and J120, respectively. EGA improved approximately 1.14%, 13.53%, and 43.53% for J30, J60, and J120, respectively. EGA cannot surpass the average fitness value obtained from the PSPLIB because the results are currently known as the optimal solutions to the problem instances. The algorithm run times measured in seconds are 2.84, 4.99, and 6.45 for J30, J60, and J120, respectively. EGA shows the capability of searching for the suboptimal solutions close to the lower bound solutions for 120-Activity project problems.

Table 1: Comparison results with well-known optimality

Measurement	PSPLIB instances (No. of problems)	Average optimal/LB from PSPLIB	EGA	Average Deviation (%)
Ave_Fitness	J30 (480)	58.99	59.66	1.14
	J60 (480)	72.54	82.36	13.53
	J120 (600)	94.95	136.28	43.53

PROJECT MANAGEMENT PACKAGES FOR LEVELING RESOURCES

This section considers project management packages for solving resource-constrained project scheduling problem. We selected Primavera Project Planner (P5) to build add-in function on it because it is one of the two most popular packages for project scheduling. It is notable that P5 employs a priority rule for leveling resources when resource conflicts occur, thus does not provide optimal schedule. Horroelen and Leus (2001) clearly mentioned that "if management relies on commercial software for the generation of a baseline schedule, the result may be far off the optimum (even if only a few activities are involved), especially if resource contention is rather tricky and the "wrong" priority rule is chosen." Recent computational experiments (Kolisch 1999) with seven commercial packages on 160 test instances revealed that average performance is variable, with the best package deviating on the average 4.39% and the worst package deviating on the average 9.76% from the optimum makespan (also known as project duration). The mean deviation from the optimum makespan is 5.79%, while the standard deviation calculates to 7.51% and the range is from 0 to 51.85%.

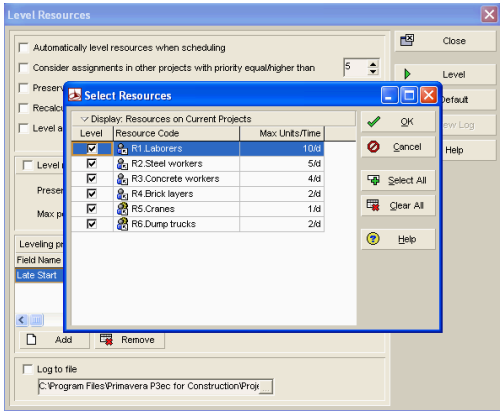


Figure 2: Resource leveling options – Priority and Resources

Figure 2 shows the resource leveling options in P5, depending on the priority and resources that users can determine which priorities and resources are leveled. P5 has a capability of leveling priorities that specify which activity is leveled first when resource conflicts occur. User can also preserve scheduled early and late dates so that the resource leveling can be performed within the time-constrained condition, which is different from resource-constrained project scheduling that we considered in this paper. P5 generates a resource leveling solution based on the priority rules set by the user.

PROPOSED MODEL FOR RESOURCE SCHEDULING AS ADD-IN FUNCTION

Figure 3 illustrates a framework for data integration methodology to integrate different data structure. The integration model starts with comparison of input data between EGA and P5. With the confirmation of correct data information given, data format transition function is operated to run P5 as an add-in function by changing from data structure for EGA to one for P5 through the spreadsheet form. EGA produces a near-optimal and/or optimal solution that contains the project duration, which is the most reliable measurement as the algorithm performance; resource profiles that is similar to one produced from P5; and start and finish times of the activities considered. The possibility of add-in function that we proposed here can be found by making heterogeneous data homogeneous so that the resulting schedule can be beneficial to project planners in comparing their schedules in practice.

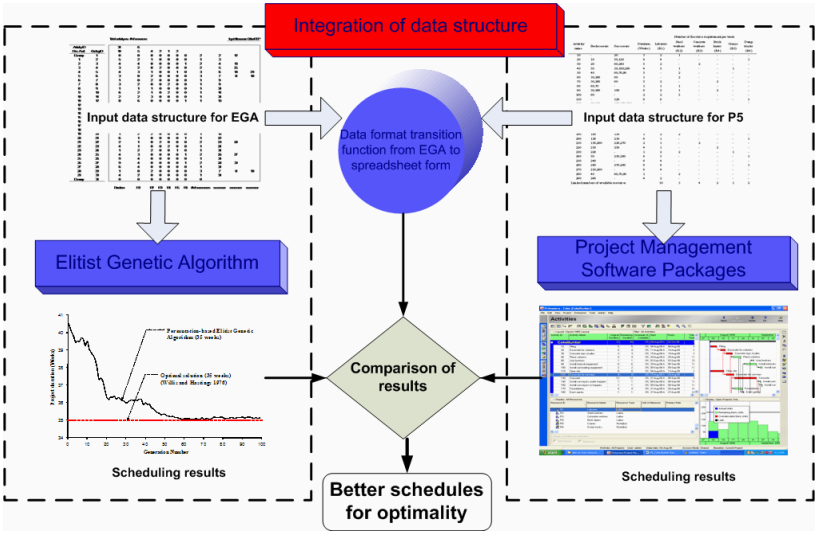
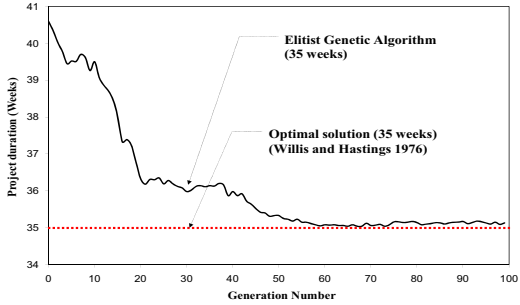


Figure 3: A framework for data integration methodology

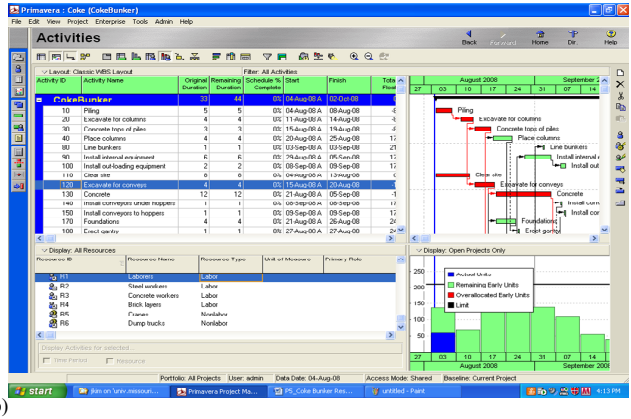
CASE EXAMPLE: COKE BUNKER CONSTRUCTION PROJECT

To examine the possibility of the proposed model as add-in function, we applied both EGA and P5 to solve the resource-constrained project scheduling problem of the Coke bunker construction project obtained from Willis and Hastings (1976). The warehouse project is to be completed for the purpose of storing coke, and loading and dispatching trucks. Main features include a block of bunker, interconnecting conveyors, and weighing facilities. An area of hardstand and an access road have to be laid to the site around the bunkers. The project consists of six different types of renewable resources and each activity has zero to three successors. It is assumed that the resource requirements and the durations are fixed.

The project duration calculated from the CPM with the assumption of the unlimited resources was 33 weeks. For the sake of simplicity, the unit of the duration for an activity was changed from the unit of week to the unit of day when the problem of the example was input to EGA. Figure 4(a) shows the performance of EGA for the coke bunker project. The result shows that the fitness values did converge constantly to the optimal solution that was known as 35 weeks for the bunker project (Willis and Hastings 1976). Figure 4(b) shows the scheduling results produced from P5, in which project start and finish time, bar chart with precedence relationship, resource profile, resource usages, and other project specific information are obtained. The project duration is one of the most reliable measurements for a comparison purpose.



(a)



(b)

Figure 4: Scheduling results for coke bunker project from (a) EGA and (b) P5

The original baseline schedule obtained from P5 indicates the project duration of 33 weeks with the assumption of unlimited available resources. Since P5 does allow the user to assign scheduling priority on the basis of activity attributes such as late start time (LST), late finish time (LFT), and others, we run P5 to generate resource leveling results based on Late Finish Time (LFT) and Late Start Time (LST), respectively. We obtained the project durations of 44 weeks and 48 weeks for LFT and LST, respectively. The scheduling result, which is the project duration, is far off from the optimal project durations obtained from both the branch-and-bound method of Willis and Hastings (1976) and EGA. Priority-rule-based heuristic procedures generally produce solutions to the resource-constrained project scheduling problem in a reasonable amount of time, even though the size of the project network is large. However, they have proven to be inconsistent with regard to the quality of results produced on project networks (Hegazy 1999). This means that the comparison

between the schedules is needed for examining the optimality so that project planners will make a better decision on schedules.

CONCLUING REMARKS

Project scheduling revealed a distinct gap between theory and practice. As an attempt to make the gap close, this paper proposed a framework for integrating Elitist Genetic Algorithm (EGA) and a project management tool for construction resource-constrained project scheduling as an add-in function, in which a near-optimal and/or optimal solution can be obtained as well as project planners enable to compare the scheduling results for better decision on their planned schedule. Project planners can compare the scheduling results generated from the P5 with those obtained from EGA that can produce optimal solutions for a project up to 60-activity and near-optimal solutions for a project up to 120-activity. A case example using a commercial warehouse project was introduced to show the possibility of implementing the function through the integration of data structure. The add-in function that we proposed here is now underway through the transition into homogeneous data and can be beneficial to project planners in comparing their schedules in practice.

REFERENCES

Hegazy, T. (1999). "Optimization of resource allocation and leveling using genetic algorithms." *J. Constr. Engrg. and Mgmt.*, 125(3): 167-175.

Horroelen, W. (2004). "Project scheduling-Theory and practice." *Production and Operations Management*, 14(4): 413-432.

Horroelen, W., and Leus, R. (2001). "On the merits and pitfalls of critical chain scheduling." *Journal of Operations Management*, 18: 559-577.

Herroelen, W., and Leus, R. (2005). "Identification and illumination of popular misconceptions about project scheduling and time buffering in a resource-constrained environment." *Journal of the Operational Research Society*, 56: 102-109.

Kim, J.-L., and Ellis, R. D. (2008). "Permutation-based elitist genetic algorithm for optimization of large-sized resource-constrained project scheduling." *J. Constr. Engrg. and Mgmt.*, 134(11): 904-913.

Kolisch, R. (1999). "Resource allocation capabilities of commercial project management software packages." *Interfaces*, 29(4): 19-31.

Kolisch, R., and Sprecher, A. (1996). "PSPLIB - a project scheduling problem library." *European Journal of Operational Research*, 96: 205-216.

Primavera (2005). *Project Management Reference Manual*, Primavera Systems, Inc., Bala Cynwyd, PA.

Willis, R. J., and Hastings, N. A. J. (1976). "Project scheduling with resource constraints using branch and bound methods." *Operational Research Quarterly* (1970-1977), 27(2): 341-349.

CREATING VALUE IN HOUSING PROJECTS: THE USE OF POST-OCCUPANCY ANALYSIS TO DEVELOP NEW PROJECTS

Thaís da C. L. Alves[1], George S. Costa[2], José de P. Barros Neto[3]

[1]Structural Engineering and Construction Department, Federal University of Ceará, Campus do Pici, s/n, Bloco 710, Pici, 60455-760, Fortaleza, CE, Brazil, thaiscla@ufc.br

[2]Structural Engineering and Construction Department, Federal University of Ceará, georgesilvacosta@yahoo.com.br

[3]Structural Engineering and Construction Department, Federal University of Ceará, jpbarros@ufc.br

ABSTRACT

Value generation is a goal of the Lean Production/Construction philosophy. However, defining value is difficult as value may vary according to user requirements and the capacity to afford desirable products and services. This paper presents two post-occupancy studies carried out in Brazilian housing projects and discusses how the results were collected, analyzed, and how they can be used for developing new projects. The first study presents the method used to collect and analyze data regarding users' opinions about housing units in low-income housing projects funded by the Brazilian Government. The second study presents the method used to capture the opinion of users of high-rise housing projects for medium- and high-income families. Results were categorized to reflect client satisfaction vs. how much they value specific items (importance) and provided designers and developers with clues about what clients actually value and how close/far the developers are from meeting or exceeding client expectations.

INTRODUCTION

One of the main goals of Lean Production is value generation for the end-user. However, capturing customer requirements and translating these into design parameters and ultimately into perceived value is not easy. According to Womack and Jones (1998, p.5): *"Value can only be defined by the end-user. And it is only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time."* Juran (1990) suggests that quality of a good or service is related to the development of products that meet customer desires. Juran highlights that customers often reveal their needs using their own language and their own points of view, which

may not be captured and explicitly translated into design parameters even by specialists. Different methods have been used to capture client requirements in different product development areas. The post-occupancy analysis (POA) is one of the methods that has been used to capture customer satisfaction regarding housing units.

It is worth noting that construction products have unique characteristics: the product is large, bulky, expensive, fixed and has a long lead time from design to completion and delivery to the end-user (Koskela, 1992). Due to these characteristics, it is hard to find alternative clients for the products offered by construction companies given that the product cannot be transported and sold in a location different from the one it was planned for.

Due to the aforementioned reasons, it is critical to the construction industry to study methods that both organize the capturing and processing of information related to client requirements, and help translate these requirements to design and construction teams.

PRODUCT DEVELOPMENT AND POST OCCUPANCY ANALYSIS

According to Syal et al. (2005, p.3), who defined a housing research agenda for NSF, "*addressing deficiencies in the existing housing stock*" comprises a topic of investigation for improving quality and productivity in the housing industry. A structured method to capture and translate customer needs into quality buildings is necessary in order to understand client values and address these deficiencies.

Ulrich and Eppinger (2000) point out that the identification of customer needs is the first stage of the concept development phase for a new product. The POA is a method that uses interviews, as well as direct observation, to capture client's needs and understand how satisfied the client is while using the product.

The literature presents different examples of how client's needs are captured and evaluated. Forsythe (2007) presents a conceptual framework to study client satisfaction in housing construction. Forsythe highlights the importance of understanding how client expectations build over the purchasing process and how they contribute to client satisfaction once the project is delivered. His idea is to understand what makes clients give different ratings for the project, the construction company, and the developer throughout the project's life cycle, and ultimately to understand how expectations are confirmed or disconfirmed during the long lead time from purchasing a housing unit to receiving it.

Along these lines, Tobica and Stroh (2001) carried out a study to understand customer satisfaction in terms of design, housing unit quality, and service (all factors which are under developers' control). They used a questionnaire which allowed customers to give performance and importance ratings for 51 items in the three categories. They found out that the item service is a major determinant of customer satisfaction, which reveals that end-user satisfaction is not related only to the housing unit itself.

Reis (1997) studied how user participation in the design of low-income projects affects user satisfaction levels. He stresses the importance of collecting data about which factors affect client satisfaction and the need to properly incorporate these in the new product development process for low-income housing projects.

Similarly, Leite et al. (2005) stress the need to properly address client requirements for low-income projects. They suggest that, as public agencies take care of registering clients who need a house, officials could also capture customer requirements in terms of what customers value. However, often this does not happen: by the time a housing unit is assigned to the client, the design process is already over. Also, customer requirements could be shared between financing agents, city councils, and construction companies. In order to best organize these requirements, Lima et al. (2008) suggest Quality Function Deployment (QFD) as a tool to help developers and designers make sure requirements are not lost throughout the process.

According to the literature, customer satisfaction can be explained by a combination of items. Items frequently cited as drivers of user satisfaction levels include: issues related to the quality of the unit; how adequate the unit is to the customer's needs; and the service provided by construction companies. However, capturing customer requirements and translating them into value-added features requires an organized method covering data collection through analysis and presentation of results. This paper expands on previous research carried out by Leite et al. (2005) and Lima et al. (2008) and suggests that construction designers should know the factors that contribute to client satisfaction as well as what items clients value the most in housing projects. According to the research presented here, the item clients value the most is project location, regardless of their income. Given that in many parts of the world good and affordable pieces of real states are getting scarcer, developers have to make sure they can differentiate their projects according to what clients value and are willing to pay.

RESEARCH METHOD

The objective of this paper is to present how post-occupancy analysis can be used to provide value-adding feedback to developers and design teams during the development of new projects. The authors aim to contribute to the development of products that have high value-adding features. The research method described in this paper was used for two major research projects and has been evolving over the past 5 years. The method comprises the phases of questionnaire development, research plan, data collection, data analysis, and definition of critical items.

The two major research projects that used this method differ only regarding the housing units analyzed. The Research Project A (RPA) analyzed client requirements for low-income housing projects and was developed simultaneously in five cities in different regions of Brazil (i.e., Fortaleza/CE, Feira de Santana/BA, Londrina/PR, Porto Alegre/RS, Pelotas/RS). A total of 727 clients were interviewed in these five cities. The Research Project B (RPB) comprised four POA carried out in the city of Fortaleza/CE. The main characteristic of this second project is that the POA involves medium- to high-income housing units and was motivated by developers who were interested in knowing more about their clients' needs and satisfaction levels regarding the projects they offer. Table 1 provides a characterization of both projects analyzed.

Table 1: Characteristics of the low and medium-high income projects analyzed

Characteristics	***Research Project A - Low income (RPA)***	***Research Project B - Medium-High income (RPB)***
Driver for carrying out the POA	*Public research funds, Government Bank (CAIXA)*	*Private Developers*
Type of project	*Apartments (up to 4 stores high)*	*Apartments (in high-rise buildings)*
Flexibility	*Clients cannot make changes during the design and construction phases.*	*Clients can make changes during the construction phase.*
Differentiation	*Projects are mass produced with little or no change across a same region.*	*Projects usually have different façades and landscaping, and allow for customization of most of the floor plan.*
Feedback for future projects	*Construction companies follow the public financing agent requirements and may use a standard design for the housing units*	*Clients' requirements are captured from completed projects and incorporated into future projects.*
Project location	*Projects are developed in the outskirts, in areas where low cost large states are still available.*	*The project location is one of the main factors for the project success. Developers chose areas that are most valued by potential clients.*
Solar orientation	*Units are disposed to allow for the highest utilization of the real state available and not according to comfort and performance criteria.*	*The majority of projects face East to take advantage of ventilation and solar orientation due to high temperatures all over the year.*
Affordability	*Clients value a series of items that they cannot afford or the financing agency opts out to keep costs low and affordable for a larger number of low income families.*	*The developer offers the design and specs that fit most of the client's needs and allows for customization according to each client's financial possibilities.*

Research Project A – Low-income housing units (RPA)

In RPA, the first phase used a questionnaire developed by researchers at NORIE/UFRGS, a research group located at the southern part of Brazil (Miron, 2002; Leite, 2005). The questionnaire comprised 63 items regarding: information about the housing unit; characteristics about the client interviewed and the family; and the five items the client liked and disliked the most. The other questions were related to client satisfaction regarding characteristics of the housing complex and the housing unit in terms of electrical and hydraulic systems; space distribution; comfort in terms of ventilation and natural light; quality of finishings, windows and doors; and safety. Finally, the last five questions asked clients about overall satisfaction with the housing unit; any changes they had made to the unit or intended to make; and how the unit compared to their previous unit, as well as to other similar units built by other construction companies.

In the RPA questionnaire (figure 1) clients could indicate their level of satisfaction for 44 items (questions) related to the housing unit and the housing complex based on a 5-point scale: very unsatisfied (VU), unsatisfied (US), neutral (NE), satisfied (SA), and very satisfied (VS).

	Rate your level of satisfaction regarding this item				
Characteristic	VU	US	NE	SA	VS
Quality of the housing complex How adequate the common areas are to the client's needs					
1. Garage 2. Playground…					
Quality of the housing unit How adequate the unit's space is to the furniture and its use					
1. Living room 2. Kitchen…					

Figure 1: Example of questionnaire in RPA

The second and third phases of RPA were carried out similarly to RPB. In the third phase, the data was collected after at least one client living in each housing unit was contacted in advance, so that a group of researchers could visit the housing complex and interview the clients. "In person" interviews were carried out mainly by a group of undergraduate students trained to use the questionnaire and deal with situations that could arise during the interview process. The researchers took pictures and recorded observations (drawings and comments) to illustrate client comments about the housing units/complex.

The fourth phase (data analysis) of RPA was carried out by grouping client answers in histograms that categorized answers according to the 5-point scale from very unsatisfied to very satisfied with the housing unit/complex characteristics. RPA also utilized a cross-data analysis, with researchers using the software SPSS® to evaluate correlations between different groups of answers. An example of cross-data analysis was to investigate how the level of satisfaction with the current housing unit correlated with how much the client liked their previous unit. Finally, the fifth phase comprised the analysis of the 5 critical items that the clients liked and disliked the most.

Research Project B – Medium- to high-income housing units (RPB)

The research method used in RPB evolved from the one used in RPA. The first major change regarding the methods used in RPA and RPB was the structure of the questionnaire used for POA. In RPB, the questionnaire was altered to capture the level of satisfaction as well as the level of importance given by the clients to different characteristics of the housing unit and the housing complex in which the unit was located. The questionnaire was also shortened.

The next major change in the questionnaire was the use of a Likert scale varying from 0 to 10 in which the clients could express their level of satisfaction with a specific item as well as express how important/unimportant that item was for them (Figure 2). This allowed the researchers to calculate a delta between the level of importance (what the client values) and the level of satisfaction (how the client feels about the item) indicated by the client. The ideal situation would be for the importance and satisfaction levels to be the same, which would reflect that a client's satisfaction level is compatible with the importance level that client gives a certain item.

Rate your level of satisfaction regarding this item		
Very unsatisfied	0 1 2 3 4 5 6 7 8 9 10	Very satisfied
Rate the level of importance this item has for you		
Not important	0 1 2 3 4 5 6 7 8 9 10	Very important

Figure 2: Likert scale used in the questionnaire

The rationale behind the method used in RPB was based on the work of Noriaki Kano, who suggested that there are different kinds of attributes to be considered in a product or service (Kano et al. 1984 apud Matzler and Hinterhuber, 1998). Kano differentiates between attributes that must be present in a good or service and those that differentiate these products and services from others currently offered in the market. According to Kano's model there are three types of attributes:

- Threshold/Basic attributes ("must-be" requirements): these are essential for the good/service to sell as the clients take them for granted. These do not increase client satisfaction with the product but cause extreme dissatisfaction if they are not found in the product/service.
- One-dimensional attributes (performance/linear): client satisfaction level increases with the improvement of these attributes, and decreases when these attributes are not properly offered. Clients relate the differentiation on goods and services' prices to how well these attributes function.
- Attractive attributes (exciters/delighters): these are related to a great level of satisfaction for those clients who are willing to pay extra money to have these attributes present in a product/service. These attributes are not explicitly required by clients. Differently from the one dimensional attributes, clients are not dissatisfied if the attribute is not present.

The importance-satisfaction matrix presented in Figure 3 shows an example of multi-dimensional scaling (MDS), which is a technique that graphically represents interviewees' perceptions and preferences regarding attributes present in a product or service (Slack, 1997, Malhotra, 2001). The MDS has been used as a Marketing research tool to help in the analysis of market segmentation, new product development, and price analysis. The data collected with a questionnaire using a Likert scale, as the one shown in Figure 2, provides the researcher with two coordinates (importance, satisfaction), which are marked in a importance-satisfaction matrix (figure 3).

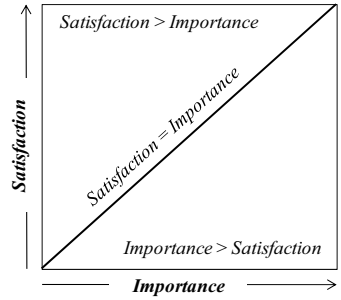


Figure 3: Importance-Satisfaction matrix

Analysis of coordinates in different areas of the importance-satisfaction matrix allows developers and design teams to focus on different issues:

- Items the clients value the most: e.g., items with high importance ratings.
- Requirements the company is failing to fulfill: e.g., items with high importance and low satisfaction ratings.

- Requirements overly fulfilled that don't increase client satisfaction: e.g., high satisfaction and low importance level.
- Requirements that may increase/decrease client satisfaction in a linear fashion: e.g., items on the central diagonal indicate that client satisfaction improves as the company improves product/service features and decreases as the company fails to fulfill these requirements.
- Items within segments defined by lines parallel to the central diagonal: e.g., items under the central diagonal (importance < satisfaction ratings) may need more urgent action depending on the delta between the satisfaction and importance ratings.

RESULTS AND ANALYSIS

This section presents the results and analysis carried out for both projects, with a discussion regarding how the methods were used to provide stakeholders with information about what clients value most in the housing units analyzed.

Results and analysis for RPA

The results presented for RPA were part of the Requali network project carried out by five universities in five different cities in Brazil, i.e., UFRGS, UFPel, UEL, UEFS and UFC (leading institution). The main goal of Requali was to provide stakeholders with information for the development of new housing projects for low-income families. The Requali network carried out 727 interviews with clients of government funded projects in five cities. In the city of Fortaleza, the same city where RPB was developed, 125 interviews were carried out in three different projects (out of a total of 224 units). The projects evaluated were funded by the Brazilian Government under the House Leasing Program (PAR). The PAR units had to be built under tight budget and schedule constraints set by the funding agency, and there was a cap for the maximum price paid for each unit delivered. Once PAR projects were approved, the construction companies were assured a government owned bank (CAIXA) would acquire all of them and take care of the leasing process.

The results of RPA showed that clients were very satisfied with the housing units, with the highest levels of satisfaction found in the Southern Region Brazil, i.e., in Londrina, Porto Alegre, and Pelotas, where 85% of the clients were satisfied or very satisfied with the units.

The five items customers liked the most were: location (32.3%), safety (23.3%), design of the housing unit (19.4%), the PAR Program (13.8%), and living in a housing complex/condo (11.1%). The five items clients disliked the most were: the project management company (29.3%); the condo fees (19.5%); location (17.9%); design of the condo common areas (17.7%); and safety (16.5%). It is worth noting that project location and safety were spontaneously cited as items that clients both liked and disliked the most, suggesting that both items deserve special attention as they strongly contribute to client satisfaction.

The study also shows that clients in different regions of the country value different items of the projects. This can be explained by cultural differences across the country. In Southern cities, with lower temperatures during the winter, clients consider the solar orientation of the units facing the sun as a positive factor. In the

Northeast region this was viewed as a negative factor, as they are closer to the Equator and face higher temperatures.

Also, as the clients cannot alter the unit during the design and construction phases of PAR projects, they make changes after the unit is delivered. In the city of Fortaleza, the main change observed was the addition of bars in the unit's windows and doors due to safety concerns (pointed out as a critical item). Finally, in Fortaleza, the cross-analysis revealed that the most highly satisfied group was 'adults without kids' followed by 'couples without kids.' This suggests the units are not adequate for families, as the level of satisfaction of groups with kids was low when compared to other groups.

Results and analysis for RPB

The RPB comprise four different POA solicited by two construction companies (Table 2). The projects investigated have similar characteristics, i.e., high-rise buildings for medium- to high-income families. The POA was carried out by the GERCON – construction research group at the Federal University of Ceará (UFC). For RPB, 450 clients from 13 projects were interviewed in 4 years. Due to space constraints, only the results for Company X in 2007 are presented to illustrate how the method used in RPB was used and validated.

The main reason cited by clients to buy a unit in the projects offered by Company X was location (37%), followed by size of apartment/space (22%) and the leisure area/common area (12%). All three items are very critical items as developers have strived to meet these criteria while orienting the units to the East. Avoiding afternoon sun is important due to Fortaleza's high temperatures and proximity to the Equator (~ Latitude: -03° 43' 02"; ~ Longitude: 38° 32' 35").

Table 2: Summary projects and samples for RPB

Research year	Population, number of apartments (% total)	Sample (% covered by the research team)	Projects (number of projects visited)
Company X			
2003	192 (100%)	128 (67%)	4
2005	208 (100%)	135 (65%)	4
2007	278 (100%)	162 (58%)	4
Total Company X	678 (100%)	425(63%)	12
Company Y			
2008	46 (100%)	25 (54%)	1
Total (Company X and Y)	724 (100%)	450 (62%)	13

Table 3 shows a summary presented to developers at Company X. Overall, on a Likert scale varying from 0 to 10, clients of Company X are satisfied (8.28) but there is a negative delta (satisfaction - importance ratings) given that on average importance ratings are higher (9.36) than satisfaction ratings. The item 'project appearance' presents the lowest absolute delta, which means that client satisfaction and importance ratings for this item are close (0.44), i.e. the company delivered what clients expected. The highest absolute delta can be found in the ratings clients gave to the company overall service (1.73), i.e., clients want the company to deliver a better service.

Table 3: Summary of results for Company X - 2007

Items	Project - X1			Project - X2			Project - X3			Total		
	Sat.	Imp.	*Delta*	Sat.	Imp.	*Delta*	Sat.	Imp.	*Delta*	**Sat.**	**Imp.**	***Delta***
01.Condo facilities and use	7,11	8,33	*-1,22*	7,87	9,32	*-1,45*	8,20	9,43	*-1,23*	7,73	9,03	*-1,30*
02. Quality of finishings	6,87	8,04	*-1,16*	8,49	9,29	*-0,80*	7,93	8,79	*-0,86*	7,76	8,70	*-0,94*
03. Project appearance	8,71	9,41	*-0,71*	9,03	9,50	*-0,47*	8,71	8,86	*-0,14*	8,82	9,26	*-0,44*
04. Safety	8,00	9,65	*-1,65*	7,82	9,70	*-1,87*	8,93	10,00	*-1,07*	8,25	9,78	*-1,53*
05. Area distribution and size of rooms	7,28	8,98	*-1,70*	8,44	9,50	*-1,07*	8,96	9,75	*-0,79*	8,23	9,41	*-1,18*
06. Comfort (natural conditions)	8,46	9,49	*-1,03*	8,56	9,54	*-0,98*	9,18	9,86	*-0,68*	8,73	9,63	*-0,90*
07. Electrical systems	8,60	9,12	*-0,51*	8,66	9,59	*-0,92*	9,46	9,84	*-0,37*	8,91	9,51	*-0,60*
08. Hidraulic systems	8,75	9,39	*-0,64*	8,63	9,56	*-0,93*	8,98	9,84	*-0,86*	8,79	9,60	*-0,81*
09. Quality of finishings (per room)	7,82	8,95	*-1,14*	8,39	9,57	*-1,18*	8,93	9,79	*-0,86*	8,38	9,44	*-1,06*
10. About the Company X	8,00	10,00	*-2,00*	7,85	9,75	*-1,90*	8,59	9,89	*-1,30*	8,15	9,88	*-1,73*
Comparison	Sat.	Imp.	*Delta*	Sat.	Imp.	*Delta*	Sat.	Imp.	*Delta*	**Sat.**	**Imp.**	***Delta***
Average	7,74	8,94	*-1,20*	8,34	9,50	*-1,15*	8,76	9,63	*-0,87*	**8,28**	**9,36**	***-1,07***
Standard deviation	1,24	0,81		0,77	0,26		0,77	0,44		**0,93**	**0,50**	

In previous years (2003, 2005), clients also said the company needed to meet deadlines and honor commitments, and they also complained that the company took too long to solve maintenance problems. Finally, the negative deltas have shown that company X has not exceeded client expectations, as none of the deltas were positive. On average, importance was higher than satisfaction for all items. Another interpretation is that the negative deltas show that company X has room for improvement, and it is not investing money in features clients do not value.

CONCLUSIONS

The paper presented the method used to collect and analyze data in different types of housing projects ranging from low-income, mass-produced projects to medium- to high-income, high-rise apartments with some degree of internal customization. In both studies some similarities were found, i.e., importance of project location, space distribution, and safety, regardless of how much income clients earn. There was evolution in the methodology from the first to the second project, so that the tools and the analysis were better able to portray the items clients value and, at the same time, indicate how satisfied the clients are with these items. When the results were presented to developers and Government agencies, the researchers led a discussion focused on the items that clients value the most and how they can be incorporated in future projects. The way results are presented in RPB allows public agencies and developers to prioritize what actions are more urgent depending on where project characteristics stand in the importance-satisfaction matrix and how low or high their deltas are. It is worth noting that in major cities, good pieces of real states are becoming scarce and less affordable, and clients highly value the location of projects. Therefore, developers will have to be more creative and precise while addressing client's needs.

REFERENCES

Forsythe, P.J. (2007) A conceptual framework for studying customer satisfaction in residential construction. *Construction Mgmt and Econ.* February, 25, 171-182

Juran, J. M. (1990) *Juran Planejando para a qualidade.* (In Portuguese: Juran planning for quality) São Paulo: Pioneira.

Koskela, L. *Application of the New Production Philosophy to Construction.* Stanford University, CIFE, 1992, Technical Report # 72, 87 pp.

Leite, F. (2005) *Contribuições para o gerenciamento de requisitos do cliente em empreendimentos do Programa de Arrendamento Residencial.* (in Portuguese) Master's thesis. Porto Alegre: NORIE/UFRGS

Leite, F.L.; Miron, L.I.G., and Formoso, C.T. (2005) Opportunities for client requirements management in low-income house building projects in Brazil. *Proc. 13th Annual Conf. of the Intl Group for Lean Construction* (IGLC 13). Sydney, Australia

Lima, L. P., Formoso, C. T. and Echevest M.E.S. (2008) Client Requirements Processing in Low-Income House-Building Using Visual Displays and the House of Quality, *Proc. 16th Annual Conf. of the Intl Group for Lean Construction* (IGLC 16), 459 -470, Manchester, UK

Malhotra, N. (2001) *Pesquisa de Marketing: uma orientação aplicada* (in Portuguese, translation of Marketing Research: an applied orientation), 3rd ed., Porto Alegre: Bookman

Matzler, K. and Hinterhuber, H.H. (1998) How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment. *Technovation*, v. 18, No.1 , 25-38

Miron, L. (2002) *Diretrizes para o gerenciamento os requisitos do cliente final no processo de desenvolvimento do produto em empreendimentos habitacionais.* (in Portuguese) Master's thesis. Porto Alegre: NORIE/UFRGS

Reis, A (1997) Participação do usuário no projeto de habitação popular (In Portuguese). *Ambiente Construído*, Junho, 31-44

Slack, N. et al. *Administração da produção* (in Portuguese, Operations Management), São Paulo: Atlas, 1997.

Syal, M. et al. (2005) Housing research agenda for NSF-PATH. *Journal of Architectural Engineering*, ASCE, March, 1-6

Tobica, Z.M. and Stroh, R.C. Customer satisfaction in home building. *Journal of Construction Engineering and Management,* Vol.127, No. 1, 82-86

Ulrich, K.T. and Eppinger, S.D. (2000) *Product design and development.* 2nd ed. Boston: Irwin McGRaw-Hill, 358pp

Womack, J.P. and Jones, D.T. *A Mentalidade Enxuta nas Empresas.* (In Portuguese: translation of Lean Thinking) Rio de Janeiro: Campus, 1998. 427p.

PREPARATION OF INCONGRUOUS ECONOMIC DATASETS FOR REGRESSION ANALYSIS

Gunnar Lucko[1], Ph.D., A.M.ASCE, Zane W. Mitchell Jr.[2], Ph.D., M.ASCE

[1] Assistant Professor of Civil Engineering and Director of Construction Engineering and Management Program, Department of Civil Engineering, The Catholic University of America, 620 Michigan Avenue NE, Washington, DC 20064
Phone: 202-319-4381, fax: 202-319-6677, email: lucko@cua.edu

[2] Assistant Professor and Deputy Department Head, Department of Civil and Environmental Engineering, United States Air Force Academy, Colorado Springs, CO 80840
Phone: 719-333-2054, fax: 719-333-2234, email: zane.mitchell@usafa.edu

ABSTRACT

Datasets in construction engineering and management are not always as clean and consistent as one would desire. They may not match in format or content between companies that are studied and within them they may require substantial preparation. This makes the examination of theories and the extrapolation of trends from historic data more difficult than it is for carefully controlled experimental studies or collection of new data. The purpose of this paper is not to review the regression models that the writers developed during their research, but to focus on the data preparation that had to be applied prior to those analyses. It outlines general techniques that can be applied to field data from construction companies or data repositories to give researchers various best practices that will help gleaning further truths from already existing data.

INTRODUCTION

Field operations are a fundamental component of the area of construction engineering and management. Contractors routinely measure various aspects, e.g. time, cost, and productivity, to fulfill their project management functions of planning, optimization, and control. This accumulates a valuable pool of data for construction researchers to explore. However, such data are often collected in a 'home-grown' manner, lacking a standard format across different companies (Mitchell 1998). Data, especially paper-based, can require substantial preparation to be usable. Scholarly publications may contain separate sections on how their data were collected (Severson *et al.* 1994), but hardly describe what practical problems were encountered in preparing them. Literature specifically on the preparation of data for construction engineering and

management studies is sparse, underlining the importance of this paper. A dilemma emerges; quantification of economic phenomena is crucial to stay competitive in today's industry and years of existing data can be at the researcher's disposal, if only scientifically valid ways to compare 'apples to apples' can be devised for them.
Central questions for the researcher at the onset of a study include the type, range, and source of the necessary data. In this paper it is assumed that the pros and cons of using existing data from one or several field sources instead of collecting new observations in the field or the laboratory have been evaluated, which is not an easy decision. The researcher has great control over the collection methodology for new data, but no influence on how the existing data were created. Data from field sources are more prone to containing irregularities (noise), which can be somewhat dampened by their potentially larger volume. Yet laboratory studies are often infeasible or impossible for examining economic phenomena in construction. The trade-off thus is between the challenges of extracting quality data versus savings in time, which can reach the order of years. This paper presents various techniques that the writers have successfully used in their research on heavy construction equipment. Mitchell's (1998) objective was to devise a predictive model for repair costs based on data from four companies. Lucko (2003) built a model for residual value from auction records.

DATA SOURCES

Proprietary Data

The construction industry is very competitive; contracts are won or lost by small margins. While construction firms are often willing to cooperate with researchers who develop and test theories that will help them improve their business, they are disinclined to share their data in a forum where other firms might gain an advantage. In Mitchell's (1998) study, some of the firms competed against each other in the same market. Proprietary corporate data therefore typically require written permission to be usable for non-commercial scholarly purposes. Confidentiality agreements regulate the disclosure of planned publications to the data supplying company and also their contents. They can establish that only significantly aggregated, averaged, or artificially created data that exhibit similar statistical properties to the original ones may be published and that descriptions and illustrations are created without making raw data discernable. The agreement should still permit discussion of general aspects with other researchers. Other precautions are anonymity of participating companies and protecting raw data by limiting access and destroying them after a specified time.

Multiple Sources

Ideally, data should be collected from several sources to allow validation of their order of magnitude, mean, and variance and enable cross-comparisons. However, each additional source also introduces new biases and possible sources of errors. It is essential to fully understand the mechanism by which the data were collected and recorded, e.g. by interviewing the respective staff (Mitchell 1998). Data sources also vary in accuracy and reliability. Governmental sources are generally considered of high quality and typically reveal the data collection process while corporate sources often exhibit more incongruities. Sources must be coded, e.g. with integer numbers, in the final merged dataset to allow testing for statistical differences between them.

After surveying the data available from different sources, it is important to determine what common data fields are available and whether or not those data fields suit the purpose of the study at hand. During the source selection phase of Mitchell's (1998) research, it was found that the data from some companies, although extensive, did not have all of necessary attributes to contribute to the study. Such data of insufficient quality should be eliminated, even if it reduces the potential overall sample size.

DATA CHARACTERISTICS

Frequency and Resolution

The definition of what constitutes an individual data point depends on the internal practices of each source. Economic data from several different companies may deviate from each other in frequency and resolution. Such data often accumulate as events occur, e.g. an equipment repair. However, macroeconomic data typically have a monthly or quarterly frequency. Different frequencies, spanning from an individual machine to the economy at large, influence the time intervals of the response variable. The largest one generally becomes the valid frequency, e.g. the year of manufacture (Lucko 2003). Another consideration is the resolution of numerical data, i.e. their significant digits, which determines the possible accuracy of the response variable. Data can be averaged if their frequency is higher than needed, e.g. to match a monthly averaged annual producer price index with age, which was measured in years only.

In Mitchell's (1998) study of repair costs the time scale had to be determined to properly reflect how heavy construction equipment ages. The best way to account for aging of this type of asset was not calendar age, but age in terms of cumulative usage. This became the explanatory variable. Problematic in this study was one company without any dataset that included both cumulative usage and repair costs *together*. Repair costs were tracked in one database on a monthly basis. Cumulative hours of usage were available in a different database which recorded cumulative hours on a machine whenever an oil change took place. Calendar date was used as the common point to combine these two internal datasets. Costs from months in which oil changes took place were associated with the meter hour readings from those months. One problem was that cost data were reported in end-of-the-month increments but oil changes may not have anytime. Oil changes that took place on or prior to the 15th day of a month were thus assumed to have taken place at its beginning, otherwise at its end. A certain amount of error is induced by this assumption. Repair costs that were associated with cumulative hours from oil changes early in a month are probably understated because not all costs that had taken place up to that oil change were necessarily included. By the same token, costs associated with oil changes that took place late in a month are probably overstated because they could include expenditures that occurred after the oil change. It was assumed that these errors were offsetting in the long run. It was critical that there was no more than one data pair per month (since the repair cost data were tabulated on a monthly basis) and no more than one data pair per oil change. To allow more data pairs would have artificially fabricated data.

A problem encountered with data from other companies was that there were multiple data points for the same cumulative hours of use on some machines that occurred while those machines were idle for long periods. To make the data model work, all but one of the data pairs for multiple occurrences of the same cumulative hours of use

were eliminated. The first data pair occurrence was kept because the repair costs associated with a specific cumulative meter hour reading for a machine should include all repair costs *up to* the point where those hours were reached. Costs incurred after the meter hour reading was reached were then ascribed to the next data pair.

Storage Medium

The medium in which data are recorded can range from informal paper records via ad-hoc spreadsheets to professional databases. Data might be readily accessible on personal computers (PC) or might need to be retrieved off of mainframe computers using data mining software. Paper records are more vulnerable to transcription errors, both by the individual who originally recorded the data and by the researcher wishing to use the data. Special care should be taken when scanning or typing data to an electronic format. Existing electronic data need to be at least skimmed to ascertain their quality. Find and sort functions of computer software assist with this task.

Spreadsheets are common for storing electronic data. Lucko (2003) subscribed to the online databases of Last Bid®, formerly Green Guide Auction Report™ and Top Bid, which covered most construction equipment auctions that were held in the North American market and obtained Microsoft® Excel spreadsheets for specific makes and models. All data had to be prepared by bringing them into the same medium and format, so that further verifying and 'cleaning' techniques can be applied evenly. Individual spreadsheets were time-stamped and consolidated into one workbook.

In Mitchell's (1998) research, the data came in three different media: PC-formatted, mainframe, and manually recorded data. The data extracted from PCs were the easiest to manipulate and assimilate. These files came in a format that could be used directly by standard software packages. Data in spreadsheets (Excel or Corel® Quattro) required the least amount of preparation because they were already in the file format that would be used for analysis. Others were stored in databases (Microsoft® Access or Corel® Paradox). They were extracted from the database files into spreadsheets. In some cases, this was faster than preparing data that already came in spreadsheets, as queries to extract the data into the desired spreadsheet format could be generated.

Mainframe data posed another challenge. Some companies ran reports and generated all printouts from their mainframe computer using individually programmed applications. The data were converted by transferring them to ASCII print files, which could then be opened on a PC, but were not parsed into discrete components. They could not be directly used in spreadsheets as all of the data in a given row of the ASCII file would be imported into one cell. Although converters exist in spreadsheet programs that permit the parsing of data, they only work with data that originally were in tabular format, which was not always the case. Mainframe reports also contained cost data that were not a part of this study. Usually more than one report was needed to accumulate all data on a machine. The process of extracting the useful data was simplified by building templates in DataWatch® Monarch™ to recognize row formats. Cost data were extracted, associated with specific machines, and subtotaled by cost code for each month. Unwanted cost data were then filtered out by cost code and a spreadsheet containing only the desired data was exported. Paper-only records were the hardest to prepare for analysis. In some cases, folders containing records and receipts for each machine had to be examined page-by-page to enter them into a spreadsheet. Due to the amount of labor involved in transcribing these raw data,

paper-only data sources were used only when electronic sources were not available.

Formatting and Labeling

Since terminology strongly depends on the data source, it is recommended that each column of data points receive an intuitive label for future reference. Spreadsheet software allows formatting cells as text, numbers, dates, or prices according to their type of data. Editing functions in text processing software can be used to find and replace superfluous blank spaces, inconsistent capitalization, and discrepancies among individual entries. To remove superfluous formatting from electronic data it can be useful to copy and paste datasets first into a simple text editor and then into the spreadsheet software. Sorting columns of data alphabetically and numerically brought cells with symbols, e.g. "N/A" or "-", to the top to be filled with "." This symbol is commonly used in statistics software to represent missing data (Lucko 2003).

Column header cells with minimum, maximum, mean, and variance were added to numerical data in the spreadsheet to gauge their range, centricity, and spread. Calculated data columns were added, e.g. determining age as the difference between the manufacturing date and the date of the auction at which the machine was sold. Age had an accuracy of years, since only the year of manufacturing was known, not its exact day or month. Sorting by numeric values, e.g. by age, revealed unreasonable extremes caused by incomplete entries, e.g. negative values (199_ - 1996) or large values (2002 - 199_), that were corrected or deleted. Setup descriptions was scanned for negations, e.g. "no", "not", and "inoperable," to delete entries of machines that had missing parts or were otherwise unsuitable. Finally, simple `IF` formulas in the spreadsheet converted postal ZIP codes and state name abbreviations into auction regions to be used as an explanatory variable in the statistical model. For large datasets it is recommended to create a control column that provides an independent checksum of a conversion formula and verifies its cell references and commands.

In Mitchell's (1998) research, two types of accounting errors occurred that had to be corrected prior to analysis. The most common error was that of negative repair costs for a given month. When the question of negative costs was posed to the companies involved, the answer obtained was that the negative charges were due to either overcharges or mistaken charges that occurred in an earlier month. In order to fix this type of error, the mistaken charges were removed in the months that they occurred and the negative charges were eliminated. The mistaken charges were moved to the months in which they actually occurred. The reason for doing this was to eliminate the false fluctuations in cumulative repair cost induced by adding and subtracting charges that should not have been there in the first place. Another error, though not as common as negative charges, was that of replaced hour meters. This was obvious in that either the cumulative cost at time zero was not zero or the cumulative hours associated with a given machine went down with the passage of calendar time. The fix for this problem was to first confirm that the meter had been replaced. After this confirmation, the cumulative hours at replacement of the meter were used as a baseline to correct later readings. In cases where the cumulative hours at time of replacement were not available, the machine was eliminated from the dataset.

Typographical Errors

Skimming the entire sorted dataset for deviations from the regular 'pattern' among the data can help identifying and eliminating typographical errors. Lucko (2003) was able to make very detailed corrections, some of which may have stemmed from converting the original handwritten record into electronic form, as they typically occurred between similar looking letters and digits:

- Letter or digit switches: `7XM` instead of `7MX` within a serial number;
- Letter or digit changes: `1` = `I`, `2` = `Z`, `3` = `6` = `8` = `B` = `S`, `7` = `F` = `T`.

Others varied the spelling in alpha-numeric entries, e.g. the model of the machine:

- Incomplete model name: `PC300`, not `PC300HD-5`;
- Incomplete series name: `PC100 II`, not `PC100C Series II`.

It was found that long numbers contained superfluous zeros that were eliminated. Serial numbers are sequential for newly manufactured equipment, which allowed correcting sudden deviations in the year of manufacture in otherwise constant entries.

DATA CONVERSION PROCESS

Verbal Descriptors

A problem that is frequently encountered in existing datasets is that they contain explanatory variables with categorical verbal descriptors. All explanatory variables must be expressed numerically to be usable in a statistical analysis. In Lucko's (2003) study, the manufacturer name, condition rating, and auction region were categorical. Some were hierarchical, e.g. condition (excellent, very good, good, fair, poor); others were not, e.g. region (Northeast, South, Midwest, West). Both had to be transformed into numerical form. Categorical variables often serve as somewhat subjective proxies for complex phenomena. Condition e.g. is typically appraised visually using a checklist and aggregates the result of wear and tear on different parts of a machine, e.g. tires or tracks, undercarriage, and engine, which is offset by maintenance and repairs. However, simply assigning numerical values, i.e. integers, is problematic in the statistical model. For non-hierarchical variables this would fabricate a hierarchy. For hierarchical variables it would assume regular distances within such hierarchy.
A solution is to convert the integer into binary sets of indicator variables. Table 1 converts four verbal descriptors into a triplet of zeros and ones that act like switches. Each binary provides only part of the distinction. The triplet was chosen over an equally possible binary pair to not assign all zeros to one 'benchmark' category.

Table 1: Conversion of Verbal Descriptors to Binary Numbers

Descriptor	Number	Binary 1	Binary 2	Binary 3
A	1	0	0	1
B	2	0	1	0
C	3	0	1	1
D	4	1	0	0

Either all or none should be included in a statistical model. A drawback is that this conversion removes any hierarchical information that may have existed. The numbering begins with one, since zero would favor the first category and consider it the *de facto* benchmark for further variability in the particular explanatory variable.

Reconstruction

Datasets need to be checked for completeness and consistency. If each data point contains several pieces of information and the dataset contains redundancy, it is possible to carefully fill gaps by sorting and comparing neighboring entries, provided that no data are fabricated *a posteriori*. Only in rare cases do datasets directly overlap, such as the data from Last Bid® and Top Bid used by Lucko (2003). They provided independent records of the same heavy equipment auction events. Redundancy of the two datasets allowed verification by comparing pairs of entries, i.e. one machine being sold at a particular auction, via unique identifiers in the data point such as date, location, and serial number. Machines could appear in several data points if they were sold several times during their life. It was assumed that they were independent.
Reconstruction required that all data points in the merged dataset were sorted in the hierarchical order of model, serial number, and auction date. A computer macro called *FillGaps* automated the otherwise time-intensive process. For several columns that contained cells with "." the macro first matched several identifiers with preceding or succeeding entries to find redundant data points, i.e. two records of the same auction sales event. The placeholder "." was then replaced with the value of the directly adjacent cell through the use of the *FillGaps* macro. A variation of this technique was applied to the aforementioned changes in an otherwise sequential list of numerical values. Once gaps had been filled, any redundant entries had to be identified and deleted. A second macro called *DeleteDoubles* was programmed that – similar to the previous one – compared identifiers, allowing for a small variability between auction prices due to currency conversion, and deleted the first entry of each pair. Non-redundant entries still increased the sample size, but had to be verified by other means to ensure they achieved the same quality as the redundant data points.

Inflation Correction

The phenomenon of inflation is an imbalance between the supply of money on the one side and the supply of goods and services on the other side (Bodie *et al.* 2002). Manufacturers' suggested retail prices, auction prices, maintenance and repair costs, and any other items that are modeled should be corrected for inflation to an arbitrary common date before they can be analyzed. Inflation adjustments can be made with an annual percentage rate, which creates an exponential growth. If data are insufficient or unavailable to estimate said rate accurately for the application of interest, using governmental indices as per Eq. 1 is a widely accepted technique. They are ratios of current to past prices for standardized baskets that contain a mixture of goods and services. Indices of different levels of detail and composition are available. Some apply to the entire economy; others are regional and just cover specific industries, commodities, and stages of processing. The producer price index for finished goods (PPI) was considered to be applicable for construction projects and has been used in several other studies to adjust for inflation the costs related to heavy equipment (Cross and Perry 1995, Cross and Perry 1996, Kastens 1997) as per Eq. 1:

$$Price_2 = Price_1 \cdot \frac{Index_2}{Index_1} \qquad \text{Eq. 1}$$

where *Price* is any price in U.S. dollars and *Index* is a price index. Once an index, e.g. the PPI, has been used for inflation correction, it cannot to be used as an explanatory variable. Otherwise, the model would suffer from multicollinearity, i.e. a very high Pearson coefficient of correlation between them, which would make obtaining a unique closed-form solution impossible. Ideally, all explanatory variables, including economic indicators, should therefore be only weakly correlated with each other.

Matching Data

If existing data are augmented by other data, the question arises of how to efficiently match them. In Lucko's (2003) study, the auction records were categorized with size parameters, normalized by list prices, corrected for inflation, and matched with economic indicators for the respective dates. A size parameter catalog was assembled from manufacturers and their distributors in analogy to the list price catalog. Size parameters characterized the equipment by its performance or capacity, e.g. standard operating weight (empty), general purpose bucket volume, and net horse power (flywheel). Minor conversions and rounding between English and metric units were performed. Rather than introducing an explanatory variable for size, a separate model was created for each smaller, but more consistent category to improve the goodness-of-fit. A computer macro called *MatchData* was reading unique identifiers in each row of the existing data, looped through a given block of new data, and in case of a match wrote the new data next to the existing. For list prices and size parameters, the identifier was the model name; for economic indicators it was the auction date.

Normalization

It is often useful to normalize variables to make them comparable across categories. All values are divided by their respective values from a baseline variable. In the residual value study, the dollar values were divided by their manufacturers' suggested retail prices, also known as list price. Actual initial sales prices would have been ideal, but in their absence for proprietary reasons, list prices had to be assumed to be generated in a sufficiently consistent manner across manufacturers (Lucko 2003). List prices are also devoid of discounts that specific companies may receive and thus less biased than purchase prices. They were collected from manufacturers and their distributors, interpolated across gaps and extrapolated to the necessary range with the inflation correction, and matched with the other data on auction sales and sizes.

Occasionally, a researcher may want to perform economic research on assets that do not have identical attributes. Units of construction equipment can vary in many regards. Mitchell used a cumulative cost index (CCI) instead of raw dollar figures to help normalize data for differing construction equipment. The differences between the machines could be characterized as physical and usage differences. Physical differences can be seen just by looking at the machine, e.g. type (bulldozer, scraper, etc.), size, and make (Caterpillar, Volvo, etc.). Usage differences are less apparent. This category relates to the application the machine normally performs and to the company that owns the machine. Repair costs, as well as initial purchase price, can differ considerably between the different categories. Mitchell (1998) was able to compare unlike machines by indexing their repair costs to their initial list price to develop prediction equations. Eq. 2 was used to calculate the final response variable:

$$CCI_t = \frac{\sum_0^t (P_t + L_t + O_t) + PP_0}{PP_0} \quad \text{Eq. 2}$$

where CCI_t is the cumulative cost index at time t, P_t is the cost of parts at time t, L_t is the cost of labor at time t, O_t are other maintenance costs at time t, and PP_o is the list price of the machine. Parts, labor, and other maintenance costs were cumulative. The CCI provided the common ground for comparisons between non-identical machines.

PREPARATION FOR STATISTICAL ANALYSIS

Outliers

Considering that data may be faulty without being detectable, e.g. from measurement errors, it is prudent to prepare a dataset that has been purged of these so-called outliers. Such extreme data differ significantly from the basic relationship captured by the other data, either in their sign or magnitude and can often be visually identified in a scatter plot. They can substantially distort regression models. Statistical techniques can identify them. Residuals measure how much a data point deviates from the value that is predicted by the model. Scaled residuals are recommended for their constant variance (Montgomery *et al.* 2001). An `IF` formula in a new column marked data points for removal if the absolute value of their residual exceeded 3 (Montgomery *et al.* 2001). The final model coefficients were then based on the 'cleaned' dataset.

Relative Dominance

A statistical issue that manifests itself in the data collected by Mitchell (1998) was that of relative dominance. Some machines had more data pairs than other machines. This was due to differences in usage, dates of purchase, or data collection styles of the companies involved. Machines that had more data pairs could have had more of an influence on the regression analysis than those with fewer pairs had. The way that relative dominance was addressed was to use interpolated values of the CCI at discrete, evenly spaced intervals. What is important to emphasize is that *there should only be one interpolated data pair between any two actual data pairs*. The interpolation of more than one data pair between actual data pairs would be the creation of more data than actually exist. The cumulative usage interval selected must support the interpolation rule. Mitchell (1998) found 500-hour intervals to work well.

Variable Selection

Note that for observational studies, including research that uses existing data from construction companies, no causality can be established statistically. Nonetheless, predictive models with high confidence levels can still be created by carefully selecting their components and structure. Various techniques exist for researchers to identify and understand the possible contributions of their explanatory variables to a statistical model. A scatter plot of the dataset should be visually inspected to identify any trends or patterns, e.g. linear dependencies. If several explanatory variables exist, their possible pairs yield a triangular matrix of scatter plots, which can identify pairwise interactions that may be included as separate terms. Such initial observations assist in determining the model composition, i.e. which mathematical function to use, what order of variable terms, and what interaction terms between them, if any.

Three techniques can be used to statistically select appropriate explanatory variables for being included in a regression model: Forward selection, backward elimination, and stepwise selection (Montgomery *et al.* 2001). Forward selection starts with an 'empty' model, tests which variable is most significant if added, adds it, and tests the remaining variables. Backward elimination is the inverse, sequentially removing least significant variables from a 'full' model, and assists in quickly discarding unwanted variables. Stepwise selection extends forward selection by alternating between adding and removing to arrive at the best model. Despite these techniques, statistical modeling still depends on the conscious researcher and remains both art and science.

CONCLUSIONS

This paper has described how different types of existing data in the area of construction engineering and management can be prepared in a valid manner while preserving their integrity. It included validating the sample size, handling confidential data, unifying the format, filling missing values as far as possible, checking the dataset for various types of inconsistencies, matching data with each other, performing an inflation adjustment on financial data, removing outliers and selecting what explanatory variables to ultimately include in the model. While each study of existing data will present the researcher with unique problems, these guidelines are hoped to serve as a reference and source of inspiration in surmounting the crucial, often underestimated phase between collecting data and being able to analyze them.

REFERENCES

Bodie, Z., Kane, A., Marcus, A. J. (2002). *Investments*. 5th ed., McGraw-Hill, New York, NY.

Cross, T. L., Perry, G. M. (1995). "Depreciation patterns for agricultural machinery." *American Journal of Agricultural Economics* 77(1): 194-204.

Cross, T. L., Perry, G. M. (1996). "Remaining value functions for farm equipment." *Applied Engineering in Agriculture* 12(5): 547-553.

Kastens, T. (1997). "Farm machinery operation cost calculations." Farm Management Guide MF-2244, Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, KS.

Lucko, G. (2003). *A statistical analysis and model of the residual value of different types of heavy construction equipment.* Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Mitchell, Z. W. (1998). *A statistical analysis of construction equipment repair costs using field data & the cumulative cost model.* Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Montgomery, D. C., Peck, E. A., Vining, G. G. (2001). *Introduction to Linear Regression Analysis.* 3rd ed., John Wiley & Sons, New York, NY.

Severson, G. D., Russell, J. S., Jaselskis, E. J. (1994). "Predicting contract surety bond claims using contractor financial data." *Journal of Construction Engineering and Management* 120(2): 405-420.

RISK ASSESSMENT FOR WATER MAINS USING FUZZY APPROACH

H. Fares[1] and T. Zayed[2].

[1] Former Graduate Student, Department of Building, Civil, and Environmental Engineering, Concordia University, Montreal, Quebec, Canada.
Email: hussamfa@hotmail.com
[2] Associate Professor, Department of Building, Civil, and Environmental Engineering, Concordia University, Montreal, Quebec, Canada.
Email: zayed@encs.concordia.ca

Abstract

The concept of responding to the risk of water pipelines failure has been undergoing through a great change from being active to being proactive to failure events by planning for rehabilitation plans that maintain the water main in good working conditions. This paper designs a framework to evaluate the risk of water main failure using hierarchal fuzzy expert system. There are sixteen risk-of-failure factors that represent both the probability of failure and the negative consequences of failure event and are categorized into four main risk-of-failure factors. A risk of failure model is built that evaluates the risk of pipelines failure using Fuzzy Expert System technique that accounts for the uncertainty usually encountered when evaluating the risk of failure. Some of the findings are that the pipe age gives a strong indication of the condition of the water mains, then, the pipe material and breakage rate come into play, and that the damage to surroundings/business disruption has the most negative impact of a failure event.

1. INTRODUCTION

In a recent survey conducted by the United States Environmental Protection Agency, it is estimated that $77 billion will be needed to repair and rehabilitate the water main over the next 20 years (Selvakumar *et al.* 2002). In Canada and the United States, on average, there are more than 700 water main breaks every day (Infrastructure Report, 2007). Providing communities with reliable and safe water has become more and more a topic of concern. The breakage rate and the high associated costs of failure have reached a level that now draws the attention of both the public and the decision makers.

A new model to evaluate the risk of water main failure is proposed here. Deterioration factors that lead to the failure event and the consequence factors that result from the failure event (failure impact) are considered in this research. In order to guide the water main management team to the best management plan, a risk scale of failure is proposed that highlights a water main at various risk stages.

The objectives of the current research can be summarized as follows:

- Design a risk model of water main failure to evaluate the risk associated with each pipeline in the network.
- Propose a risk scale of failure that provides guidance to decision makers.

2. LITERATURE REVIEW

Risk is defined by InfraGuide (2006) as the combination of the probability and impact severity of a particular circumstance that negatively impacts the ability of infrastructure assets to meet the objectives of the municipality. Moreover, the probability is defined as the likelihood of an event occurring. Pipeline failure is defined as *the inability to satisfy basic requirements from the distribution system, failure to satisfy customer demand or failure to maintain pressures within specific limits*. The types of water distribution failure can be categorized into: 1) performance failure and 2) mechanical failure (Ozger, 2003). In this paper, only the risk of water main mechanical failure is considered. The mechanical failure factors are either static (material, diameter, wall thickness, soil, installation), dynamic (age, temperature, soil moisture and electrical characteristics, resistivity, and loading), or operational (replacement rates, cathodic protection, water pressure) (Kleiner and Rajani, 2000; Kleiner and Rajani, 2002; Kleiner et al. 2006; Pelletier et al. 2003).

A judgment of the potential consequences is inherent in any risk evaluation. Consequence implies a loss of some kind. Losses can be quantified into direct costs and indirect costs. Example of the direct costs are property damage, damages to human health, environmental damage, loss of production, repairs costs, cleanup and remediation costs, and so on. Some of the indirect costs are litigation and contract violations, customer dissatisfaction, political reactions, loss of market share, and government fines and penalties (Muhlbauer, 2004; Bhave, 2003). Some of these consequences are monetized in a straight forward process. However, for indirect consequences, it is more difficult to quantify the consequences in a monetary value (Muhlbauer, 2004). Consequence of failure is different among pipelines and varies with time relative to a business cycle. It is also affected by pipeline flow load and by the generated revenue from that pipeline (Nikolaidis *et al*. 2005).

The review of work of other researches and various efforts related to water main failure risk helps insight the research and problem solving process. In this context, some other works are reviewed as follows. Christodoulou *et al*. (2003) used Artificial Neural Networks (ANN) to analyze the preliminary water main failure risk in an urban area with historical breakage data spanning two decades. Yan and

Vairavamoorthy (2003) proposed a methodology to assess pipeline condition using Multi-Criteria Decision Making (MCDM) techniques which combine the available pipe condition indicators into one single indicator. Kleiner *et al*. (2004) used a fuzzy rule-based, non-homogeneous Markov process to model the deterioration process of buried pipes. Sadiq *et al*. (2004) developed a methodology for evaluating the time-dependent reliability of underground grey cast iron water mains, and for identifying the major factors that contribute to water main failures. Kleiner *et al*. (2006) developed a methodology to evaluate pipeline failure risk using the fuzzy logic technique. Rajani *et al*. (2006) used a fuzzy synthetic evaluation technique to translate observations from visual inspection and non-destructive tests into water main condition ratings. Al-Barqawi (2006) designed two condition rating models for water mains using artificial neural networks (ANN) and the analytical hierarchy process (AHP). Rogers (2006) developed a model to assess water main failure risk using the Power Law form of a Non-Homogeneous Poisson Process (NHPP) and Multi-Criteria Decision Analysis (MCDA) based on the Weighted Average Method.

From the literature review, it is obvious that the works that have addressed the problem of water main failure risk have certain limitations, and therefore a research that addresses the problem with a broad, concrete, and robust approach is still needed. Certain researchers have approached the problem in too shallow fashion, considering very few risk factors which sometimes were limited to only the deterioration factors. Moreover, some of these researches were so complicated in their derivation and usage that different municipalities and authorities management teams are reluctant to use and depend on them. Other efforts were too specific to certain network characteristics (such as pipe material, diameter, function, etc…) and thus are not applicable to different water distribution networks. The most relevant and solid research was done by Rogers (2006); however, there are some limitations inherent to his research such as: the model uses the weighted average method which does not address the uncertainty and the model is too sensitive to the weights of the factors. Moreover, Rogers' failure consequence model is not well-established and depends solely on the input of the model user. In addition, some of the risk factors are derived from a specific data set and seem to be more reflective of that data set instead of reflecting the state of the art.

Based on this exhaustive literature review, it is clear that there is a need to address the problem of water main failure risk using a technique such as fuzzy logic that can be used as a tool to deal with imprecision and the qualitative aspects that are associated with problem solving and in the development of expert systems. Fuzzy expert systems use the knowledge of humans, which is qualitative and inexact. In many cases, decisions are to be taken even if the experts may be only partially knowledgeable about the problem domain, or data may not be fully available.

3. RESEARCH METHODOLOGY

The research methodology consists of many stages. It starts with a full literature review of the risk of water main failure followed by data collection (to build the model). A hierarchical fuzzy expert system (HFES) is developed using model

information data. The next part of the research methodology is to develop a risk scale of failure which will guide the network operators to best manage their networks.

4. DATA COLLECTION

The information needed to develop the model consists of two parts: factors' weights and factors' performance impact. The majority of information is gathered from the literature. The information that can not be collected from the literature is collected via a questionnaire.

5. HIERARCHAL FUZZY EXPERT SYSTEM FOR WATER MAIN RISK OF FAILURE

5.1 Risk Factors Incorporated in the Model

In this step, the failure risk factors are identified and selected. Sixteen factors are incorporated in this model, which represents the deterioration and post-failure factors. The deterioration factors chosen to be incorporated in this model are selected based on the ease of gaining the required attributes of the water main by the facility managers. These attributes can be gathered from different types of documents such as: design information, visual inspection reports, maintenance reports, etc. The cost of failure and consequence factors are difficult to quantify and thus a qualitative approach will be followed. The factors selected to be incorporated in the pipeline failure risk model are shown in Figure 1.

5.2 Hierarchical Fuzzy Model

The hierarchical fuzzy model structure consists of four branches (models) which correspond to the four main factors and another model that combines the results of the four branches of the hierarchy to produce risk of failure. The fuzzy structure of each of the five models is identical and only the membership functions of each factor in each model and the knowledge base rules of each model are different. The full view of the hierarchical fuzzy model is shown in Figure 2 which shows the processing of the observations characteristics of the water main network.

5.3 Fuzzy Sets Definitions and Membership Functions

The membership functions of the different factors are built based on the information gathered from the literature, such as the characteristics of each factor, and the effects of these characteristics on the risk of failure. The qualitative factors are evaluated on a 0-10 scale and assigned a standard five membership functions.

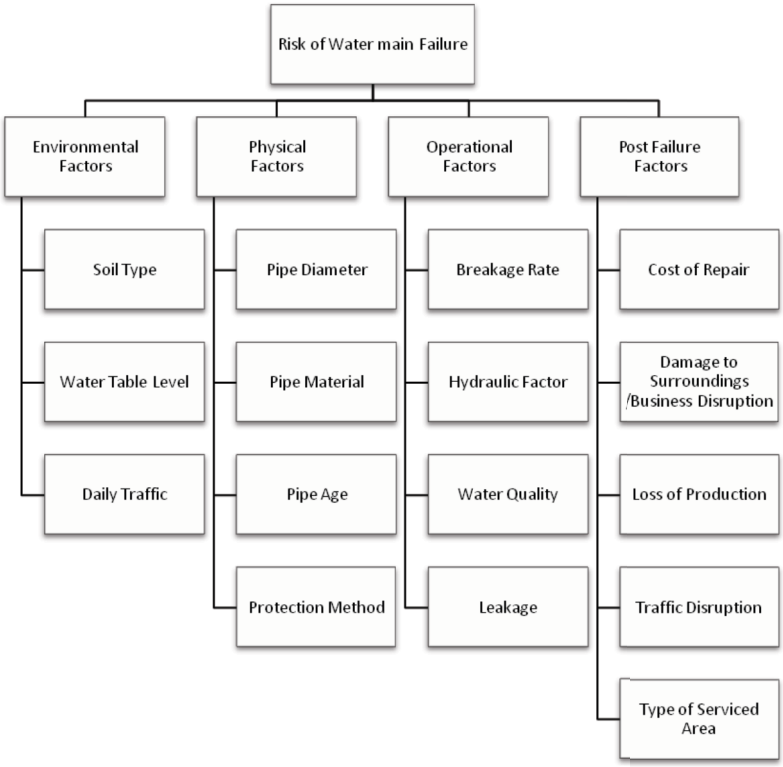


Figure 1 – Hierarchical risk factors of water main failure.

5.3 Fuzzy Inference

In this research, the indirect knowledge acquisition method (by means of a questionnaire and the available literature) is used to develop the knowledge base of the risk of water main failure model. The Mamdani method is used in the model which is based on a simple structure of Min operations as follows (Jin, 2003):

$$R^j: If\ x_1\ is\ A_1^j\ and\ x_2\ is\ A_2^j\ and\ x_3\ is\ A_3^j\ and\ \dots x_n\ is\ A_n^j\ THEN\ y\ is\ B^j \quad (1)$$

Where R^j is the j-th rule, A_i^j $(j = 1,2,\dots N, i = 1,2,\dots n)$, B^j are the fuzzy subsets of the inputs and outputs respectively.

This rule can be written mathematically as (2 (Jin, 2003):

$$\mu_{R^j}(x_1, x_2, x_3, \dots, x_n, y) = \mu_{A_1^j} \wedge \mu_{A_2^j} \wedge \mu_{A_3^j} \dots \wedge \mu_{A_n^j} \wedge \mu_B \quad (2)$$

Where $\wedge$ denotes the minimum operator.

In this research, the consequent linguistic variable *B* is standardized on a list of seven linguistic variables (Extremely low, Very low, Moderately Low, Medium, Moderately High, Very High, and Extremely High as shown in Figure 3). This is applicable to each model of the five models (environmental, physical, operational, post failure, and risk of failure).

5.4 Consequents Aggregation

After evaluating each rule in the knowledge base, the membership value of each consequent membership function (output linguistic variable) is aggregated using a maximum operation as shown in (3. In other words, the maximum membership value of any consequent membership function (shown in Figure 3) is used to truncate that consequent membership function for later use in the defuzzification of the fuzzy output.

$$\mu_R(x_1, x_2, x_3, \ldots, x_n, y) = \bigvee_{j=1}^{N} [\mu_{R^j}(x_1, x_2, x_3, \ldots, x_n, y)] \quad (3)$$

Where $\bigvee$ denotes the maximum operation, *R* represents each of the consequent membership functions as standardized to the list of (Extremely low, Very low, Moderately Low, Medium, Moderately High, Very High, and Extremely High).

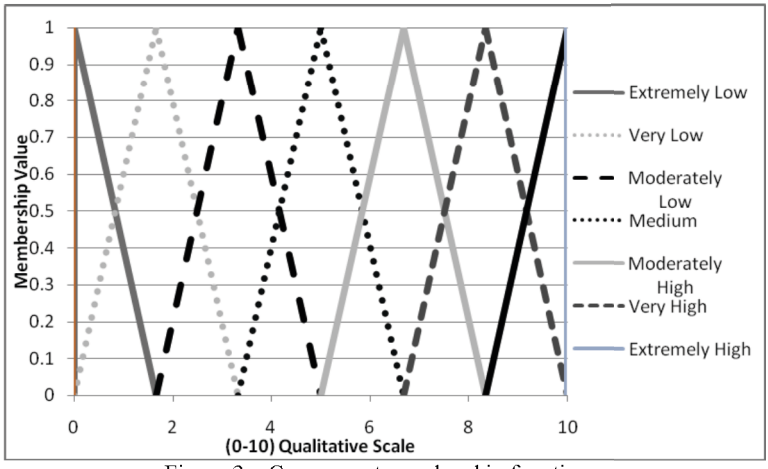


Figure 3 – Consequent membership functions.

5.5 Defuzzification Process

There are many defuzzification methods that convert the fuzzy consequents into a crisp value. The method used in this research is the Center of Sum which is shown in (4.

$$Crisp\ Risk\ Output = \sum_{n=extremely\ low}^{extremely\ high} Truncated\ Area_n \times Centeriod_n \Big/ \sum_{n=extremely\ low}^{extremely\ high} Truncated\ Area_n \quad (4)$$

This equation calculates the center of gravity of each truncated consequent membership function found from the previous step (neglecting the union operation) and then average-weights them by their areas. It has the advantage of being simple to program, requiring less computer resources, and it gives reasonable results.

5.6 Proposed Risk of Failure Scale

In light of the literature review, a risk of failure scale is proposed to help the decision makers in water main management companies/ municipalities make an informed decision. The scale ranges numerically from 0 to 10, where 10 indicates the riskiest condition of the pipeline and 0 indicates the least risky condition. Linguistically, the scale is divided into five groups or regions that describe the risk of pipeline failure. This scale is developed in the light of the literature review of the relating topic of different scales used in areas of infrastructure risk of failure and watermains condition assessment.

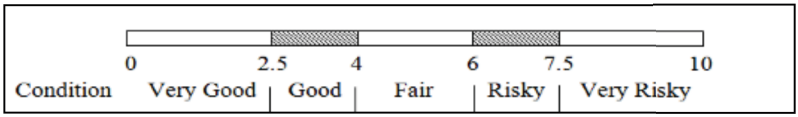


Figure 4 – Proposed risk of failure scale.

6. SENSITIVITY ANALYSIS

One of the model sensitivity tests scenarios is done by close testing of the factor that has the highest weight in the physical model. That is the Age factor tested at an increment of 10 years (fixing the rest of the physical factors at medium consequents) and draws a curve for the physical risk values (Figure 5). By analyzing the effect of age factor on the risk of failure values, one can observe that it is difficult to make a change in the risk of failure value by only changing the performance of one factor, since the other fifteen factors try to resist the change in the risk values.

Another scenario to examine the sensitivity of the model is done by close testing the physical model sensitivity towards change in the consequents of the two highest weighted factors (Age and Pipe material). This is done by fixing the values of the other physical factors at the medium consequents and at the same time changing the values of the factors under study from lowest to highest risks consequents. Analyzing the results of physical model sensitivity towards the age and pipe material factors and analyzing Figure 6 (which represents the examined five values of Age and Pipe material on the abscissa and their predicted risk of failure values on ordinate axis), it is obvious that the physical model is more sensitive toward the age factor.

Many other sensitivity test scenarios are conducted (not shown in this paper) which examines the sensitivity toward other risk of failure factors under different conditions and assumptions and examines other variables that effects the model performance such as the weight of the different factors.

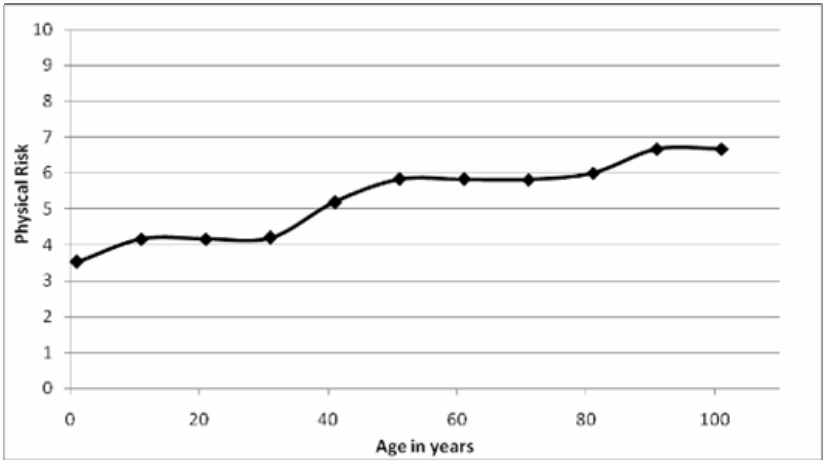


Figure 5 – Sensitivity analysis of Age factor on physical risk assuming other physical factors are present.

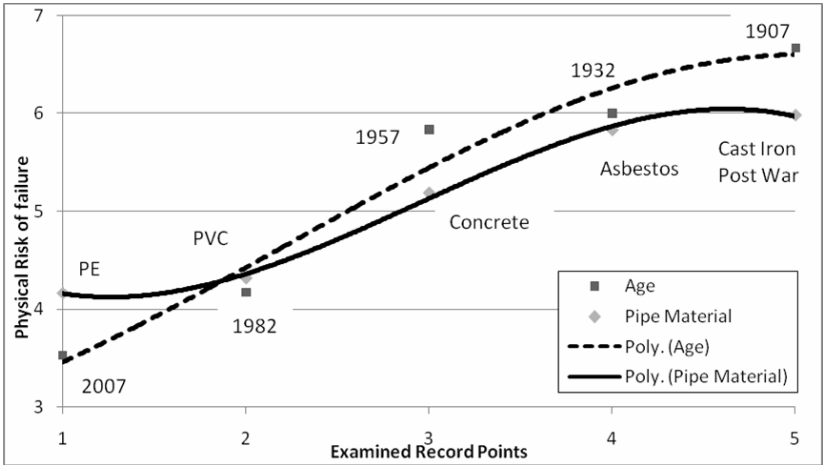


Figure 6 – Physical model sensitivity analysis of age and pipe material factors at medium risk level.

7. MODEL APPLICATION

In order to use the developed model to assess the risk of failure of watermains network, the different information and characteristics of the network pipelines can be collected and used as input data to the model. This information can be in quantitative forms (water table level, pipe diameter, material, age, protection method, breakage rate, Hydraulic factor (Hazen-William factor), Damage to surroundings, loss of production (diameter and pipeline redundancy) and type of serviced area) or qualitative on a scale (0 to 10) for other factors (soil type, daily traffic, water quality, leakage rate, cost of repair, and traffic disruption). The output of the model is a number that represents the risk of failure of each pipeline on a scale (0-10) as shown before.

8. CONCLUSIONS

The current research solves the challenge faced by municipalities and other authorities on prioritizing the rehabilitation works of their distribution water main. It offers a model to evaluate the risk of water main failure. The model considers many risk factors which can be divided broadly into deterioration factors that lead to the failure event and consequences factors that are resulted from the failure event (failure impact). Sixteen risk of failure factors are incorporated in the model (11 deterioration factors and 5 consequence factors). To build this model, hierarchal fuzzy expert system is used which considers the uncertainty in the water main attributes. From the developed model, it can be deduced that pipe age has the highest effect on risk of water main failure among the other factors then come pipe material and breakage rate. Municipal water main managers, consultants, and contractors can use the developed application to assess the risk of water main failure and to plan their rehabilitation works accordingly. One of the future works of this research is to incorporate the GIS in the model. This will lead to a more efficient use of recourses allocated for the rehabilitation of the water mains network.

8. REFERENCES

Al Barqawi, H. (2006). “Condition Rating Models for Underground Infrastructure: Sustainable Water-Mains”. MS. Thesis, Concordia University, Montreal, QC, Canada.

Bhave, P. (2003). “Optimal Design of Water Distribution Networks”. Alpha Science Int'l Ltd., Oxford, UK.

Christodoulou, S., Aslani, P., and Vanrenterghem, A. (2003). “Risk Analysis Framework for Evaluating Structural Degradation of Water Mains in Urban Settings Using Neurofuzzy Systems and Statistical Modeling Techniques”. World Water and Environmental Resources Congress, ASCE, Philadelphia, PA, USA, 1-9.

Giustolisi, O., Laucelli, D., and Savic, D. (2006). “Development of rehabilitation plans for water mains replacement considering risk and cost-benefit assessment”. Civil Engineering and Environmental Systems, 23: 175–190.

InfraGuide, N. G. (2006). "Managing Risk". Decision Making and Investment Planning, <http://www.infraguide.ca/bestPractices/PublishedBP_e.asp#dmip> (Jan. 17, 2007).

Infrastructure Report, (2007). "The Water Main Break Clock", Canada Free Press, <http://www.canadafreepress.com/infrastructure.htm> (Jan. 23, 2008).

Jin, Y. 2003. "Advanced Fuzzy Systems Design and Applications". A Springer-Verlag Company, New York, USA.

Kleiner, Y., and Rajani, B. (2000). "Considering Time-dependent Factors in the Statistical Prediction of Water Main Breaks". AWWA Infrastructure Conference, Baltimore, MD, USA. 1-12.

Kleiner, Y., and Rajani, B. (2002). "Forecasting Variations and Trends in Water-Main Breaks". Journal of Infrastructure Systems, 8: 122-131.

Kleiner, Y., Sadiq, R., and Rajani, B. (2004). "Modeling Failure Risk in Buried Pipes Using Fuzzy Markov Deterioration Process". Pipeline Engineering and Construction: What's on the Horizon?, ASCE, San Diego, CA, USA, 1-12.

Kleiner, Y., Rajani, B., and Sadiq, R. (2006). "Failure risk management of buried infrastructure using fuzzy-based techniques". Journal of Water Supply Research and Technology : Aqua , 55: 81-94.

Muhlbauer, W. K. (2004). "Pipeline Risk Management Manual", 3rd ed., Gulf Professional Publishing, Burlington, Ontario, Canada.

Nikolaidis, E., Ghiocel, D., and Singha, S. (2005). "Engineering design reliability handbook", CRC Press, Florida, USA.

Ozger, S. (2003). "A semi-pressure-driven approach to reliability assessment of water distribution networks". PhD Dissertation, Arizona State University, Arizona, USA.

Pelletier, G., Mailhot, A., and Villeneuve, J. (2003). "Modeling Water Pipe Breaks-Three Case Studies". Journal of Water Resources Planning and Management 10 , 129: 115–123.

Rajani, B., Kleiner, Y., and Sadiq, R. (2006). "Translation of pipe inspection results into condition ratings using the fuzzy synthetic evaluation technique". Journal of Water Supply Research and Technology: Aqua, 55: 11-24.

Rogers, P. (2006). "Failure Assessment Model to Prioritize Pipe Replacement in Water Utility Asset Management". Phd Dissertation, Colorado State University, Colorado, USA.

Sadiq, R., Rajani, B., and Kleiner, Y. (2004). "Probabilistic risk analysis of corrosion associated failures in cast iron water mains". Reliability Engineering and System Safety, 86: 1-10.

Selvakumar, A., Clark, R., and Sivaganesan, M. (2002). "Costs for Water Supply Distribution System Rehabilitation". Environmental Protection Agency, New Jersy, USA.

Yan, J., and Vairavamoorthy, K. (2003). "Fuzzy Approach for Pipeline Condition Assessment". New Pipeline Technologies, Security, and Safety, ASCE, Baltimore, MD, USA, 467-476.

AN AUTOMATED SYSTEM FOR OPTIMIZING TEMPORARY HOUSING ARRANGEMENTS AFTER NATURAL DISASTERS

Omar El-Anwar[1], Khaled El-Rayes[2], and Amr Elnashai[3]

ABSTRACT

Post-disaster temporary housing programs have often been criticized due their inability to fulfill the socioeconomic and safety needs of the displaced families and for being overly expensive. Impact assessment software systems, such as HAZUS-MH (FEMA) and MAEviz (Mid-America Earthquake Center), enable emergency planners to estimate post-disaster housing damage and displacement of families. This paper presents the development of an automated temporary housing planning system, which incorporates a preparedness model and a response model. These models are currently being integrated in MAEviz to support decision-makers in (1) identifying available temporary housing resources prior to a disaster; and (2) identifying optimal configurations of post-disaster temporary housing arrangements, which satisfy the safety and socioeconomic needs of displaced families, while minimizing public expenditures. A large-scale application example is provided to demonstrate the capabilities of the system in identifying feasible temporary housing alternatives and generating optimal trade-offs among different optimization objectives.

INTRODUCTION

In the aftermath of natural disasters, temporary housing solutions are essential to enable displaced families reestablish their household daily activities until permanent housing solutions can be provided (Quarantelli 1985). Natural disasters, such as Hurricanes Katrina and Rita (2005), demonstrated that the Federal Emergency Management Agency (FEMA) needs to enhance its preparedness to quickly provide temporary housing for large numbers of displaced families (FEMA 2008). Finding suitable temporary housing locations is one of the main challenges in the rapid

[1] Ph.D. Candidate, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, e-mail: elanwar2@illinois.edu
[2] Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, e-mail: elrayes@illinois.edu
[3] Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, e-mail: aelnash@illinois.edu

provision of temporary housing (Johnson 2002), and accordingly there is a need to identify potential temporary housing locations prior to a disaster (Chandler 2007).

Temporary housing decisions have significant impacts on the safety and socioeconomic welfare of displaced families (El-Anwar et al. 2008). In an effort to fulfill the safety and socioeconomic needs of displaced families, FEMA sets guidelines for selecting temporary housing sites that seek to (1) avoid potential hazards, such as floodplains and hazardous materials sites; and (2) consider socioeconomic impacts of temporary housing locations, such as capacity to support needed utilities, access to essential services, and neighborhood safety and crime levels (FEMA 2007). Temporary housing programs, however, have often been criticized due to their inability to select safe locations away from potential post-disaster hazards (Chandler 2007) and address the socioeconomic needs for displaced families (Bolin 1982; Bolin and Bolton 1986; Friday 1999; Golec 1983; Johnson 2007; Lizarralde and Johnson 2003), in addition of being overly expensive (Friday 1999; Johnson 2007).

A number of impact assessment software systems, such as MAEviz (Elnashai et al. 2008a; Elnashai et al. 2008b) and Hazards United States-Multihazard (HAZUS-MH), have been developed to enable emergency planners in FEMA to estimate housing damage and displacement of families in the aftermath of possible natural disasters (HAZUS-MH 2007; MAEviz 2008). Despite the important capabilities of these systems, they lack the features necessary for optimizing temporary housing arrangements after natural disasters.

The objective of this paper is to present the development of an automated system to support decision-makers in (1) evaluating the availability of adequate temporary housing alternatives using a newly developed preparedness model; and (2) identifying optimal configurations of temporary housing arrangements that would maximize temporary housing safety, while minimizing socioeconomic disruptions and expenditures on temporary housing using a newly developed response model. It should be noted that MAEviz software is currently being expanded to include the developed system. MAEviz is seismic risk assessment open-source software developed by the Mid-America Earthquake Center in cooperation with the National Center for Supercomputing Applications.

PREPAREDNESS MODEL

The preparedness model is designed to enable emergency management agencies to identify available temporary housing alternatives in each locality and their characteristics, and estimate the needs for additional temporary housing. To this end, this model consists of three phases, which are designed to (1) estimate temporary housing needs; (2) identify temporary housing alternatives; and (3) analyze temporary housing locations, a shown in Fig. 1.

Estimating Temporary Housing Needs

This phase enables decision-makers to estimate temporary housing needs in any locality while preparing for a possible disaster and it consists of two main steps: (1) estimating the number of displaced families; and (2) estimating the temporary housing needs. In the first step, decision-makers can utilize MAEviz to estimate the

number of displaced families in the aftermath of possible earthquakes (MAEviz 2008). In case of other disasters, such as hurricanes, the model is designed to enable decision-makers to input estimates of displaced families from external files to MAEviz. These estimates can be obtained from historical data or using another impact assessment software such as HAZUS-MH (HAZUS-MH 2007). In the second step, the model enables decision-makers to define the percentage of displaced families that are expected to need temporary housing solutions. Accordingly, the model can be used to estimate the temporary housing needs in the studied locality.

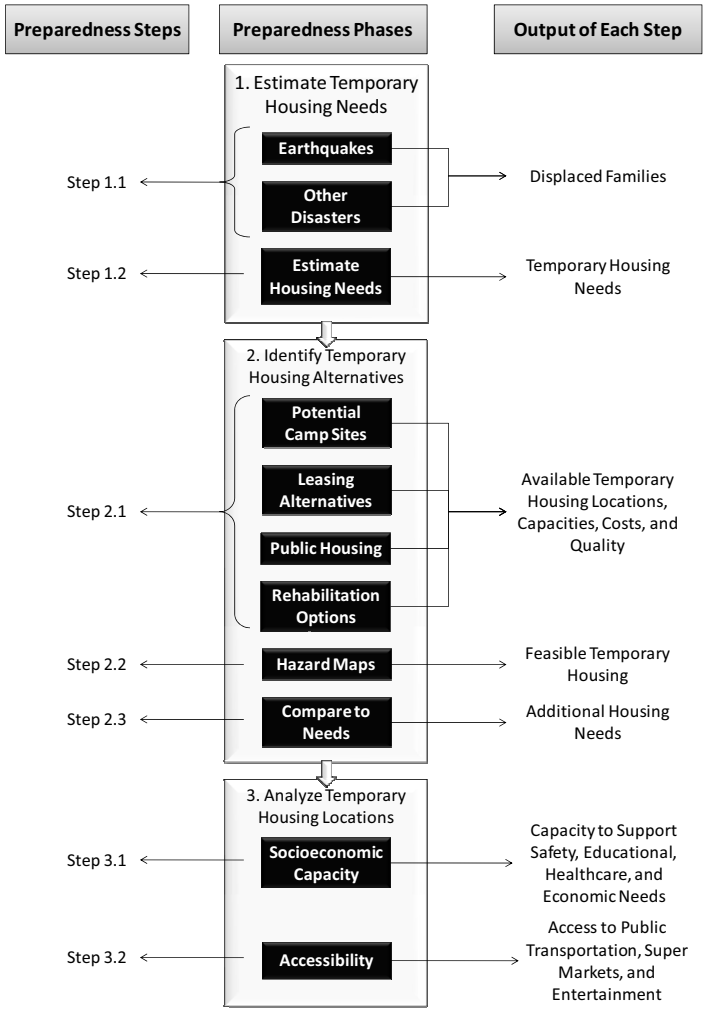


Fig. 1. Preparedness Model

Identifying Temporary Housing Alternatives

This phase incorporates three main steps in order to enable decision-makers to identify available temporary housing alternatives in the studied locality and estimate any shortage of temporary housing. First, emergency management agencies can identify available temporary housing alternatives as well as their locations, capacities to accommodate displaced families, monthly ownership or lease costs, and housing quality. The required data about these alternatives can be collected prior to a disaster using various methods, including (1) identifying potential sites for temporary housing alternatives such as mobile homes and travel trailers, and the required infrastructure and lifelines systems for each site; (2) creating a website to enable providers of leasing alternatives, such as hotels and motels, to identify their capacities to house displaced families in case of disasters and other information, such as costs and locations; (3) estimating available public housing units for use in case of a disaster, which can be updated later in the response phase to specify the exact number of available units after the disaster; and (4) identifying other possible temporary housing options, such as military bases and public schools, and their required set-up time and capacities. The model enables decision-makers to input a temporary housing database to MAEviz to store collected data about all available temporary housing alternatives in the studied locality.

The second step is designed to asses the feasibility of using the available temporary housing alternatives according to their vulnerability to potential post-disaster hazards, such as earthquake aftershocks, landslides, floodplains, and hazardous material releases (Gallagher et al. 1999; Keefer 2000; Lindell and Perry 1997; Pearce and Watson 1986; Wang et al. 2007; Young et al. 2004). To this end, the model enables decision-makers to input hazard maps to MAEviz, in addition to other relevant information about the potential hazards, such as (1) their probabilities of occurrences; (2) expected extent of damage to each temporary housing type; and (3) hazardous buffer areas around these potential hazards in which there should not be any temporary housing. This data is necessary to identify feasible temporary housing alternatives in the preparedness model and to enable maximizing temporary housing safety in the response model. Accordingly, the model computes a safety index for each temporary housing alternative, and identifies infeasible temporary housing alternatives which are located within the hazardous buffer areas using the GIS capabilities in MAEviz. Fig. 2 shows an example of feasible and infeasible temporary housing alternatives identified by the model in the presence of three potential hazards.

The third step in this phase is necessary to identify any shortage in temporary housing in the studied locality. The total capacity of feasible temporary housing alternatives is compared to the estimated number of families in need of temporary housing and the comparison results are provided to the decision-maker. In case there is enough temporary housing, the decision-maker can proceed to the next phase. Otherwise, decision-makers in emergency management agencies are informed that they need to prepare for or provide additional temporary housing alternatives.

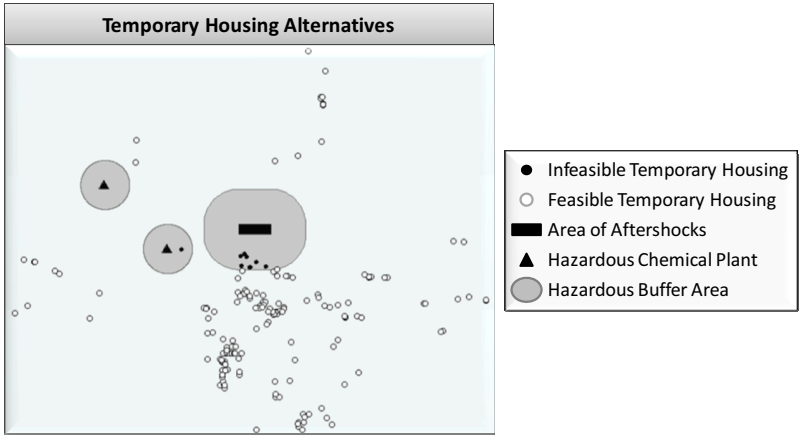


Fig. 2. Identifying Feasible Temporary Housing Alternatives

Analyzing Temporary Housing Locations

This phase enables decision-makers to analyze temporary housing locations in order to provide the response model with necessary information to minimize socioeconomic disruption for displaced families. This phase considers only feasible temporary housing alternatives, and consists of two main steps. The objective of the first step is to identify the capacity of temporary housing locations to support the safety, educational, healthcare, and economic needs of the displaced families, which has significant impact on the level of socioeconomic disruption experienced by the displaced families (El-Anwar et al. 2008). Accordingly, the model enables decision-makers to input reported crime rates at the temporary housing locations or neighborhoods to measure the locations capacity to support safety needs. Similarly, decision-makers can input the capacities of nearby schools and hospitals to measure ability of the housing location to support the educational and healthcare needs. Moreover, median household incomes and unemployment rates at the temporary housing zip codes can be obtained from the U.S. Census Bureau and used to measure the location capacity to support economic needs.

The objective of the second step is to identify the accessibility of temporary housing locations to essential utilities and services, such as public transportation, public services, supermarkets, retail stores, entertainment, and recreational activities. Accordingly, the model enables decision-makers to input the level of accessibility of each temporary housing alternative to MAEviz using a numerical value. The model then identifies a socioeconomic disruption index based on collected data in both phases of identifying and analyzing temporary housing alternatives, which is used in the response model to minimize socioeconomic disruptions for displaced families. It should be noted that the model provides decision-makers with the flexibility of selecting form the previously mentioned socioeconomic factors, in addition to adding other factors.

RESPONSE MODEL

The response model is designed to enable emergency management agencies to identify and analyze optimal temporary housing configurations in order to select an optimal implementation plan in the aftermath of a natural disaster. To this end, this model consists of three phases that are designed to (1) identify temporary housing needs; (2) identify optimal temporary housing configurations; and (3) analyze these optimal configurations, a shown in Fig. 3.

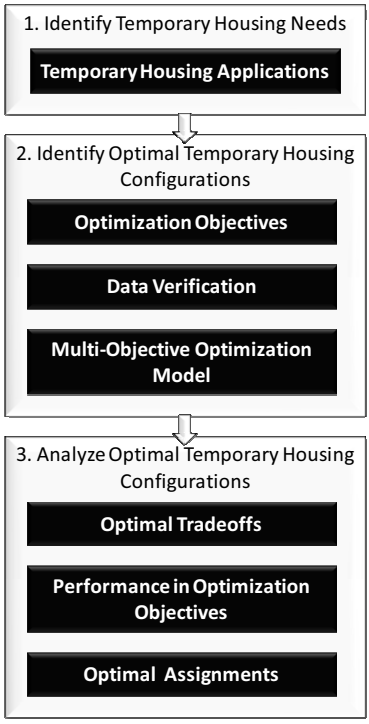


Fig. 3. Response Model

Identifying Temporary Housing Needs

The objective of this phase is to identify the number of families in need of temporary housing during the post-disaster response phase. In order to speed the process of applying for temporary housing, an online application can be offered in addition to the traditional methods. The model enables decision-makers to input the number of families in need of temporary housing and update the temporary housing database to accurately represent the post-disaster situation. The model compares the temporary housing needs to the total capacity of feasible temporary housing. If there is sufficient temporary housing, the decision-maker can proceed to the following optimization process.

Identifying Optimal Temporary Housing Configurations

This phase is designed to identify the optimal configurations of temporary housing arrangements using three main steps, as shown in Fig. 3. First, the model enables decision-makers to define the required optimization objectives, which can be performed by (1) selecting from the default objectives in the model that include maximizing temporary housing safety using the computed safety indexes in the preparedness phase, minimizing socioeconomic disruptions for displaced families using collected socioeconomic data about temporary housing alternatives, and minimizing public expenditures on temporary housing using their monthly costs; and/or (2) defining additional optimization objectives, if need be. In the second step, MAEviz verifies the completeness of the input data necessary to optimize the default and user-defined objectives. In case of identifying missing data, MAEviz enables decision-makers to input this required optimization data. In the third step, the model generates optimal tradeoffs among the defined optimization objectives by incorporating the multi-objective optimization model developed by El-Anwar et al. (2008) in MAEviz software. This optimization model generates unique combinations of relative weights among the optimization objectives using a pre-defined weight increment. Each unique combination of weights represents a unique optimization problem, and is solved using integer programming to generate a unique optimal tradeoff solution. Each of the generated optimal tradeoff solutions corresponds to a unique optimal configuration of temporary housing arrangements.

Analyzing Optimal Temporary Housing Configurations

The objective of this phase is to enable decision-makers to analyze the generated optimal configurations of temporary housing arrangements, using three main output capabilities, as shown in Fig. 3. First, decision-makers can use two dimensional graphs to visualize the optimal tradeoff solutions between any two optimization objectives. Second, the model enables decision-makers to select any optimal solution and view its performance in each of the optimization objectives. The third capability provides decision-makers with the optimal assignments of families among feasible temporary housing alternatives, which represents the optimal configuration of temporary housing arrangements. These capabilities enable decision-makers to analyze all the generated optimal solutions, and select an optimal temporary housing plan for implementation in the aftermath of the disaster.

APPLICATION EXAMPLE

An application example is presented to demonstrate the capabilities of the proposed models in assisting decision-makers to optimize large-scale temporary housing problems after natural disasters. The example involves providing temporary housing arrangements for 10,000 displaced families in the aftermath of a major earthquake. A comprehensive online search was conducted, which identified data about 179 available temporary housing alternatives in the impacted area, with a total capacity of 25,305 families. In the preparedness phase, this date was provided to the model. The hazard maps of the impacted area include three potential post-disaster hazards, representing the aftershocks area and two locations of hazardous chemical plants, as shown in Fig. 2. After entering all required data, the preparedness model identified 9

infeasible temporary housing alternatives because of their existence in the hazardous buffer areas around potential hazards, as shown in Fig. 2. The 170 feasible temporary housing alternatives have a total capacity of 23,604 families, which is sufficient to house the displaced families.

The response model can also be used in the aftermath of the aforementioned natural disaster to identify optimal temporary housing plans that would minimize socioeconomic disruptions and public expenditures, while maximizing housing safety. For this example, the response model generated 66 unique optimal tradeoff solutions among the three optimization objectives using a 10% weight increment. Each of these solutions corresponds to a unique optimal configuration of temporary housing arrangements. Fig. 4(a) shows the optimal tradeoffs between two optimization objectives; namely minimizing socioeconomic disruptions for displaced families and minimizing public expenditures on temporary housing. Moreover, the details of optimal solution # 63 are shown in Fig. 4, which includes (1) its weights combination and performance in each optimization objective, as shown in Fig. 4(b); and (2) the corresponding optimal assignments of displaced families among feasible temporary housing alternatives, as shown in Fig. 4(c).

The computational time for optimizing this large-scale temporary housing problem was less than 1 minute on a 2.6 GHz Intel Pentium 4 processor with 2 GB of RAM. These results illustrate the practical computational requirements of the developed system for optimizing realistic temporary housing problems.

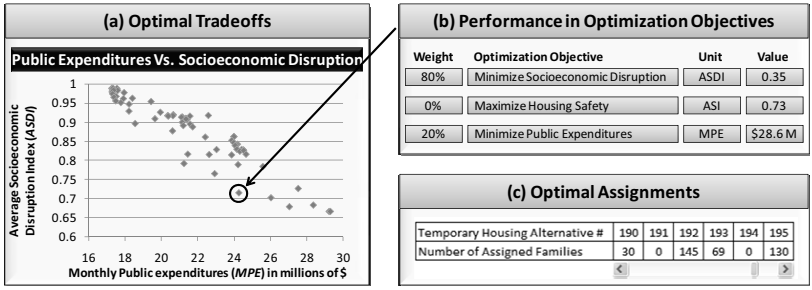


Fig. 4. Optimization Results

CONCLUSIONS

An automated temporary housing planning system is developed to support decision-makers in identifying available temporary housing resources prior to a disaster and developing optimal configurations of post-disaster temporary housing arrangements. The system is integrated in MAEviz (Mid-America Earthquake Center, MAEviz, 2008) and is capable of simultaneously optimizing a set of critical objectives, such as maximizing temporary housing safety, while minimizing socioeconomic disruptions for displaced families and minimizing public expenditures on temporary housing. In addition, the model offers decision-makers the flexibility to optimize other user-defined objectives. The system incorporates two main models: (1) a preparedness model that is capable of identifying available temporary housing alternatives in each locality and estimating any shortage in temporary housing; and (2) a response model

that is capable of identifying and analyzing optimal temporary housing configurations. An application example is presented to demonstrate the unique capabilities of the models in generating optimal trade-offs among the optimization objectives in an effective and efficient manner. The model should prove useful to emergency management agencies at the local and federal levels.

ACKNOWLEDGEMENTS

This material is based upon work supported by the Mid-America Earthquake Center and the National Science Foundation under NSF CAREER Award No. CMS 0238470. Any opinions, findings, and conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Bolin, R. (1982). "Long-term family recovery from disaster." Institute of Behavioral Science Monograph 36, University of Colorado, Boulder.

Bolin, R. C. and Bolton, P. (1986). Race, religion, and ethnicity in disaster recovery, Boulder, CO: Institute of Behavioral Science, University of Colorado.

Chandler, P. J. (2007). "Environmental factors influencing the siting of temporary housing in Orleans parish." MS Thesis, Louisiana State University, Baton Rouge, Louisiana.

El-Anwar, O., El-Rayes, K., and Elnashai, A. (2008). "Multi-objective optimization of temporary housing for the 1994 Northridge earthquake." *Journal of Earthquake Engineering*, 12(1), 81 — 91.

Elnashai, A., Hampton, S., Karaman, H., Lee, J.S., McLaren, T., Myers, J., Navarro, C., Sahin, M., Spencer, B., and Tolbert, N. (2008) (a). "Overview and Applications of Maeviz – HAZTURK 2007." *Journal of Earthquake Engineering*, 12(1), 100 — 108.

Elnashai, A., Hampton, S., Lee, J.S., McLaren, T., Myers, J., Navarro, C., Spencer, B., and Tolbert, N. (2008) (b). "Architectural Overview of MAEviz – HAZTURK." *Journal of Earthquake Engineering*, 12(1), 92 — 99.

FEMA (2007). "Emergency temporary group housing site selection guidelines - Minimizing environmental/historic/safety problems." Federal Emergency Management Agency, FEMA HQ, Regions 4 and 6, <http://www.fema.gov/pdf/plan/ehp/thsiteselection.pdf>, (November 15, 2007).

FEMA (2008). "FEMA evaluating non-traditional alternatives to trailers/mobile homes for future disaster housing." Federal Emergency Management Agency, Release number: HQ-08-028, <http://www.fema.gov/news/newsrelease.fema?id=42811>, (March 14, 2008).

Friday, B. E. (1999). "Rebuilding shelter after natural disasters: Three decades of USAID experience in Latin America and the Caribbean." Prepared for United States Agency for International Development, Contract No. PCE-I-00-96-00008-00, Delivery Order Number 3, PADCO, Inc.

Gallagher, R. P., Reasenberg, P. A., and Poland, C. D. (1999). "Earthquake aftershocks: Entering damaged buildings." Applied Technology Council, Redwood City, California, ATC TechBrief, No. 2.

Golec, J. (1983). "A contextual approach to the social psychological study of disaster recovery." *Journal of Mass Emergencies and Disasters*, 1, August, 255-276.

HAZUS-MH (2007). "HAZUS-MH Overview." <http://www.fema.gov/plan/prevent/hazus/hz_overview.shtm>, (January 8, 2008).

Johnson, C. (2002). "What's the big deal about temporary housing? Types of temporary accommodation after disasters: An example of the 1999 Turkish earthquake." *Proc., TIEMS 2002 International Disaster Management Conference*, University of Waterloo, 14-17 May, 2002. TIEMS, Canada.

Johnson, C. (2007). "Impacts of prefabricated temporary housing after disasters: 1999 earthquakes in Turkey." *Habitat International*, 31(1), 36-52.

Keefer, D. K. (2000). "Statistical analysis of an earthquake-induced landslide distribution — The 1989 Loma Prieta. California event." *Engineering Geology*, 58, 231–249.

Lindell, M. K. and Perry, R. W. (1997). "Hazardous materials releases in the Northridge earthquake: Implications for seismic risk assessment." *Risk Analysis*, 17(2), 147–156.

Lizarralde, G. and Johnson, C. (2003). "Houses of candied sugar: Comparative research on controversial temporary housing after earthquake disasters in Colombia and Turkey." *Proc., International Association for Housing Science World Congress on Housing Process and Product*, Montreal, Canada, 23–27 June, 2003. Montreal: IAHS.

MAEviz (2008). "MAEviz Software." Mid-America Earthquake Center, <http://mae.ce.uiuc.edu/software_and_tools/maeviz.html>, (Febraury 12, 2008).

Pearce, A. J. and Watson, A. J. (1986). "Effects of earthquake-induced landslides on sediment budget and transport over a 50-yr period." *Geology*, 14, 52-55.

Quarantelli, E. L. (1985). "Social support systems: Some behavioral patterns in the context of mass evacuation activities." in B. Sowder (ed.), Disasters and Mental Health: Selected Contemporary Perspectives. DHHS Publication 85-1421: Rockville, MD., 122-136.

Wang, H. B., Sassa, K., and Xu, W. Y. (2007). "Analysis of a spatial distribution of landslides triggered by the 2004 Chuetsu earthquakes of Niigata prefecture, Japan." *Natural Hazards*, (41), 43–60.

Young, S., Balluz, L., and Malilay, J. (2004). "Natural and technologic hazardous material releases during and after natural disasters: A review." *Science of the Total Environment*, 322, 3–20.

PLANNING POST-DISASTER RECONSTRUCTION EFFORTS OF DAMAGED TRANSPORTATION NETWORKS

Wallied Orabi,[1] Khaled El-Rayes,[2] Ahmed Senouci,[3] and Hassan Al-Derham[4]

ABSTRACT

Planning the reconstruction efforts of damaged transportation networks in the aftermath of natural disasters is a challenging task due to the limited availability of construction resources. The utilization of these limited resources can have a significant impact on the societal needs of minimizing the reconstruction costs and the performance loss of the damaged transportation network. These resources therefore need to be deployed and utilized in an effective and efficient manner that accomplishes these two critical objectives. This paper presents the development of a planning model for post-disaster reconstruction efforts for damaged transportation networks. The model is developed in four stages: (1) allocating the available reconstruction resources to competing recovery projects; (2) estimating the reconstruction costs; (3) measuring the performance loss during the recovery period; and (4) optimizing the reconstruction efforts to minimize reconstruction costs and performance loss. An application example is analyzed to illustrate the use of the model and demonstrate its capabilities in planning post-disaster reconstruction efforts.

KEYWORDS: Project Planning, Resource Allocation, Optimization, Recovery Planning, Reconstruction Efforts, Transportation, Network Analysis.

[1] Ph.D. Candidate, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801; PH (217) 265-5215; FAX (217) 265-8039; email: orabi@uiuc.edu

[2] Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801; PH (217) 265-0557; FAX (217) 265-8039; email: elrayes@uiuc.edu

[3] Associate Professor, Department of Civil Engineering, Qatar University, Doha, Qatar; PH (+974) 5809682; FAX (+974) 4851781; email: a.senouci@qu.edu.qa

[4] Vice President, Research, Qatar University, Doha, Qatar; FAX (+974) 4934754; email: alderham@qu.edu.qa

INTRODUCTION

The lack of reconstruction resources in the aftermath of natural disasters adds to the complexity of planning the recovery efforts for damaged transportation networks (Augusti et al. 1998). The deployment and utilization of these resources can have a significant impact on both the public expenditures on reconstruction efforts and the amount of service disruption experienced by travelers during the recovery period (Kozin and Zhou, 1990). Therefore, planners and decision makers need to carefully select a reconstruction plan that can effectively and efficiently accomplish the two critical societal objectives of minimizing the reconstruction costs and network performance loss, simultaneously.

A number of research studies were conducted to investigate various aspects of post-disaster reconstruction efforts. These studies focused on: (1) analyzing post-disaster procurement methods for reconstruction (Le Masurier et al. 2005); (2) developing loss estimation tools for disaster response (Huyck et al. 2006); (3) allocating available funds to transportation network recovery projects (Karlaftis et al. 2007); and (4) measuring the post-disaster performance of critical damaged infrastructure systems (Chang and Nojima 1998; Chang and Nojima 2001; Chen and Eguchi 2003; Nojima and Sugito 2000). Despite the contributions of these studies, there is no reported research that has focused on planning the reconstruction efforts for damaged transportation networks. In order to address this important research area, this paper presents the development of a reconstruction planning model that is capable of identifying the optimal reconstruction plan(s) that satisfy the above societal needs. As shown in Figure 1, the model is developed in four stages: (1) allocating the available reconstruction resources to competing recovery projects; (2) estimating the reconstruction costs; (3) measuring the performance loss during the recovery period; and (4) optimizing the reconstruction efforts to minimize reconstruction costs and performance loss. The following sections describe these four development stages.

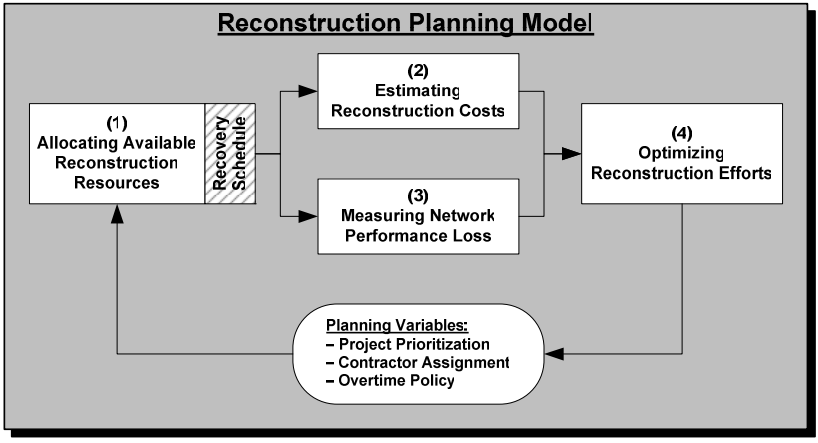


Figure 1. Reconstruction planning model

ALLOCATING RECONSTRUCTION RESOURCES

The main objective of this development stage is to calculate the recovery schedule for the damaged transportation network for a given set of planning variables including: (1) contractor assignment; (2) project prioritization; and (3) overtime policy. This includes allocating the limited reconstruction resources available to the competing recovery projects, as shown in Figure 2. To accomplish this task, the model uses the following three steps:

Step 1 – Generating Work Packages

Based on the contractor assignment identified in the given set of planning variables, the recovery projects are grouped in separate work packages and assigned to competing contractors, as shown in Figure 2. Each work package includes two types of data: the scope of work to be performed by the relevant contractor and the available resource data in the contractor's resource pool.

Step 2 – Deploying Resources to Recovery Projects

The project prioritization specified in the given planning variables is used to identify the execution order of the recovery projects in any work package, as shown in Figure 2. The reconstruction resources available in the contractor's resource pool are deployed to the recovery projects in a single work package based on the execution order of these projects. For example, the resources available in the work package assigned to contractor C2 are used first to complete the activities of project P7 before they can be deployed to the activities of project P3, as shown in Figure 2.

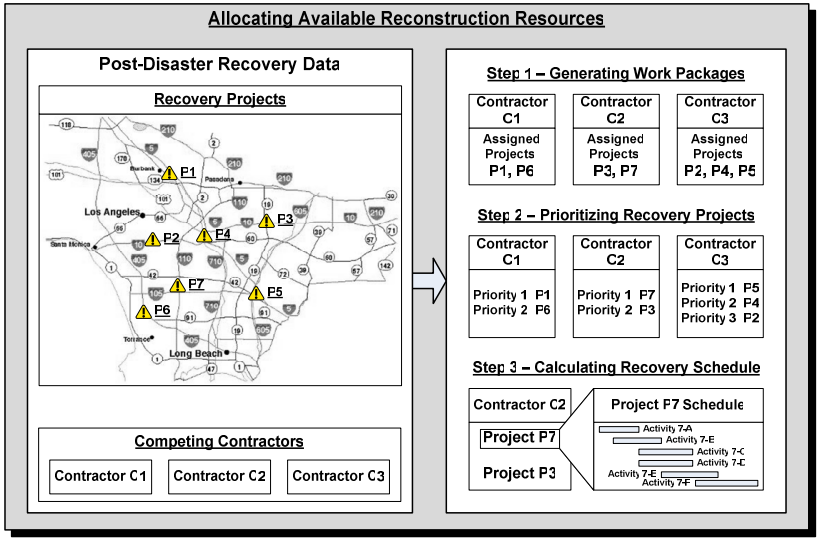


Figure 2. Allocation of available reconstruction resources

The following set of rules and assumptions is adopted by the present model in the process of deploying the reconstruction resources to the recovery projects:

- recovery projects can start with less than their full resource requirements and they can later receive additional resources as they become available;
- recovery projects cannot be interrupted once started;
- project durations are allowed to extend or shrink according to the number of resources assigned to a project and their availability dates; and
- once resources are no longer needed for a project, they are retuned to the resource pool of the contractor.

Step 3 – Calculating Recovery Schedule

Once reconstruction resources are deployed to a recovery project, the schedule of this project can be calculated, as shown in Figure 2. This involves identifying two pieces of information for each activity in that project: the start date and duration. First, the start date is identified as the latest of: (1) the earliest start date according to the project logic; and (2) the availability date of the reconstruction resources needed for this specific activity. Second, the duration of the activity is estimated based on: (1) the number of crews assigned to this activity; (2) the productivity and availability dates of these crews; and (3) the overtime policy adopted for the recovery project. It should be noted that the overtime policy adopted for the project has a significant impact on the productivity of the resources and therefore on the activity durations.

ESTIMATING RECONSTRUCTION COSTS

According to the recovery schedule calculated in the previous stage, all the relevant direct and indirect reconstruction costs are estimated in this stage of the model development. First, direct costs include all the labor, equipment and materials needed to complete the reconstruction works and can be estimated using Equation (1). Similar to its impact on the productivity of reconstruction resources, the overtime policy has a significant impact on the reconstruction costs since working for extended hours and/or multiple shifts: (1) requires paying overtime premiums; and (2) increases the effective cost due to decreased productivity. Second, the indirect costs such as site overhead and profit are included in this model using a time-dependent unit rate and can be estimated as shown in Equation (2).

$$DC_n = \sum_{a=1}^{A} m_a \times mc_a + \sum_{a=1}^{A} d_a \times lc_a + \sum_{a=1}^{A} d_a \times ec_a \quad (1)$$

$$IC_n = D_n \times ic_n \quad (2)$$

$$C = \sum_{n=1}^{N} DC_n + IC_n \quad (3)$$

Where,

DC_n = direct component of reconstruction cost of project (n = 1 to N); IC_n = indirect component of reconstruction cost of project (n); m_a = quantity of material required for activity (a = 1 to A); mc_a = unit cost of material required for activity (a); d_a = duration of activity (a); lc_a = daily labor (payroll) cost rate for the crew(s) assigned to activity (a); ec_a = daily equipment cost rate for the crew(s) assigned to activity (a); ic_n = daily indirect costs rate for project (n); D_n = duration of project (n); and C = total reconstruction costs.

MEASURING NETWORK PERFORMANCE LOSS

The main objective of this development stage is to measure the network performance loss for the damaged transportation network when a given reconstruction plan is implemented. The performance loss is measured in terms of the additional travel time spent by travelers on the damaged transportation network compared to the pre-disasters conditions. In order to estimate the total additional travel time during the recovery duration, snapshots of the total daily travel time on the network are taken at different milestones (i = 1 to I) throughout the recovery duration and these milestones represent the times at which the state of the network changes, e.g. reopening a repaired segment of the road for public use, as shown in Figure 3. This total daily travel time is compared to the pre-disaster total daily travel time to estimate the additional daily travel time at this milestone and it is assumed to remain constant until the next milestone, as shown in Figure 3. These additional daily travel times are integrated, as shown in Equation (4), to estimate the total additional travel time experienced by travelers during the whole recovery duration, and it is represented by the area under the curve in Figure 3.

$$P = \sum_{i=1}^{I} p_i \times h_i \quad (4)$$

Where,

P = total additional travel time during recovery duration; p_i = additional daily travel time at completion milestone (i = 1 to I); and h_i = the number of days elapsed since the last milestone (i–1).

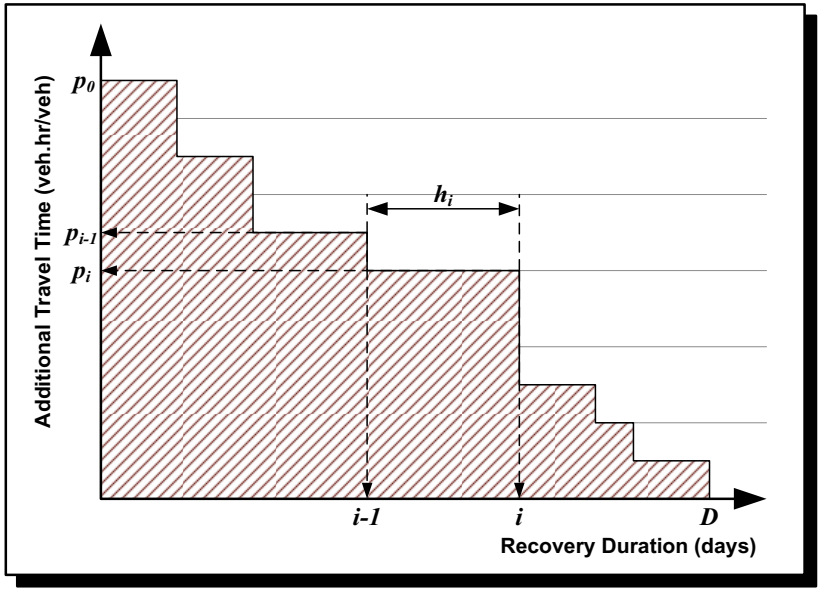


Figure 3. Estimating network performance loss

OPTIMIZING RECONSTRUCTION EFFORTS

The main objective of this development stage is to develop a multi-objective genetic algorithm (Deb et al. 2000; El-Rayes and Kandil, 2005; and Kandil and El-Rayes, 2006) that is capable of generating optimal reconstruction plan(s) that satisfy the societal needs of minimizing both the reconstruction costs and network performance loss. The multi-objective genetic algorithm (GA) initiates the optimization process by generating a population of random solution each representing a construction plan. These solutions are passed to the resource allocation development stage in order to generate a recovery schedule for each of the reconstruction plans, as shown in Figure 2. Based on the recovery schedule calculated for each reconstruction plan, the fitness of each of these solutions is evaluated against the optimization objectives using Equations (3) and (4). The solutions are then sorted and ranked according to the fitness evaluation and the genetic operators of selection, crossover and mutation are applied on the best solutions to generate a new population that is closer to the optimal front. The aforementioned steps of resource allocation, evaluation and modification are repeated on successive populations for a predefined number of generations to ensure convergence and the optimal/near optimal reconstruction plan(s) are obtained from the final population.

APPLICATION EXAMPLE

An application example is analyzed to illustrate the use of the developed planning model and demonstrate it capabilities in generating optimal tradeoffs between reconstruction costs and performance loss of damaged transportation networks in the aftermath of natural disasters. The application example analyzes the transportation network of Los Angeles, California that is assumed to endure damages of varying levels at seven different locations after an earthquake hits the area. The example seeks to plan the reconstruction efforts for the damaged network in order to identify optimal recovery plan(s) that minimize the reconstruction costs and the network performance loss. The model was used to analyze this example and was capable of generating a wide range of optimal solutions each providing a unique and non-dominated tradeoff between minimizing both the reconstruction costs and the network performance loss, as shown in Figure 4.

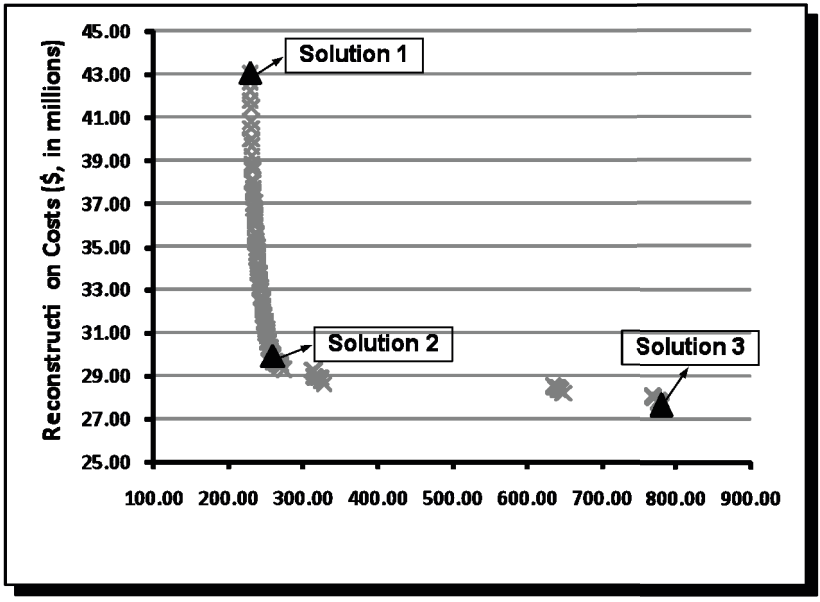


Figure 4. Generated optimal tradeoffs between reconstruction costs and additional travel time

The results show that minimizing the network performance loss (Solution 1) require accelerating the reconstruction efforts in order to decrease the recovery duration and therefore the level of service disruption experienced by travelers. This acceleration requires working for extended hours and/or multiple shifts which significantly increases the reconstruction costs due to the overtime premiums and the adverse impact of overtime on resource productivity, as shown on Figure 4. On the other end of the optimal front, minimizing the reconstruction costs (Solution 2) is achieved by

working for only one regular shift for 5 days per week and assigning the recovery projects to the contractor(s) with the least costs. This solution however provides extended project durations and therefore increases the level of service disruption to travelers, as shown in Figure 4. The model also generated a wide range of optimal tradeoff solutions between these two extreme solutions that provide a balance between minimizing these two important optimization objectives. For example, Solution 3 provides a decrease of more than 67% of the network performance loss compared to Solution 2 at an additional cost of approximately $2.6 million, as shown in Figure 4. Similarly, Solution 3 decreases the reconstruction costs by almost $12.8 million compared to Solution 1 at an increase of 11% in the network performance loss, as shown in Figure 4. The analysis of this application example demonstrates the unique capabilities of the developed planning model in searching for and identifying a wide range of construction plans that provide optimal tradeoffs between minimizing both the reconstruction efforts and the network performance loss. This provides decision makers and planners with new capabilities to generate and evaluate a wide range of optimal tradeoff solutions in order to select the most suitable one for the reconstruction efforts being planned.

SUMMARY

A model was developed to support planning the reconstruction efforts of damaged transportation networks in the aftermath of natural disasters. The model is designed to generate reconstruction plans that provide optimal tradeoffs between minimizing the reconstruction efforts and network performance loss. The model was developed in four stages: (1) allocation of the limited reconstruction resources; (2) estimation of the reconstruction costs; (3) measurement of network performance loss during the recovery period; and (4) optimization of the reconstruction efforts. An application example was analyzed to demonstrate the capabilities of the model in generating a wide range of optimal reconstruction plans that provide unique and non-dominated tradeoffs between the two important planning objectives. This model should prove useful to decision makers and planners and is expected to contribute to enhancing and optimizing the planning of reconstruction efforts after natural disasters.

ACKNOWLEDGEMENTS

This material is based upon work supported by the Qatar National Research Fund under Award No. QNRF-NPRP26-6-7-2. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Qatar National Research Fund.

REFERENCES

Augusti, G., Ciampoli, M., and Frangopol, D. M. (1998). “Optimal planning of retrofitting interventions on bridges in a highway network.” Engineering Structures, 20(11), 933-939.

Chang, S. E., and Nojima, N. (1998). "Measuring Lifeline System Performance: Highway Transportation Systems in Recent Earthquakes." 6th National Conference on Earthquake Engineering, Seattle, Washington, USA.

Chang, S. E., and Nojima, N. (2001). "Measuring post-disaster transportation system performance: the 1995 Kobe earthquake in comparative perspective." Transportation Research Part A, 35, 475-494.

Chen, Y., and Eguchi, R. T. "Post-Earthquake Road Unblocked Reliability Estimation based on an Analysis of Randomicity of Traffic Demands and Road Capacities." Earthquake Engineering 2003, Long Beach, California, USA, 93-102.

Deb, K., Pratap, A., Agarwal, S., and Meyarivan, T. (2001). "A Fast and Elitist Multi-Objective Genetic Algorithm: NSGA-II." Kanpur Genetic Algorithm Laboratory (KanGAL) Rep. No. 200001, Indian Institute of Technology, Kanpur, India.

El-Rayes, K. and Kandil, A. (2005). "Time-Cost-Quality Trade off Analysis for Highway Construction," Journal of Construction Engineering and Management, ASCE, 131(4), 477-486.

Huyck, C. K., Chung, H-C., Cho, S., Mio, M. Z., Ghosh, S., Eguchi, R. T., and Mehrotra, S., (2006). "Centralized Web-Based Loss Estimation Tool: INLET for Disaster Response." SPIE Vol. 6178, 61780B.

Karlaftis, M. G., Kepaptsoglou, K. L., and Lambropoulos, S. (2007) "Fund Allocation for Transportation Network Recovery Following Natural Disasters," Journal of Urban Planning and Development, ASCE, 133(1), 82-89.

Kandil, A. and El-Rayes, K. (2006) "MACROS: Multi-Objective Automated Construction Resource Optimization System," Journal of Management in Engineering, ASCE, 22(3), 126-134.

Kozin, F. and Zhou, H. (1990). "System Study of Urban Response and Reconstruction due to Earthquake." Journal of Engineering Mechanics, ASCE, 116(9), 1959-1972.

Le Masurier, J., Wilkinson, S., and Shestakova, Y. (2006). "An Analysis of the Alliancing Procurement Method for Reconstruction Following an Earthquake." 8th U.S. National Conference on Earthquake Engineering, San Francisco, California, USA.

Nojima, N., and Sugito, M. (2000). "Simulation and Evaluation of Post-Earthquake Functional Performance of Transportation Network." 12th World Conference on Earthquake Engineering, Auckland, New Zealand.

ASSESSMENT OF IMPACTS OF HIGH-RISE BUILDINGS ON THE ELECTRIC AND TRANSPORTATION INFRASTRUCTURES IN DEVELOPING COUNTRIES

María L. Peralta[1], Dulcy M. Abraham[2] and Fred L. Mannering[3]

[1]School of Civil Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907-2051; PH (765) 496-1822; FAX (765) 494-0644; email: mperalta@purdue.edu
[2]School of Civil Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907-2051; PH (765) 494-2239; FAX (765) 494-0644; email: dulcy@ecn.purdue.edu
[3]School of Civil Engineering, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907-2051; PH (765) 496-7913; FAX (765) 494-0395; email: flm@ecn.purdue.edu

Abstract

A tendency affecting the performance of infrastructures in developing countries is the growing number of high-rise buildings. These new buildings put intense pressure on existing infrastructures especially on road transportation and electric systems, due to the traffic they generate and the high number of resources they require to function. This study uses a hybrid approach to assess the impact of high-rise buildings on two critical infrastructures. First, a user-equilibrium approach is used to assess the effect of high-rise buildings on the performance of the transportation infrastructure. A system dynamics model is then used to evaluate the effect of high-rise buildings on the electric power system. The models developed are verified and validated using data from a large city in a developing country. This research illustrates the impact of new disruptors, on the services provided by critical infrastructures and on their interdependencies in developing countries.

Introduction

Critical infrastructure systems produce and distribute essential goods and services which are important for the economic and social well-being of a nation and its citizens (Rinaldi et al. 2001). These infrastructures as well as their interdependencies are vulnerable to disruption by different types of threats, including physical (e.g., natural disasters) and non-physical interventions (e.g., government decisions).

Hurricane Katrina provides an example of the effect of natural disasters on the services provided by electric power and communications systems (Rahman 2005).

In addition to physical disruptors or incidents, lack of investment for rehabilitation and repair of infrastructures that are already working close to their capacity levels, can be disruptors to services provided by infrastructures. Cities in developing countries constitute an example of this problem. In these cities, skyscrapers and high-rise buildings are being constructed in areas where the existing infrastructures cannot appropriately meet the demand for resources required by high-rise buildings, such as a high demand for electric power, water, and efficient transport systems. As a result, several new problems can arise or existing problems may be aggravated. For instance, traffic congestion in the area surrounding clusters of high-rise buildings can increase to the point of gridlock, reducing the efficiency of the transportation road system. In such instances, the use of high-rise buildings may not be fully realized. Travel times to and from high-rise buildings could increase significantly, hence producing a negative impact on households and business activities taking place in residential and commercial high-rise buildings, respectively. In a similar manner, the electric supply system and the water infrastructures may be affected by the presence of high-rise buildings as high occupancy levels in these buildings increase the demand for water and electric power.

In the published literature there is insufficient information about the analysis of interdependencies of critical infrastructures in megacities in developing countries. These cities are characterized by growing populations and limited land available for new developments. A consequence of the combination of these two factors is an increasing number of high-rise buildings.

The Idaho National Laboratory conducted a survey to identify and describe current research in the analysis of critical infrastructures. The main objective of the survey was to create a reference of critical infrastructure interdependency modeling tools (CIIMT) that could help users to better assess the potential of such tools (Pederson et al. 2006). The examination of this survey shows that most of the studies regarding critical infrastructures have been conducted in developed nations, including United States and Canada. This paper outlines the assessment of impacts of high-rise buildings on the transportation and electric infrastructures and also on their interdependencies in developing countries.

Methodology

In this study, a two-stage approach is used to model, simulate, and analyze the operating conditions of critical infrastructures in developing countries. The first stage consists of a user-equilibrium analysis of the transportation infrastructure. A system dynamics model is then used to evaluate the effect of high-rise buildings on the electric power infrastructure. First, each infrastructure is considered as being independently impacted by the presence of high-rise buildings. Then, results from the electric power model are incorporated in the transportation analysis to quantify the

impact of the performance of the electric system on the service provided by the transportation infrastructure.

User-equilibrium analysis of the Transportation Network: User equilibrium is a popular approach for traffic assignment. User equilibrium is defined as follows (Mannering et al. 2009):

The travel time between a specified origin and destination on all used routes is equal, and less than or equal to the travel time that would be experienced by a traveler on any unused route.

The mathematical formulation for user-equilibrium discussed by Sheffi (1985), as cited by Mannering (2009), is as follows:

$$\text{minimize z (v)} = \text{minimize} \sum_{a} \int_{0}^{v_a} f(w)dw \tag{1}$$

where *f(w)* is the performance function for a specific route. The performance function most frequently used in user-equilibrium estimation was first published by the Bureau of Public Roads (BPR) (Mannering et al. 2009). The equation is known as the BPR formulation, and estimates the travel time on a highway link as a function of the volume to capacity ratio:

$$t_n = t_{fn} \times \left(1 + \alpha \times \left[\frac{x_n}{x_{cn}} \right]^{\beta} \right) \tag{2}$$

where:

t_n = travel time on link, usually in minutes.

t_{fn} = free-flow travel time on link, usually in minutes. The free-flow occurs when travelers can drive freely on a road segment with a speed close to the design speed of the section (Mannering et al. 2009).

$\alpha \beta$ = volume/delay parameters. Typical values of these parameters have been estimated by the BPR for different values of route speed (Mannering et al. 1990).

x_n = traffic volume on the link, usually in vehicles per hour.

x_{cn} = traffic flow capacity of the link, usually in vehicles per hour.

The problem being studied and analyzed applying the user-equilibrium approach is the change in the performance of the transportation network due to an increasing number of high-rise buildings in the area of study. Travel times and volume to capacity ratios (v/c ratios) on links are used as performance measures. The model boundary includes the capacity of the transportation infrastructure and the number of high-rise buildings. Since the land available for expansion in the area is limited, it is assumed that the current capacity of the roads cannot be modified significantly. However, the performance of the transportation system will experience challenges due to changes in traffic flow caused by the increased number of high-rise buildings.

To develop a model of user-equilibrium assignment, Equation 1 is solved subject to the following constraints known as Beckmann's transformation (Mannering et al. 1990):

$$\sum_k v_k^{rs} = q_{rs} \qquad \forall r,s \tag{3}$$

where v_k^{rs} is the flow of vehicles on link *k*, which connects the origin and destination nodes r and s, and q_{rs} is the element in the OD matrix which represents the demand between the origin r and the destination s. The first constraint represented by Equation 3 states the conservation of flows.

$$v^{rs}k > 0 \qquad \forall k,r,s \tag{4}$$

The second constraint, represented by Equation 4, restricts the negative flow of vehicles in the network. Equation 5, the third constraint, states that a flow on a particular link is a function of all flows passing through the link.

$$v_a = \sum_r \sum_s \sum_k v_k^{rs} . \delta^{r.s} a,k \qquad \forall a \tag{5}$$

Where v_a is the flow on link a, and the element $\delta^{rs} a,k$ has a value of 1 if the link a (on path k), connects the origin and destination nodes r and s, or 0 otherwise.

With the user-equilibrium assignment, it is possible to obtain information about the congestion of the transportation network and its links, such as total travel time in the network, travel time on links, and volume to capacity ratios for each link. These metrics are used to study the impact of high-rise buildings on the performance of the transportation network. The transportation infrastructure that is analyzed in this study does not consider mass transportation systems, such as subways. It includes urban roads with traffic signals, which are used by cars, buses, and trucks. The basis for this assumption is that mass transportation systems, other than buses, are not encountered often in urban areas in developing countries, or if they are present, they are typically in their infancy.

Electric Power Model: For the purpose of analyzing the electric power infrastructure, a system dynamic model of the power network is created. This model, developed using Vensim®, is used to simulate the effect of an increasing number of high-rise buildings on the service provided by the electric power infrastructure in a particular area. The model uses the capacity margin as a performance metric of the electric system. The capacity margin is the amount of unused available capability of an electric power system at peak load as a percentage of the total capacity resources and is a measure of the potential of the system to satisfy demand (commercial and residential high-rise buildings, traffic signals, and other municipal demand). This is a measure of the reliability of the electric system, and it is quantified as the unused available capability of an electric power system at peak load as a percentage of the total capacity resources (Equation 6). Although there is no single value of capacity margin that can be used for analysis purposes, a capacity margin of 20% is widely accepted (Hani et al. 2006). Large capacity margins require high investments from electric companies because it involves installed capacity that is not necessarily

charged to customers. On the other hand, small capacity margins could lead to the inability of the electric system to manage unanticipated electricity demand from customers or to satisfy demands during equipment failures, maintenance operations, unforeseen loss of generation capacity, or weather related events.

$$\textit{Capacity Margin} = (\textit{Installed Capacity} - \textit{Peak Hour Demand}) / \textit{Installed Capacity} \quad (6)$$

Future demands from high-rise buildings are added to the model using different growth rates, which are translated to differential power consumption, and the unsatisfied demand due to new developments is estimated. Potential programmed and unintentional blackouts are also estimated using this model. In this study, a blackout is assumed to occur during periods when the capacity margin falls below 15%. If the capacity margin falls below this value, the electric network may not be able to satisfy demand in the event of unforeseen equipment failures, increased demand, etc. This number was set based on historical events, such as the California electric crisis in 2001. During that period the average capacity margin in the United States was below 15% and was even lower in California (Stahlkopf 2001). Using the information regarding potential power outages, the performance of the transportation network during blackouts is modeled. The blackouts are simulated by a reduction in the capacity of some links, since some additional movements (e.g. left turns) may be restricted due to the absence of traffic signals. During the blackouts drivers will continue on the roads, trying to reach their destination in the transportation network

Case Study: City of Transelectville

To demonstrate the methodology used in this research a large city in a developing country in Latin America was selected. This city has been ranked among the top 100 cities in the world, because of the visual impact of its skyline. Current construction projects in the city and some of the proposed buildings will be counted among the world's tallest buildings. This growth in high-rise buildings in the area of study is in contrast to an underdeveloped infrastructure, which supports the existing and future residential and commercial facilities.

Transportation Network model. A baseline network was created to replicate current conditions in the area of study. The baseline model consists of 93 directional links and 41 nodes, as shown in Figure 1. The links are distributed as 40 transportation links and 53 links that connect the transportation network with the centroids of the Traffic Analysis Zones (TAZs). The TAZs characterize sectors of the study area for transportation planning. The centroids represent the areas where trips are generated and attracted. The traffic generated by new high-rise buildings is incorporated to the transportation network through TAZs. The centroids are numbered from 1 to 12 (origins) and from 13 to 24 (destinations). Two areas are identified in the vicinity of the transportation network considered that may have a higher number of new high-rise buildings. One of these areas is located on a landfill over the sea. Several new buildings are planned for construction. The centroid of this area is identified in Figure 1 with the numbers 12/24. The second area identified by the numbers 8/20 is experiencing a transition from individual households to high-rise buildings. Each of

these TAZs, which represent either a single building or groups of buildings, has its own trip generation rate. The number of trips generated is a function of the height of the building, the floor areas, and the type of building (residential and commercial), etc. The information used to model the transportation network has been estimated using data provided by the Department of Transportation of the city in the case study.

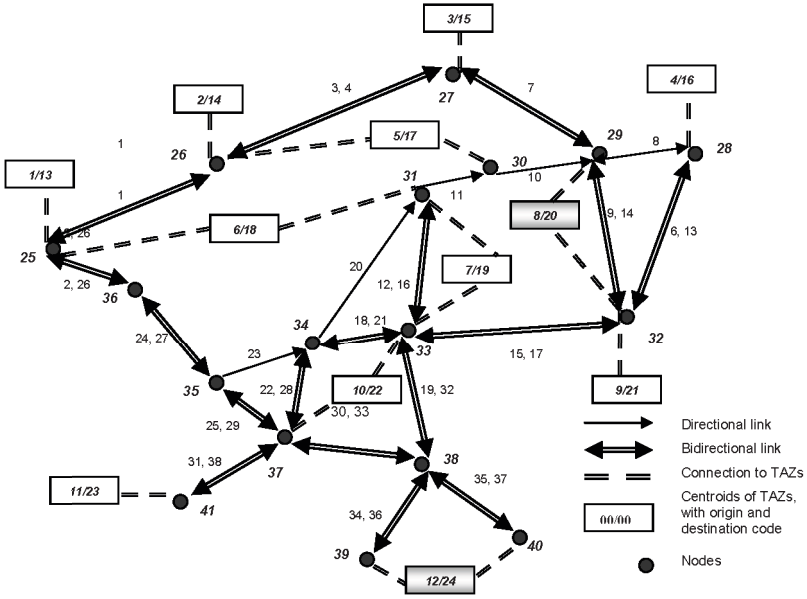


Figure 1. Links and TAZs in the Transportation Network.

Electric Power model. The system dynamics model is initiated with a value of current demand for electric power, which corresponds to the peak demand for electricity in the area. To simulate future demand, growth rates are assigned to three different sectors: a) residential and b) commercial (where high-rise buildings are included), and c) industry and other sectors, which include the demand from different industries. The growth rates are based on estimates of demand growth obtained from electric companies in the city that is used as case study. Using these data, the capacity margin for the electric network is calculated and compared with the 15% criterion established in this research. For planning purposes, the electric companies in the area of study use a capacity margin of 14% as the minimum value required. Values of demand, which produce a capacity margin below 15%, may be considered as potential intervals of blackouts. Using this information, the performance of the transportation network during the period of blackout is modeled. To simulate the impacts of blackouts on the transportation network using user-equilibrium assignment, the capacity of the transportation links in one sector of the network (where the traffic lights are removed) is reduced. Different values of reduction in capacity are modeled: 50, 70, and 90 %, which represent the degree of impact of the blackout on the capacity of the link.

Analysis of models

User equilibrium results are shown in Table 1. For each link, the user-equilibrium analysis is used to calculate the volume of traffic, the v/c ratio, and the travel time. When new high-rise buildings are added to the area (additional trips) the average congestion in the network is 0.638, and the total travel time is 5,675 hours. These values can be compared with the results obtained for the baseline network. For example, the travel time changed from 3,542 hours (baseline network) to 5,675 hours (network with additional high-rise buildings). This result represents an average increment close to 60% due to an additional number of vehicles in the network. This time is the product of the travel time in each link and the number of cars in the same link and it represents average conditions in the network. By considering the condition on specific links, it is possible to obtain more meaningful information that can be used by drivers to make decisions about their travel routes. For example, drivers on link 33 that goes from node 38 to node 37 would experience an increase of 42% in their travel time. In the same link, the v/c ratio changes from 0.536 to 0.865, indicating that after the addition of high-rise buildings in the area, drivers experience serious difficulties to maneuver freely on this road segment.

Table 1. Increases in travel time and congestion with new high-rise buildings

			Baseline	New buildings	Baseline	New buildings	Increase in Travel time
Link #	Node		v/c Ratio	v/c Ratio	Travel time	Travel time	
	From	To			Hr	hr	%
4	27	26	0.495	0.582	0.0255	0.0263	3.14%
6	28	32	0.866	0.883	0.0367	0.0380	3.54%
7	29	27	0.619	0.779	0.0268	0.0315	17.54%
8	29	28	0.486	0.522	0.0255	0.0257	0.78%
9	29	32	0.996	1.032	0.0574	0.0635	10.63%
14	32	29	0.388	0.505	0.0251	0.0256	1.99%
17	33	32	0.589	0.806	0.0264	0.0329	24.62%
18	33	34	0.803	0.887	0.0327	0.0383	17.13%
19	33	38	0.902	0.907	0.0396	0.0400	1.01%
22	34	37	0.803	0.887	0.0327	0.0383	17.13%
24	35	36	1.096	1.315	0.0678	0.1417	109.00%
26	36	25	0.965	1.130	0.0461	0.0755	63.77%
29	37	35	1.296	1.565	0.1326	0.3301	148.94%
33	38	37	0.536	0.865	0.0258	0.0366	41.86%
Baseline network: Average Congestion = 0.582					*Total Travel Time = 3,542 hours*		
New buildings: Average Congestion = 0.638					*Total Travel Time = 5,675 hours*		

Links 24 and 29 that go from node 35 to 36 and from node 37 to 35 respectively, experience an increment in travel time of more than 100%. The configuration of the network (Figure 1) shows that although these links are not connected directly to the zones where high-rise buildings have been added (TAZs 8 and 12), these links collect

part of the traffic that is being generated by the newly constructed facilities. The reduction in system and links performance could also be the result of limited alternative routes for drivers who want to reach node 35. The other links in the network, that have not been included in Table 1, have experienced little (less than 1%) or no increment in their travel time. Even after the addition of high-rise buildings, these links still have capacity to received additional traffic and could be used as alternative routes to reduce congestion on other roads. These findings may be useful in urban planning decisions, regarding the location of new facilities, or changes in the use of the land.

The results obtained from the electric power model using values of installed capacity, and peak demand forecasted for the year 2009, show a capacity margin of 14% as seen in Table 2. Based on the criterion of a 15% capacity margin, selected as baseline in this research, there is insufficient capacity in the electric system to satisfy demand in the event of malfunctioning of equipment or unforeseen increases in demand. Hence blackouts are likely to occur in the electric system.

Table 2. Capacity margin in the electric system

Baseline network			**New high-rise buildings**		
Peak demand	Installed capacity	Capacity margin	Peak demand	Installed capacity	Capacity margin
994 MW	1200 MW	17%	1008 MW	1200 MW	14%

The performance of the transportation network during the period of the blackout is obtained by examining the results of the user-equilibrium analysis, obtained from the user-equilibrium assignment, as shown in Table 3. When new high-rise buildings are added to the area (additional trips) and blackouts occur, the average congestion in the network is 0.711 and the total travel time is 7,609 hours. This represents a noticeable worsening of traffic conditions in the network, especially in those links connected to nodes 28, 29, 30, 31 and 34. These nodes represent the traffic lights where the power outages have been simulated.

The significant increases in travel time (over 100%) in links 5 and 7 are most likely due to the lack of sufficient diversionary routes in the transportation network, particularly for drivers who want to reach node 27 from the south section of the network, and node 29 from the north section. In these cases, drivers are forced to remain on the roads and wait until queues are reduced, or resort to aggressive driving behaviors in order to reach their destination.

The results for the transportation network obtained during the period of blackout could change as a function of variables such as the number of informed drivers in the network and the factor of reduction used to simulate the power outage. For this study all drivers (100%) were assumed to be informed about the conditions of the network, which allow them to take actions about alternative routes. The capacity of links affected by the blackout was assumed to be 70%. Other values of reduction (50%, 90%) were simulated. However it was found that in the absence of diversionary routes, the reductions in the capacity of the links would not have a significant impact

on the routes not directly affected by the blackouts. This is due to the fact that drivers will continue on the same routes.

These results can be used to provide recommendations regarding measures to improve the use of the capabilities of the electric infrastructure, and reduce the adverse consequences of potential power outages on the performance of the transportation network. The problem studied in this research has several variables, including increased number of high-rise buildings, limitations in the area to expansion, increased demand for electric power, limited capacity in the roads, limited capacity to produce electric power, cost constraints, etc. Extended research in this area could include a combination of these variables to obtain results for worse-case scenarios that could be used to take actions to mitigate adverse consequences of the construction of high-rise buildings in developing countries.

Table 3. Increases in travel time with new high-rise buildings and power outages

			New buildings		New buidlings + blackouts		
	Node		v/c Ratio	Travel time	v/c Ratio	Travel time	Increase in Travel time
Link #	From	To		hr		hr	
5	27	29	1.317	0.1428	1.882	0.8687	508.33%
6	28	32	0.883	0.0380	1.047	0.0582	53.16%
7	29	27	0.779	0.0315	1.113	0.0715	126.98%
8	29	28	0.522	0.0257	0.969	0.0467	81.71%
9	29	32	1.032	0.0635	1.188	0.1046	64.72%
10	30	29	0.474	0.0254	0.633	0.0271	6.69%
11	31	30	0.485	0.0255	0.649	0.0274	7.45%
14	32	29	0.505	0.0256	0.762	0.0307	19.92%
16	33	31	0.516	0.0293	0.738	0.0341	16.38%
17	33	32	0.806	0.0329	0.844	0.0351	6.69%
Impact of new buildings:			*Average congestion= 0.638*		*Total Travel Time = 5,675 hours*		
Impact of new buildings and blackouts:			*Average congestion= 0.711*		*Total Travel Time = 7,609 hours*		

Summary and Conclusions

This paper illustrates the impact of additional disruptors, such as insufficient investment for rehabilitation and repair of infrastructures, and high-rise buildings on the services provided by the electric and road transportation infrastructures in developing countries. Using data from a large city in a developing country, this study provides some important findings. First, the inability of the electric system to satisfy demand, due to limited installed capacity, could result in uncontrolled blackouts that will produce an increase in travel time in the transportation network. Second, depending on the configuration of the network and the location of blackouts, volume to capacity ratios can deteriorate, potentially to the point of gridlock. These blackouts

also have the potential to produce adverse impact on the activities taking place in high-rise buildings.

The presence of high-rise buildings can cause an increase in the population in the city, resulting in an increase in the number of additional drivers on the transportation network. At this stage, the data related to increased population due to high-rise buildings, is not available. Nonetheless, the models developed in this study can be replicated for different rates of population growth.

While this study is in its first stages, it does suggest that additional disruptors to critical infrastructures in developing countries have considerable potential to produce impacts as severe as natural disasters or malicious acts. These disruptors, for instance, may impede the use of the transportation network, due to prolonged traffic congestion.

This study can assist decision-makers (urban planners, electric companies, departments of transportation, other government officials) in managing key infrastructures in developing countries. Continued research in this area will provide recommendations that can be implemented during the design process of key infrastructures systems, in order to maximize the performance during the service life of the infrastructure, in particular, the transportation and the electric systems.

References

Hani, Th., Bialek, J. W., and Cherkaoui, R. (2006). "Modeling Generation Capacity Margin as a Dynamic Control Problem." Power Engineering Society General Meeting, IEEE, 8pp, Montreal, Canada, 18-22 June 2006. ISBN: 1-4244-0493-2.

Mannering, F. L., Garrison, D., and Sebranke, B. (1990). Generation and Assessment of Incident Management Strategies, Volume IV, Seattle-Area Incident Impact Analysis: Microcomputer Traffic Simulation Results, Final Report TMW90-11.4.

Mannering, F., Washburn, S., and Kilareski, W. (2009). Principles of Highway Engineering and Traffic Analysis, 4th Ed, John Wiley and Sons, Inc. New York, NY. ISBN: 978-0-470-29075-0.

Pederson, P., Dudenhoeffer, D., Hartley, S., and Permann, M. (2006). Interdependency Modeling: A Survey of U.S. and International Research, Technical Support Working Group, Idaho National Laboratory.

Rahman, S. (2005) "Information and Communication Technologies: Powerful Enabler or Weakest Link." Proc., EAPC/PfP Workshop on Critical Infrastructure Protection and Civil Emergency Planning: Interdependencies and Vulnerabilities of Energy, Transportation and Communication, Zurich, 24-25 September 2005.

Rinaldi, S., Peerenboom, J. P., and Kelly, T. (2001). "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies." Control System Magazine, IEEE, 21(6), 11-25. ISSN: 0272-1708.

Sheffi, Y. (1985). Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods, Prentice-Hall, Englewood Cliffs, N.J. ISBN: 0139397299.

Stahlkopf, K. (2001). "Technology Offers Solutions to the Current Power Crisis", IEEE SPECTRUM, June 2001, 14-15. ISSN: 0018-9235.

EXTRACTING SURVEYING GOALS FROM POINT CLOUDS TO SUPPORT CONSTRUCTION AND INFRASTRUCTURE INSPECTION

Pingbo Tang[1], and Burcu Akinci[1]

[1]Civil and Environmental Engineering Department, Carnegie Mellon University

Abstract

Inspectors need accurate and efficient methods for obtaining geometric information about facilities for construction and infrastructure management. Laser scanners can capture millions of 3D points, which have mm accuracy, in minutes, and hence can streamline extraction of geometric information. Currently, extraction of geometric information is done manually. This paper describes a case study, which shows that manual approach is inefficient and error-prone. Aiming at improving the efficiency and effectiveness of extracting survey goals, this paper discusses computer interpretable representations of surveying goals as a first step towards extraction of surveying goals. The described approach targets enabling surveyors to compose surveying goals as <facility parts, features, operations> tuples. Reasoning mechanisms can transform user-defined surveying goals described by these tuples into a sequence of measurement operations to generate results.

Keywords: Laser Scanning; Information Retrieval; Construction and Infrastructure Inspection, Surveying Goal

Introduction

Construction and infrastructure inspectors need accurate and efficient methods for obtaining geometric information about facilities. Laser scanners can collect millions of 3D points in minutes with mm-level accuracy in the form of dense point clouds (Zoller+Fröhlich 2005), and hence provide data to extract detailed geometric information. At the same time, laser scanned data also brings unique challenges for geometric information retrieval. State-of-art 3D reverse engineering environments, such as Polyworks (InnovMetric 2005), enable inspectors to manually conduct measurement operations, such as extraction of geometric features (e.g. plane, edge and point) and spatial relationships between geometric features (e.g. distances between points). However, a case study described in this paper indicates that many inspection tasks, such as obtaining the minimum vertical underclearance of a bridge, require inspectors to execute a few types of measurement operations repetitively. This not only reduces the efficiency of the information retrieval process, but also causes subjectivity and reliability issues due to being a manual process.

The research described in this paper targets streamlining extraction of surveying goals

(e.g., the minimum vertical underclearance of a bridge) by enabling capture and representation of surveying goals in a computer interpretable way. With formal representations developed in this research, inspectors can compose surveying goals as <facility parts, features, operations> tuples. Using several geometric reasoning mechanisms that are currently being developed, it is possible to reason with surveying goal tuples to generate and automatically execute operation sequences. This results in automatic generation of results for specified surveying goals.

Motivating Case

This case study investigates the technical feasibility of using a laser scanner for geometric assessments of a highway bridge. Specifically, the authors reconstructed a polygonal model from eleven scans using a commercially available reverse engineering environment (Figure 1), and took measurements on that 3D model for obtaining two surveying goals: 1) the minimum vertical underclearance of the bridge; 2) the average cross-section loss of each column of the bridge. National Bridge Inventory (NBI) program requires inspectors to document these two goals for more than 600,000 bridges every two years. These two goals are also different with respect to two aspects: (1) the number of components that need to be reasoned about (minimum vertical clearance requires reasoning with many components and average cross-section loss of a column involves a single component); and (2) the type of the result (the former queries a distance and the latter queries an area). Hence, the authors picked them as a preliminary testbed for evaluating current approaches for extracting surveying goals.

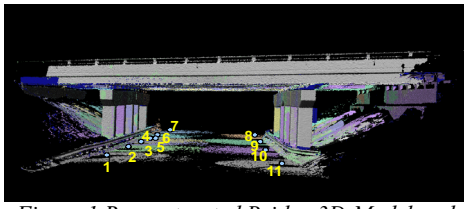


Figure 1 Reconstructed Bridge 3D Model and Scanning Locations

The reverse engineering environment used in this case study provides functionalities for extracting geometric features, such as surfaces and lines; and spatial relationships, such as the distance between two points. Using these functionalities, a goal extraction process involves two aspects: (1) Extracting geometric features (e.g. plane, edge) or spatial relationships (e.g. distance, angle); (2) Calculating surveying goal results, based on extracted features or spatial relationships. The first aspect involves two types of measurement operations: feature extraction and spatial relationship extraction. The second one mainly involves geometric observations and arithmetic operations. Geometric observations take values of the attributes of geometric features or spatial relationships as inputs, and then determine which features or spatial relationships satisfy a set of predefined requirements. An example of a geometric observation is “given a surface, identify which parts of it are deviating from an as-designed plane more than a threshold”. Arithmetic operations are mostly standard mathematic operators, such as “Minimum” and “Maximum”.

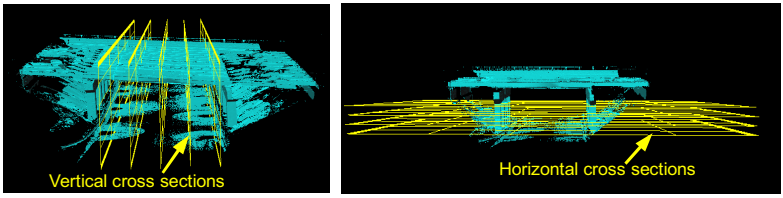


Figure 2 Vertical and Horizontal Cross Sections of the Bridge 3D Model

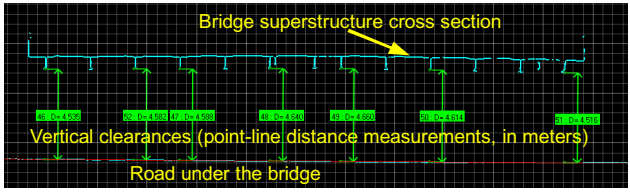


Figure 3 One Vertical Cross Section for Measuring Bridge Vertical Underclearance

Following the goal extraction process discussed above, the authors extracted two surveying goals and documented the goal extraction processes. The surveying goal, "the minimum vertical under-clearance of a bridge," refers to the minimum vertical distance between the superstructure and the road under the superstructure. To identify the minimum vertical clearance, a method is to first generate several vertical cross sections of the reconstructed polygonal bridge model at a series of manually determined locations (Figure 2). Then, on those cross sections, it is necessary to extract road surface cross section lines and sample points on the bottom surface of the superstructure to measure several point-line distances between these surfaces. Finally, the authors identified the minimum distance among all distances measured on all vertical cross sections (Figure 3). As shown in Table 1, the process described above includes five steps, each of which may involve multiple operations (e.g. extract multiple vertical cross sections). Table 1 also shows steps for extracting "the average cross section loss of each column."

Table 1 Processes of Extracting Two Example Surveying Goals

Step	Minimum Vertical Underclearance of the Bridge		Average cross section loss of each column of the bridge	
	Operation	**Operation Type**	**Operation**	**Operation Type**
1	Extract multiple vertical cross sections of the bridge 3D model	Geometric feature extraction	Extract multiple horizontal cross sections of the bridge 3D model	Geometric feature extraction
2	Extract road cross section lines on each vertical cross section of the bridge 3D model	Geometric feature extraction	Extract all columns' cross section lines on each horizontal cross section of the bridge 3D model	Geometric feature extraction
3	Sample multiple points on the bottom surface of the bridge superstructure on each vertical cross section	Geometric feature extraction	For every column of the bridge, sample multiple points on one side surface of a column on each horizontal cross section	Geometric feature extraction

4	Measure point-line distance from each sampled bottom surface points to the road line on each vertical cross section	Spatial relationship extraction	On each horizontal cross section, measure point-line distance from each sampled side surface point to the cross section line of the other side surface to get edge lengths of the rectangular column cross section	Spatial relationship extraction
5	Minimum of all point-line distances on all vertical cross sections	Arithmetic operation	For each cross section of each column, multiply the length and the width of the rectangular cross section to get its area	Arithmetic operation
6			The average cross section loss is the average cross section area of a column minus the as-designed cross section area of it	Arithmetic operation

In this study, the authors found that the generated surveying goal results could vary substantially depending on where inspectors choose to extract geometric features and spatial relationships. For the first surveying goal, the extracted vertical distance between the bridge superstructure and the road at different locations had variations larger than 20 cm. For the second surveying goal, at different locations along a column, the extracted widths had variations larger than 1.5 cm. First, this case indicates that subjectivity of the manual process may influence the reliability of the surveying goal results. Moreover, it is necessary to repeat similar operations multiple times to increase the reliability and accuracy of the surveying goal results. For example, for extracting the minimum vertical underclearance, inspectors need to take measurements at several locations to get a result close to the actual minimum vertical underclearance. Such repetitions of operations can make surveying goal extraction processes tedious and time-consuming. For example, when determining the average cross section losses of all bridge columns, the authors measured the cross section sizes on four cross sections spread out on each column, and for each cross section, the authors took four "point-line distance" measurements to get the lengths of four edges of the column's rectangular cross section. Hence, the authors took sixteen measurements for each column and since that bridge has 10 columns, there were 160 measurements in total. Each measurement took about 1 minute. Hence, for such a small bridge, getting average cross section losses of all columns required two and a half hours spent on manual measurements. Even with such measurements, it is not clear how reliable the results are and hence more measurements might be needed to increase the reliability. In addition, the measured distances still need to be processed further to determine the average cross-section loss of each column; this also adds to the time spent. In the motivating case study, manually extracting relevant measurements and calculating average cross section loss for one column takes about 2 minutes. Hence, it takes about 20 minutes for the authors to get average losses of all 10 columns.

Overall, for this 30m highway bridge, the authors spent more than four hours to determine the values of two surveying goals stated in Table 1. NBI program requires bridge inspectors to document 27 geometric data items of 600,000 bridges every two years, and some bridges can be more complicated than the one in the motivating case. In construction inspections, there are also many surveying goals targeting geometric assessment of numerous components in a facility. All of these suggest that manual approach for extracting surveying goals from point clouds is time consuming, and hence needs to be streamlined to increase the reliability of the results.

Table 1 also suggests that it is possible to automate the extraction of surveying goals. Even though the two studied goals appear to be different in several aspects, they still share many similar operations. For example, both of them need inspectors to extract cross sections of the 3D model, and both of them involve line extraction on cross sections, etc. Such commonalities of surveying goals indicate that it is possible to identify and automate a set of operations, which can cover all possible operations shared by most surveying goals required by inspectors.

Automated Surveying Goal Extraction

Figure 4 provides an IDEF0 process model showing the authors' approach for enabling automated surveying goal extraction. The overall process is composed of two sub-processes: generate an operation sequence based on a formal surveying goal definition composed by inspectors (process A1); extract surveying goals by executing that operation sequence (process A2). The inputs to A1 are surveying goal definitions described by users through a goal capture template, based on formal surveying goal representation detailed later. The outputs of A1 are operation sequences. Process A2 takes the operation sequence generated by A1 and laser scanned as-built data overlapping with a BrIM (bridge information model) as inputs. Utilizing an object recognition approach developed by (Yue et al. 2006), the authors are developing an automatic approach for extracting data points corresponding to BrIM-contained features, which are needed for extracting a surveying goal. Executions of operation sequences on those extracted data patches can generate the results of surveying goals. This paper focuses on capturing and representing surveying goals of the automated surveying goal extraction approach.

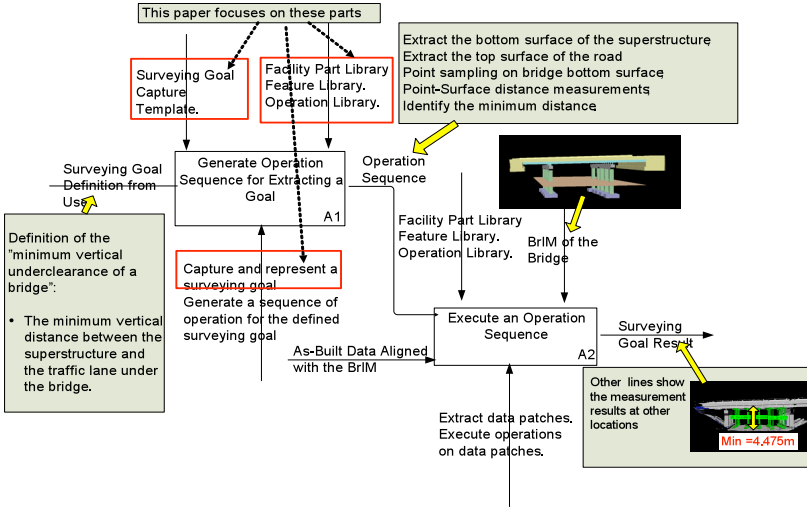


Figure 4 IDEF0 Process Model of Automated Surveying Goal Extraction Process

Formal Representations of Surveying Goals

In order to understand which surveying goals are required by inspectors, the authors have investigated a wide range of literature related to geometric assessment of facilities in construction and infrastructure management domain. Table 2 summarizes several surveying goals found in literature. The authors found that all these surveying goals are composed of three categories of information: (1) parts/components of interest, (2) geometric features of the parts/components of interest, and (3) operations operating on those features for deriving surveying goal results.

Based on the above observation, it is possible to represent surveying goals as <facility parts, features, operations> tuples (Figure 5). Due to limited space, not all aspects of the representation will be discussed here. "Facility part" is a class for representing components, or groups of components. "Feature" represents a geometric feature belonging to a facility part, such as the bottom surface of a bridge superstructure. An "operation" takes observable items, such as features, spatial relationships, as inputs, and generates some observable items, which could be inputs of other operations or surveying goal results. A class called, "Attribute Checking Result", models the results generated by geometric observations, which check attributes of features or spatial relationships for identifying features of interest, such as "identifying edges that are not plumb by checking its direction against a predefined tilt angle tolerance." Figure 6 shows more details about representations of facility parts and features. A facility part can have multiple features. Multiple features may aggregate into a composite feature, such as a cross section of a rectangular column is an aggregation of straight edges.

Table 2 Surveying Goals within Construction and Infrastructure Inspection Domains

Category Names		**Specific Surveying Goals and Related Research Studies**
Component Attributes	Size	***Length:*** Structure length and length of maximum span (Weseman 1995) ***Width:*** Curb or sidewalk widths, deck width, approach roadway width (Weseman 1995); ***Height:***Bridge railing height (Weseman 1995); Pavement thickness (Jaselskis et al. 2006) ***Area:*** Section loss of a component (Weseman 1995) ***Volume:*** Sand pile volume (Cheok et al. 2000)
	Location	Elevation of the deck, settlement of the structure (Weseman 1995)
	Orientation	Column plumbness (Akinci et al. 2006); Approach roadway alignment, approach guard rail alignment, bridge railing alignment (Weseman 1995);
	Surface Quality	Concrete floor slab flatness (ACI 2006; Walsh 2007); Concrete slump (Gordon 2006)
	Deformation	Curved girder torsion, pier and abutment surface deformation (Fuchs et al. 2004); Bridge beam camber (Jaselskis et al. 2005); Bridge superstructure deflection (Fuchs et al. 2004; Weseman 1995); Ground surface deformation during the excavation (Su et al. 2006); Hydropower station concrete surface deformation (Schafer and Weber 2004)
Spatial Relationships between Components	Alignment	Alignment of the structure parts, misalignment of bearings, alignment between the bridge railing and the approach guard rail (Weseman 1995)
	Angle	Skew angle of bridge superstructure from a reference line

		(Weseman 1995)
	Space Size	Bridge roadway width (distances between curbs), inventory route total horizontal/vertical clearance, minimum lateral under clearance on right/left , Minimum vertical underclearance (Weseman 1995)
	Relative Position	Deviation pattern of as-built model from as-designed model (Akinci et al. 2006); Positions of holes on splice plates of a steel truss (Fuchs et al. 2004)

Various 3D data processing algorithms developed in domains of computer science, remote sensing, and surveying are able to extract geometric features, spatial relationships, and geometric observation results from 3D point clouds (CGAL 2008; Eberly 2008; Franz 2003; Gielsdorf and Gruedig 2002; Haymaker et al. 2004; InnovMetric 2005; James and Charles 1996; Kwon et al. 2004; NPL Management Ltd 2004; Vosselman et al. 2004; Xiaoyi 1999). The authors organize those algorithms into four categories: (1) feature extraction algorithms, such as extracting centroids of polygons, intersecting two planes to get an edge, fitting a plane against 3D points, extracting the cross sections of an object, etc. (2) spatial relationship extraction algorithms, such as extracting point-point distances and edge-edge angles, etc. (3) reformulation, such as generating the principal axis of a solid shape, triangulating point clouds into triangulated meshes, and extracting bounding boxes of 3D shapes, etc. (4) geometric observation algorithms, such as identifying edges longer than a threshold from a set of edges, identifying points inside a given polygon from input points, and identifying surfaces neighboring a set of edges, etc. Based on this classification of 3D data processing algorithms, the authors are developing representations of measurement operations and implementing an operation library.

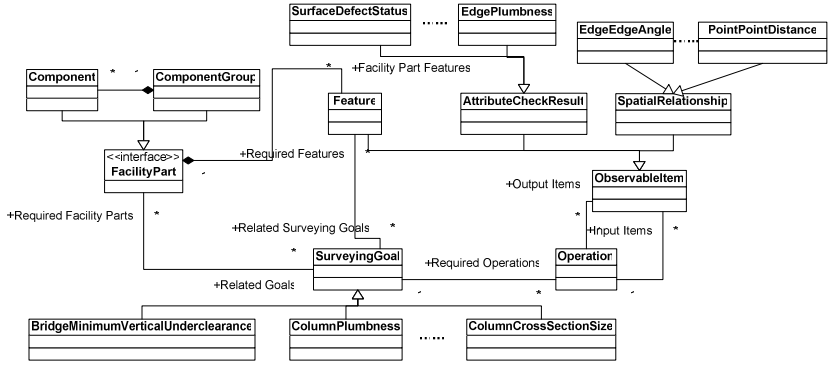


Figure 5 Surveying Goal Representation

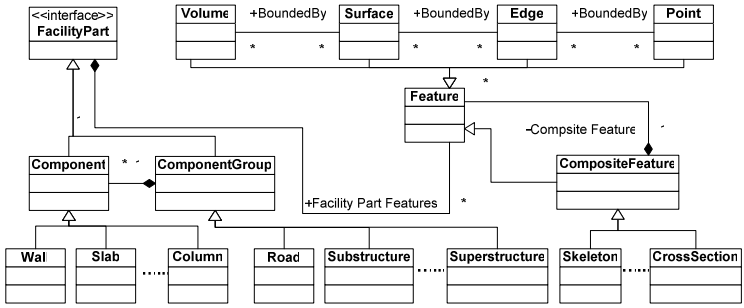


Figure 6 Detailed Representations for Facility Part and Features

In some cases, inspectors need to specify distribution patterns of some operations, and constraints on operations. For example, inspectors may want to sample points on a surface with a grid pattern, or just do random point sampling. Some surveying goals require measurements in a specific direction (e.g. vertical distance), which is a constraint on the operation "extract distance". In order to enable inspectors to customize these operations, the developed representation relates an operation object with a measurement distribution object and a constraint object. A distribution object contains information about how measurement operations should be spatially distributed, such as "on 3D grids". A constraint object specifies which parameters of an operation should be constrained to a specific value or a range.

As discussed above, by specifying <facility parts, features, operations> tuples, an inspectors can describe which types of building components they want to inspect, which features of those components are of interest, and which operations can generate required surveying goal results. With information about facility parts, a matching mechanism can query a BrIM to extract all instances of the facility part types specified in the surveying goal (e.g. all columns in a BrIM), and extract data patches belonging to those instances from a point cloud overlapping with that BrIM (e.g. data patches falling on individual column instances). Then, with information about required features and relevant operations, for each identified facility part instance, a scheduling mechanism will generate operation instances for extracting required features from the instance's data patch and calculating surveying goal result, and then sequence them into an operation sequence. Executing those operation sequences on the data patches of identified facility part instances will produce surveying goal results for all identified instances. In that way, the automatic reasoning mechanism free inspectors from manual identification of data patches belonging to individual facility part instances and manual execution of an inspection workflow on each of them. The authors are developing these reasoning mechanisms for achieving that goal.

Conclusions

This paper describes a case study to show the necessity of providing automated support for extracting surveying goals from 3D point clouds. Current manual

approach for extracting surveying goals from point clouds involves many subjective and repetitive manual operations. A limited set of operations covers the processing of a variety of surveying goals required by construction and infrastructure inspectors. Hence, it is possible to automate extraction of surveying goals from point clouds.

The proposed automated framework for extracting surveying goals from point clouds is composed of two parts: (1) Capturing of surveying goal definitions from inspectors and generation of sequences of operations for extracting inspector-defined surveying goals; (2) Automatic execution of sequences of operations for generating surveying goal results.

Capturing and representing surveying goals is the first step towards automating the virtual surveying process. The developed computer interpretable representations for surveying goals represent surveying goals using <facility parts, features, operations> tuples. Facility parts are components or groups of components. Features are geometric parts assembling the shapes of facility parts. Operations are algorithms for extracting features/spatial relationships or checking attribute values of features/spatial relationships for identifying features/spatial relationships of interest. Based on these computer interpretable representations, the authors are developing reasoning mechanisms for automating extractions of user-defined surveying goals.

References

ACI. (2006). "ACI 117-06: Specifications for Tolerances for Concrete Construction and Materials and Commentary." American Concrete Institute 1-70.

Akinci, B., Boukamp, F., Gordon, C., Huber, D., Lyons, C., and Park, K. (2006). "A formalism for utilization of sensor systems and integrated project models for active construction quality control." *Automation in Construction*, 15(2), 124-138.

CGAL. (2008). "Computational Geometry Algorithm Library." CGAL Open Source Project: http://www.cgal.org/.

Cheok, G. S., Stone, W. C., Lipman, R. R., and Witzgall, C. (2000). "Ladars for construction assessment and update." *Automation in Construction*, 9(5-6), 463-477.

Eberly, D. (2008). "Wild Magic Real-Time 3D Graphics Engine, version 4,." Wild Magic 4.7 open Source Project: http://www.geometrictools.com.

Franz, R. (2003). "Automatic Generation of High-Quality Building Models from Lidar Data." *IEEE Comput. Graph. Appl.*, 23(6), 42-50.

Fuchs, P. A., Washer, G. A., Chase, S. B., and Moore, M. (2004). "Applications of Laser-Based Instrumentation for Highway Bridges." *Journal of Bridge Engineering*, 9(6), 541-549.

Gielsdorf, F., and Gruedig, L. "Geometrical Modeling for Facility Management Systems Applying Surface Parameters." *FIG XXII International Congress*, Washington, D.C. USA, 1-10.

Gordon, C. (2006). "A Formalism and a Framework for Planning of Sensor-Based Construction Inspections," PhD Thesis, Carnegie Mellon University, Pittsburgh, Pennsylvania.

Haymaker, J., Kunz, J., Suter, B., and Fischer, M. (2004). "Perspectors: composable,

reusable reasoning modules to construct an engineering view from other engineering views." *Advanced Engineering Informatics*, 18(1), 49-67.

InnovMetric. (2005). "Polyworks Reverse Engineering Environment Version 9.0.2." InnovMetric Software: http://www.innovmetric.com.

James, V. M., and Charles, V. S. (1996). "MUSE: Robust Surface Fitting using Unbiased Scale Estimates." Proceedings of the 1996 Conference on Computer Vision and Pattern Recognition (CVPR '96), IEEE Computer Society.

Jaselskis, E. J., Cackler, E. T., Walters, R. C., Zhang, J., and Kaewmoracharoen, M. (2006). "Using Scanning Lasers for Real-Time Pavement Thickness Measurement." *CTRE Project 05-205*, National Concrete Pavement Technology Center, Iowa State University.

Jaselskis, E. J., Gao, Z., and Walters, R. C. (2005). "Improving transportation projects using laser scanning." *Journal of Construction Engineering and Management*, 131(3), 377-384.

Kwon, S. W., Bosche, F., Kim, C., Haas, C. T., and Liapi, K. A. (2004). "Fitting range data to primitives for rapid local 3D modeling using sparse range point clouds." *Automation in Construction*, 13(1), 67-81.

NPL Management Ltd. (2004). "LSGE: The Least Squares Geometric Elements Library." NPL Management Ltd.

Schafer, T., and Weber, T. "Deformation Measurement using Terrestrial Laser Scanning at the Hydropower Station of Gabčíkovo." *INGEO 2004 and FIG Regional Central and Eastern European Conference on Engineering Surveying*, Bratislava, Slovakia.

Su, Y. Y., Hashash, Y. M. A., and Liu, L. Y. (2006). "Integration of Construction As-Built Data via Laser Scanning with Geotechnical Monitoring of Urban Excavation." *Journal of Construction Engineering and Management*, 132(12), 1234-1241.

Vosselman, G., Gorte, B. G. H., Sithole, G., and Rabbani, T. (2004). "Recognising Structure in Laser Scanner Point Clouds." *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 46(part 8/W2), 33-38.

Walsh, K. D. (2007). "Performance of Methods for Analysis of Relative Floor Elevation Measurements in Residential Structures." *Journal of Performance of Constructed Facilities*, 21(5), 329-336.

Weseman, W. A. (1995). "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges." United States Department of Transportation, ed., Federal Highway Administration, USA.

Xiaoyi, J. H., Bunke. (1999). "Edge Detection in Range Images Based on Scan Line Approximation." *Computer Vision and Image Understanding*, 73(2), 183–199.

Yue, K., Huber, D., Akinci, B., and Krishnamurti, R. "The ASDMCon Project: The Challenge of Detecting Defects on Construction Sites." *Proceedings of the Third International Symposium on 3D Data Processing, Visualization, and Transmission (3DPVT'06)* Chapel Hill, USA, 1048-1055.

INFRASTRUCTURE RISK MANAGEMENT IN RENEWABLE ENERGY PROJECTS USING RISK FLEXIBILITY THEORY

Nicola Chiara[1]

ABSTRACT

Climate-change-concerns coupled with US high dependence on exhaustible resources such as oil and coal have urged the federal government to support a more extensive private sector participation in developing renewable energy projects. Though the federal government has pledged to promote private participation in renewable energy developments through supportive legislation and ad-hoc incentives, the private investors' profitability in such projects is not yet secured. As a result, potential private investors are reluctant to invest in renewal energy projects making it a lose-lose situation. Literature survey shows that there are currently no effective methods to address this important issue. This paper presents a novel approach, namely the Risk Flexibility Theory, to correctly assess the financial feasibility of renewable energy projects. Risk Flexibility Theory properly reckons flexibilities that can make the project more profitable by offsetting part of the project risk.

INTRODUCTION

In the United States, doors to electrical market restructuring opened in 1978, when a change in federal law allowed private owners of cogeneration units to sell power into utility grids. Prior to this time, the U.S. had only power generation owned by groups of utilities in power agencies or generation owned by federal agencies. But market participants needed to wait until the '90s to observe the actual implications of restructured markets. Due to a shared regulatory jurisdiction, market restructuring has required cooperation from both federal and state regulators. The U.S. market restructuring has made the composition of U.S. electric power market highly fragmented as the market structure can take now several forms. The classical market structure is the vertically-integrated monopoly utility (Figure 1) where all the four market segments – generation, transmission, distribution and system operations- are grouped within one entity. However, under the new regulations all the market segments can become disconnected entities, managed by different companies. For instance, in the wholesale/industrial competition model shown in Figure 2, the

[1] Assistant Professor, Department of Civil Engineering & Engineering Mechanics, Columbia University, New York, NY 10027; PH(212) 854-3543; FAX (212) 854-6267; email: chiara@civil.columbia.edu

generation and the system operations are activities managed by companies that are not related to the utility company.

Generation capacity fuel sources in the United States are quite diverse and include coal (32%), nuclear (10%), natural gas (42%), fuel oil (4%), hydro (10%) and renewable (2%).Within any of these fuel sources, the technology employed to generate electricity can be diverse as well. The generation capacity managed by operation systems typically comes from a portfolio of different type of generators (coal, gas, hydro, renewable, etc). It is worth noting that Federal and state laws require operation systems to maintain a certain share of renewable energy in their energy portfolio. Each type of generation has unique operating and cost characteristics that make it more or less suitable to meet the aggregate demand of all customers in a specific region. Use of generation is often divided into three categories: base load, intermediate, and peaking generation. The average annual price of electricity in the US market is strikingly dishomogeneous as it ranges from 24 cents/kWh (Hawaii) to 6 cents/kWh (Kentucky and Idaho). The reason of this wide range in electricity price is due to different portfolios of power generation types that are available in different states. In fact, if expensive generator types are used to supply the base load and the peaking then the electricity cost will be higher. In the United States the electricity price market is local – it is strongly affected by local diversification of the power generation network.

Environmental Issues and Renewable Electric Power Generation

The generation of electricity results in an environmental contradiction - use of electricity at the point of consumption is very clean yet generation of electricity often has significant environmental impacts. These include air pollution, water pollution, greenhouse emissions, ecosystem and land-use disruption, and the potential for release of radioactive materials. Different types of generation have different impacts, and environmental considerations can greatly influence how generation types are used as well as what types should be built in the future.

Renewable electricity generation is a broad category fueled by sources that can be naturally replenished. These include geothermal, solar, wind, biomass, and smaller-scale hydro generation – usually less than 30 MW. Technologies used vary widely, and the size of renewable units tends to be small. The two main advantages of renewable power are that many technologies have no ongoing fuel cost and the environmental impacts are generally minimal. One drawback is that many renewable sources are intermittent and not always available. Thus the system operators must plan for back up sources when including renewables in the generation mix. The U.S. department of Energy is fully supporting the development of renewable electric power generation for two main reasons: to preserve national security and to foster domestic economic development. In fact, the wide distribution of most renewable energy resources improves the robustness of domestic energy systems by reducing the country's reliance on a vulnerable, centralized energy infrastructure. Furthermore, renewable energy diversifies the nation's fuel resources and, because renewable resources are indigenous, reduces its dependence on imported fuels. Finally, renewable electric power generation stimulates local economies by creating permanent jobs and increasing local tax bases.

Investing in Renewable Power Generation Projects

Renewable power generation has usually been more expensive than conventional power sources. These higher costs are largely due to relative immaturity of renewable technologies and their concentration in niche markets, compared with conventional energy resources. Governments willing to expand their renewable power generation sector provide financial support to potential private investors. For instance, in the United States, wind power receives a tax credit for each kilowatt-hour produced – currently at 2 cents per kWh. However, because of higher generation cost and high volatile electricity market, private investors still view renewable power generation plants as high risk investments.

Typically, the private investors – or sponsors - finance the investment trough project finance rather than corporate loans. In the project finance framework, the project company, unlike a corporate borrower, does not have any past business record that can assist lenders for their lending decision. Therefore, lenders only rely on the project cash flows as the sole source for debt repayment (Esty 2003).

Paper Intellectual Contribution

This paper presents a new approach, namely the Risk Flexibility Theory, to thoroughly assess the financial feasibility of renewable energy projects by properly reckoning projects flexibilities that may offset part of the project risks, which in turn would make the project more profitable. The paper's sections are structured as follows: The 'Risk Flexibility Theory' section presents an overview on Risk Flexibility theory. The 'Wind Farm Project' section illustrates how to apply the Risk Flexibility theory to properly assess the profitability of a hypothetical 45 MW wind farm project. The 'Discussions' section presents some ideas for further research.

RISK FLEXIBILITY THEORY

Risk flexibility theory (RFT) evaluates risks and flexibility of infrastructure systems by reframing in a more coherent and consistent framework aspects of established infrastructure risk management methods and real options methodologies.

Background

The infrastructure risk management method considered in RFT is an enhanced quantitative simulation approach based on:

a) the method developed by the World Bank and implemented in INFRISK, a computer-based risk-management approach to infrastructure project finance transactions (Dailami et al., 1999); and,
b) the Monte Carlo risk management methods developed by several academics (Seneviratne and Ranasinghe,1997; Wibowo and Kochendörfer, 2005). In particular, the method presented by Aziz and Russell (2006) condenses and ameliorates all the other previous academic methods.

RFT 's affinity to Option theory lies in two conceptual frameworks. Firstly, RFT incorporates the theoretical concepts of flexibility/optionality that underlie both financial options and real options (upper side of Figure 3). An option is the opportunity to take a beneficial action, within a bounded time frame, when a positive/negative condition occurs. Accordingly, option theory studies how to model and price this "opportunity". Option theory embraces two principal research fields: financial option theory and the more recent real option theory. The former refers to

option theory applied to assets traded in a financial market, while the latter concerns option theory applied to non-financial assets (or real assets). Financial option theory was first developed by the French mathematician Louis Bachelier in 1900 and became a mature science in the '70s thanks to the seminal Nobel Prize winning research by Merton, Black, and Scholes (Black and Scholes, 1973). Conversely, real option theory is a relatively recent research field and Myers (1977), who first coined the term real option, is credited for its initial development. Over the years, other researchers have significantly contributed to the expansion of real option theory (Dixit and Pindyck, 1994; Trigeorgis, 1996; Amram and Kulatilaka, 1999; Copeland and Antikarov, 2001). A major contribution in clarifying the different "nature" of real options came from de Neufville, who first categorized real options into real options "on" and "in" projects. "Real options "on" projects are mostly concerned with the valuation of investment opportunities, while real options "in" projects are mostly concerned with design of flexibility" (Wang and de Neufville, 2005).

The second affinity between Risk Flexibility Theory and Real Option Theory is that both theories share a similar computational framework to resolve their stochastic multistage decision analysis problems (lower side of Figure 3). However, RFT overcomes the inherent inconsistencies and limitations of Real Option Theory's computational tools in dealing with risk management of civil infrastructure systems.

Fundamental Framework

From the Risk Flexibility Theory's perspective, an infrastructure project is seen as an engineering system characterized by some flexibility. It is useful to introduce a structural analysis analogy to explain what system flexibility means in this context. It is assumed that an infrastructure system is represented by a structural element as the one shown in Figure 4a. When the system is subjected to some external "force" F_1, the system response is SR_1. Following on the structural analogy, the slope of the straight line passing from point A to the origin 0 (Figure 4b) can be considered as the 'secant' stiffness of the system.

We may think that the infrastructure project is subjected to a risk load , $R_{project}$, as shown in Figure 4c. The system response to $R_{project}$ can be expressed as the initial project risk impact. The initial secant stiffness of the system is the slope of the straight line OA (Figure 4d). Another important risk element is the Tolerated Risk impact, the upper limit of the expected monetary loss that the sponsors are willing to accept (Figure 4d). Figure 4d describes a project risk profile **A** that will prompt sponsors to abandon the project. Figure 4f shows the changing in the system stiffness once project flexibilities are added to the system. The new risk profile **B** implies a risk impact that is below the sponsors' tolerated risk. Under risk profile **B**, sponsors will be willing to invest in the project.

ILLUSTRATIVE CASE STUDY: THE WIND FARM PROJECT

The case study examines a hypothetical project financed wind farm which is assumed to have a 1-year construction phase and a 25-year operational phase. The 45 MW wind farm's initial setting comprises 30 wind turbines of 1.5 MW capacity each.

The illustrative case study is divided in three sections. In the first section, a deterministic project analysis, or base-case analysis, is presented. The base-case

analysis is usually performed to assess the wind farm's financial feasibility when uncertainty is not considered. The second section, the stochastic financial project analysis, presents a project financial risk analysis under uncertainty. The third part illustrates how to implement the risk flexibility theory to augment the profitability of the wind project.

Base-Case Analysis

The prime objective in the base-case analysis is to assess whether or not the wind farm can generate the expected sponsor's rate of return. No uncertainty is considered at this stage, i.e. all the values used in the analysis are considered projected or expected (Yescombe, 2003). A simplified cash flow model (1) to determine the project's annual net revenue available to the sponsors during the period *i* is given by (Esty, 1999)

$$ECF_i = \text{Gross Revenue}_i - \text{Total Cost}_i - \text{Tax}_i - \text{Debt Service}_i \quad (1)$$

where

-ECF_i is the equity cash flow accumulated in the time period i;

-Gross Revenue_i is the "Annual Energy Production" multiplied by "the average energy price" for that *i* year;

-Total Cost_i represents all project costs in the time interval i;

-Tax_i represents the project tax in time interval i and it takes into account the 2 cents per kWh tax credit ; and

-Debt Service_i represents debt principal and interest paid during the time interval i;

The simplified model (1) is presented for illustrative purposes. A more sophisticated cash flow model could also be used such as the one found in Dailami et al. (1999).

The hypothetical project's capital structure, capital expenses, tax structure and other cash flow assumptions are shown in Figure 5. Energy analysts usually provide the projected average energy price and the expected annual energy production over the operational period. Regardless of the forecasting method employed, energy analysts are asked to determine an expected future scenario for a project by taking into account the critical assumptions about the evolution of the energy price, the power production and electricity demand for the wind farm lifetime. Once energy analysts have completed the forecast models, they provide the project analyst with both the vector of expected energy price (column [1] on Figure 5), and the predicted/expected annual energy production (column [2] on Figure 5)

Once the project analyst has collected all the project information about the financial projections, which is shown in the upper portion of Figure 5, s/he performs a Net Present Value analysis on the Sponsor's ECF (Yescombe, 2003). The computed project NPV on Sponsor's ECF yields a positive NPV of roughly $4.25 million.

Financial Risk Analysis under Uncertainty

The financial risk of the wind farm project can be evaluated by modeling Eq (1) as the stochastic process

$$ECF_t = f\left(\mathbf{R}_t, \mathbf{D}_t\right)$$

where $\mathbf{R}_t$ and $\mathbf{D}_t$ are the vector of risk variables and the vector of deterministic parameters relative to the time interval t, respectively (Dailami at al. 1999). The stochastic parameters are shown in Figure 6. A Monte Carlo simulation risk analysis is then performed using 10,000 simulated paths to obtain a convergent result. The Monte Carlo risk analysis generated an equity cash flow NPV distribution with an

expected NPV of $3.5 million and a probability that NPV is negative of 29.8% that is Pr(NPV<0)=29.8%.
Since the likelihood that the project is financially unfeasible exceeds the sponsors' tolerated risk, that is the threshold of Pr(NPV<0)=20%, sponsors most likely will abandon the project (see Figure 7).

Risk Flexibility Approach

One of the drawbacks of the abovementioned financial risk analysis is that inherently considers the project as a "stiff" system with no opportunity for the project manager to react to relevant information that might be revealed in the future. In other words, the system analyzed in the previous sub-section is a system that does not consider the managerial flexibility that is observed in real projects. In the examined wind farm project three project flexibilities are considered (see Figure 8):

a) Flexibility 1 is a risk hedging opportunity, that is revenue guarantee that the government may offer to the wind farm sponsors, in addition to the tax credit incentive, to hedge the risk that the actual annual equity cash flow can be lower than the 95% of the annual ECF.
b) Flexibility 2 is the opportunity to expand the wind farm capacity by 15MW over the next 5 year following the construction completion if the electricity price will be above a certain threshold and the demand will grow.
c) Flexibility 3 is the opportunity to delay the construction commencement by 1 year if the electricity price will go below a certain threshold.

All the tree flexibilities' values are assessed as real options and modeled according to the stochastic processes used in the previous financial risk analysis under uncertainty. Adding these three flexibilities to the system yields a probability that the NPV is negative of 17.5%., that is Pr(NPV<0)=17.5%. Because, the risk that the project is unfeasible is below the tolerated risk threshold, the sponsor will be willing to pursue investing in the wind farm project (Figure 7)

DISCUSSION

Current quantitative risk analysis methods consider the project as a "stiff" system (do-all or do-nothing system) with no opportunity for the project manager to react to relevant information revealed in the future. These methods may underestimate the final project risks because there are not able to capture the project opportunities that may offset negative events or create additional value when positive events occur.
The risk flexibility approach is promising in fixing this issue by integrating real option capability into the current quantitative risk analysis methods. The main characteristics that make the risk flexibility theory (RFT) appealing to project risk evaluation analysts are portability and consistency. The RFT is portable in the sense that it can be applied to any infrastructure project. Furthermore, RFT is consistent with current quantitative project risk valuation methods because it preserves their main features while enhancing them with real option capabilities. A simplified real-world project case study was presented. For illustrative purpose, the case study considered only three of the potential flexibilities typical found in wind projects. This study will be further extended by applying RFT methodology to a real-world wind project.

REFERENCES

Amram, M., and Kulatilaka, N. (1999). *Real Options: Managing Strategic Investment in an Uncertain World*, Harvard Business School Press,Cambridge, MA.

Aziz, A. M. A. and Russell, A. D. (2006) Generalized Economic Modeling for Infrastructure and Capital Investment Projects. *Journal of Infrastructure Systems*, 12(1), 18-32.

Black, F., and Scholes, M. (1973). "The Pricing of Options and Corporate Liabilities." *Journal of Political Economy*, 81(May/June 1973), 637-659.

Chiara, N. (2008). Risk Analysis of Contractual Flexibility in PPP Negotiations: a Quantitative Approach using Flexibility Theory. *Proceedings 1st IPMA/MedNet Conference,* Chios, Greece.

Chiara, N. and Garvin J., M. (2008). Variance Models for Project Financial Risk Analysis with Applications to Greenfield BOT Highway Projects. *J. Constr. Manag. & Econ.* (July-Sept) **26**, 925-939

Copeland, T. E., and Antikarov, V. (2001). *Real Options: A Practioner's Guide*, Texere, New York, NY.

Dailami, M., Lipkovich, I. and Van Dyck, J. (1999). INFRISK: A Computer Simulation Approach to Risk Management in Infrastructure Project Finance Transactions. *Paper No. 2083*, World Bank, Washington, D.C.

de Neufville, R., Scholtes, S., and Wang, T. (2006). "Valuing Real Options by Spreadsheet: Parking Garage Case Example." *Journal of Infrastructure Systems*. Vol. 12(2),107-111

Dixit, A. K., and Pindyck, R. S. (1994). *Investment Under Uncertainty*, Princeton University Press,Princeton, NJ.

Esty, B. C. (1999). "Improved Techniques for Valuing Large-Scale Projects." *Journal of Project Finance*, 5(1), 9-25.

Esty, B. C. (2003). *Modern Project Finance: A Casebook*, Wiley, New York, NY.

Myers, S. (1977). "Determinants of corporate borrowing." *Journal of Financial Economics*, 5(1), 147-175.

Seneviratne, P. N. and Ranasinghe, M. (1997) Transportation Infrastructure Financing: Evaluation of Alternatives. *Journal of Infrastructure Systems*, **3**(3), 111-8.

Trigeorgis, L. (1996). *Real Options: Managerial Flexibility and Strategy in Resource Allocation*, MIT Press, Cambridge, MA.

Wang, T., and de Neufvillee, R. (2005). "Real Options "in" Projects." *<http://realoptions.org/papers2005/Tao_Wang_RO_in_projects.pdf>*, (August 8, 2005).

Wibowo, A. (2005) Estimating general threshold traffic levels of typical build, operate, and transfer toll road projects in Indonesia. *Construction Management & Economics*, **23**(6), 621-30.

Yescombe, E. R. (2003) *Principles of Project Finance*. Academic Press, San Diego.

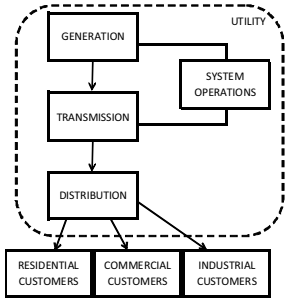


Figure 1. The Vertically-Integrated Monopoly Utility

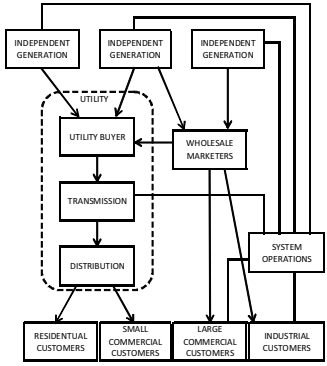


Figure 2. The Wholesale/Industrial Competition

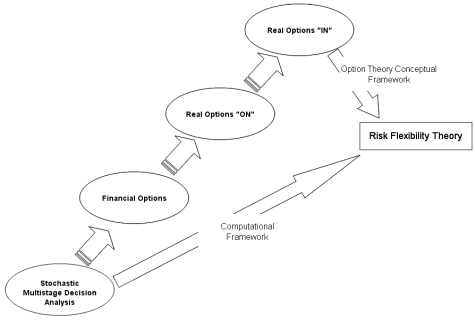


Figure 3. Real options theory details

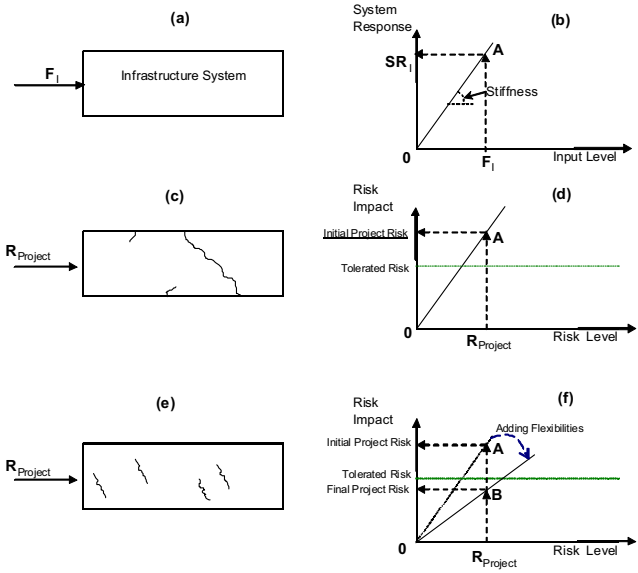


Figure 4. Risk Layout of a Flexible Infrastructure System

Period	Financial Projections							Valuation	
	Wind Energy Price	Annual Energy Production (MWh)	Gross Revenue	Total Cost (operation, maintenance, etc.)	TAX	Debt Service	Capital Expenditure	ECF	Discounted ECF
	(cents/kWh)	(MWh)	$	$	$	$	$	$	$
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
0			0	0	0	0	(42,000,000)	(8,400,000)	(8,400,000)
1	10.35	135000.00	13,972,500	(9,000,000)	146,250	5,040,000		78,750	67,308
2	10.66	135000.00	14,391,675	(9,090,000)	(2,903)	4,872,000		302,424	220,924
3	10.98	135000.00	14,823,425	(9,180,900)	(155,558)	4,704,000		783,749	489,350
4	11.31	135000.00	15,268,128	(9,272,709)	(311,826)	4,536,000		1,148,370	612,828
5	11.65	135000.00	15,726,172	(9,365,436)	(471,821)	4,368,000		1,509,187	688,357
6	12.00	135000.00	16,197,957	(9,459,090)	(635,660)	4,200,000		1,905,224	742,730
7	12.36	135000.00	16,683,896	(9,553,681)	(803,464)	4,032,000		2,284,263	761,106
8	12.73	135000.00	17,184,413	(9,649,218)	(975,358)	3,864,000		2,699,094	768,654
9	13.11	135000.00	17,699,945	(9,745,710)	(1,151,470)	3,696,000		3,110,017	756,990
10	13.50	135000.00	18,230,943	(9,843,167)	(1,331,933)	3,528,000		3,518,591	731,998
11	13.91	135000.00	18,777,872	(9,941,599)	(1,516,882)	3,360,000		3,963,883	704,817
12	14.33	135000.00	19,341,208	(10,041,015)	(1,706,458)	3,192,000		4,393,722	667,732
13	14.76	135000.00	19,921,444	(10,141,425)	(1,900,806)	3,024,000		4,860,946	631,400
14	15.20	135000.00	20,519,087	(10,242,840)	(2,100,074)	2,856,000		5,313,401	589,889
15	15.66	135000.00	21,134,660	(10,345,268)	(2,304,418)	2,688,000		5,803,947	550,726
16	16.12	135000.00	21,768,700	(10,448,721)	(2,513,994)	2,520,000		6,292,952	510,365
17	16.61	135000.00	22,421,761	(10,553,208)	(2,728,966)	2,352,000		6,869,549	476,177
18	17.11	135000.00	23,094,414	(10,658,740)	(2,949,502)	2,184,000		7,301,628	432,588
19	17.62	135000.00	23,787,246	(10,765,327)	(3,175,776)	2,016,000		7,829,594	396,468
20	18.15	135000.00	24,500,863	(10,872,981)	(3,407,965)	1,848,000		8,371,363	362,309
21	18.69	135000.00	25,235,889	(10,981,710)	(4,276,254)	0		9,977,365	369,073
22	19.25	135000.00	25,992,966	(11,091,527)	(4,470,432)	0		10,430,441	329,772
23	19.83	135000.00	26,772,755	(11,202,443)	(4,671,094)	0		10,898,647	294,508
24	20.43	135000.00	27,575,938	(11,314,467)	(4,878,441)	0		11,382,452	262,891
25	21.04	135000.00	28,403,216	(11,427,612)	(5,092,681)	0		11,882,340	234,561
									4,253,521

NPV (ECF) = PV(ECF) - PV(EQUITY) = 12,653,521 - 8,400,000 = $4,253,521

a) Cost of equity K_e = 17%
b) Borrowing interest r_b = 10%

Figure 5. Project Financial Projections

Random Variable	Stochastic Process		
Wind Energy Price	VarModel*	Year 1	Betapert() , min =10 cents, most likely = 10.35 cents, max = 11 cents; H(t)=t* ^2
Total Cost	VarModel*	Year 1	Betapert() , min =$8.5M, most likely = $9.0M, max = 9.5M; H(t)=t* ^2
Capital Expenditure			Betapert() , min =$40M, most likely = $42M, max =45M;

*Chiara, N. and Garvin J., M. (2008). Variance Models for Project Financial Risk Analysis with Applications to Greenfield BOT Highway Projects. *J. Constr. Manag. & Econ.* (July-Sept) 26, 925-939

Figure 6. Model Assumptions in the Monte Carlo Simulation

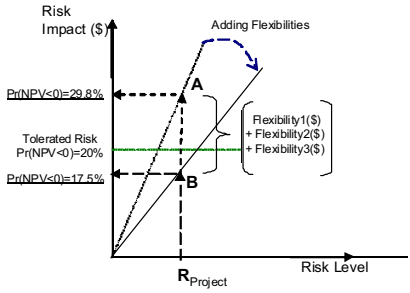


Figure 7. Risk Layout of the Wind Farm Project

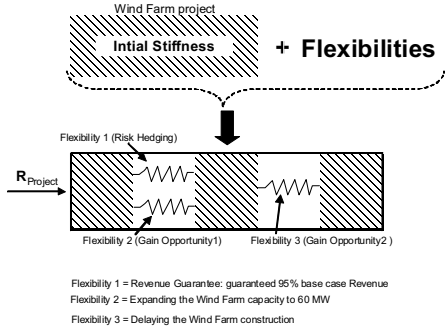


Figure 8. Flexible Wind Farm Project

THE IMPACTS OF INFRASTRUCTURE PPPs ON PUBLIC SECTOR CAPACITY

Stephan F. Jooste and Raymond E. Levitt[1]

Abstract
Infrastructure PPPs have been shown to overcome public sector capital and capacity constraints in the short term, and therefore, increase the viability of desired infrastructure projects. Their long-term impacts on the capacities of governments have, however, not been considered as explicitly. This issue is especially salient in the context of infrastructure delivery due to the central role that the public sector continues to play in the process of selecting, delivering and managing infrastructure assets. This paper seeks to illuminate this issue through a review of literature on "public sector capacity," the changing role of government, public sector contracting, and outsourcing in the private sector. We draw on these diverse streams of literature to (i) clarify the concept of "public sector capacity", (ii) identify two broad typologies of capacity, and (iii) investigate the possible impacts of PPPs on each of these dimensions of capacity. We conclude with suggestions for future research.

Introduction

The pivotal role of civil infrastructure in enhancing public health and accelerating economic growth has been widely acknowledged in the literature. It thus remains a central part of development initiatives in both developed and —more significantly— developing countries. Responsibility for infrastructure development has historically alternated between private and public provision. Providing civil infrastructure has largely been the responsibility of the public sector worldwide during the last century, particularly for water supply and roads.

In many countries, infrastructure development has been hampered by two broad public sector constraints: lack of public capital; and lack of public sector capacity.

Lack of public capital: Many countries lack the ability to access financial markets, either because their formal economies and polities are underdeveloped, or because they lack the required creditworthiness to finance themselves in the international capital markets for a variety of other reasons (including economic and political

[1] Both Authors: Collaboratory for Research on Global Projects (CRGP), Department of Civil and Environmental Engineering, Stanford University, 473 Via Ortega, # 243, Stanford, CA 94305-4020, PH: (650) 644-7607, Email: sjooste@stanford.edu

instability and lack of transparent legal systems that afford protection to investors' property rights). In contrast, many wealthy developed countries have large formal economies and well developed polities. However, widespread anti-tax sentiments have made it difficult to fund new infrastructure, and impossible to maintain and upgrade existing, often crumbling, infrastructure.

Lack of public sector capacity: Governments might also lack the resources and specialized expertise (e.g. financial and managerial skills) to develop, manage and operate infrastructure assets. This lack of institutional capacity is compounded when governments undertake especially large and complex projects. In addition this constraint leads to inefficiencies in the operation and maintenance of infrastructure. If we further include both institutional and political aspects of the public sector under our definition of capacity, this second constraint negatively impacts the first constraint (lack of capital) defined above.

To address these capacity gaps, governments have increasingly moved toward sets of arrangements involving differing degrees of private participation in financing, developing and managing of infrastructure assets over the last two or three decades. These new contractual arrangements for infrastructure delivery have generally been termed Public Private Partnerships (or PPPs).[2]

Infrastructure PPPs have been shown to overcome the two public sector constraints identified above in the short term, and therefore, increase the viability of desired infrastructure projects. Their long-term impacts on the capacities of host country governments have, however, not been considered as explicitly. A specific concern is that PPPs increasingly deliver functions traditionally provided by the public sector, so they could have the net effect of diminishing domestic human capital in service provision. This long term reliance on PPP managers (often expatriates in the case of developing countries) can lead to growing dependence on the private sector for providing managerial capacity. An alternative hypothesis is that PPPs, if set up to involve and train government officials appropriately in the course of the project, could increase human capital, transfer standard operating procedures, and otherwise increase a host government's institutional capacity for providing its infrastructure.

Problem Statement and Methodology

This question of the long term impact of PPPs on public sector capacity is especially salient in the context of infrastructure delivery, due to the central role that the public sector continues to play in the process of selecting, delivering and managing infrastructure assets. The extent to which public sector capacity is built or eroded through the use of PPPs, will clearly impact the long-term sustainability of infrastructure developments. Unfortunately this issue has not received sufficient attention in the construction management or infrastructure development literatures.

[2] Other terms have included "Private Sector Participation" or PSP, and "Performance Based Infrastructure" or PBI (as popularized by the Schwarzenegger Administration in California).

To this end, much can be gleaned from literature on public administration, the changing role of government, public sector contracting, and outsourcing in the private sector. The remainder of this paper draws on the public administration literature to illuminate this issue in the context of infrastructure delivery. In doing so, we find a host of diverse definitions for the concept of "public sector capacity" [3] which we use to formulate two broad typologies of capacity: (i) defining capacity in terms of the functions that the public sector executes, or (ii) defining it in terms of the level at which it is found in the public sector. We investigate the possible impacts of PPPs on each of these dimensions of capacity, drawing on recent findings from the literature. We conclude with a number of suggestions for future research.

Capacity embedded in public sector functions

This first approach taken by authors who study public sector capacity, is to view it in terms of the functions delivered by the public authority.[4] Although these definitions are greatly biased by the type of public sector authority they consider[5], our comparison in Table 1 identifies three broad types of capacity: strategic capacity, executive capacity, and political (or institutional) capacity.

Table 1 – Functional classification of capacity

Functional area	Lindley (1975)	Howitt (1977)	Grindle (1997)	Polidano (2000)
Strategic capacity	Ability to choose which ends to pursue	Ability to identify problems, and to develop and evaluate policy alternatives to deal with them	Ability to set coherent economic strategies	Ability to deliver policy advice to decision makers
Executive capacity	Ability to take actions to achieve the ends being pursued	Ability to operate government programs	Ability to manage economic strategies	Ability to implement policies
			Capacity to administer infrastructure and supply public goods	Ability to deliver services
Political capacity			Ability to uphold "rules of the game", mediate conflict, respond to citizens, provide for participation	

The recent increased involvement of private parties in service delivery has however meant that the role of the public sector is undergoing significant changes. Scholars in public management have popularly referred to this as moving government focus from

[3] A number of different terms are used, including "institutional capacity," "public sector capacity," "public managerial capacity," and "public sector capability." We will stick to "public sector capacity" for the purposes of this article.

[4] Our focus here is only on the executive branch of government. Although this might include input into the judiciary and legislative branches, these parts of government are outside the focus of this paper.

[5] Lindley (1975) considered the public sector in general, Howitt (1977) focused on Local Government, Grindle (1997) was more concerned with the public sectors of developing nations, while Polidano (2000) highlighted the functions of the executive branch of government.

"rowing" (i.e., service delivery) to "steering" (i.e., making policy decisions) (Osborne and Gaebler, 1992) under the reform movement generally known as the "New Public Management" (Hood, 1991). As Kaul (1997) put it, the role of government shifts from "a concern to do, toward a concern to ensure that things are done" through collaboration with other actors. The responsibility of ensuring that a service is performed is therefore separated from the actual performance of the service (Savas, 1987). The former has been termed "provision", while the latter has been referred to as "production" (Ostrom, et al., 1961).[6] The new role therefore calls for an expansion (or strengthening) of "provision" functions, as governments seek to coordinate more complex networks of actors (Peters and Pierre, 2002). The reasoning is that, because "production" of services is no longer necessarily delivered in-house, "provision" entails a host of expanded functions that seek to stimulate and orchestrate "production" success (Salamon, 2002).

Van Slyke (2003) brings this new role into the context of public sector capacity (what he terms "public management capacity"), when he proposes it requires the public sector to fulfill the following functional roles: contract management, negotiation, bargaining and mediation, oversight and program auditing, and aspects of communication and politics.

So returning to our functional typology of public sector capacity, we can identify impacts from the increased use of PPPs on each of the functional aspects of public sector capacity.

Strategic capacity

The use of PPPs require that a public sector agency is able to choose which services to expose to private participation, and to decide which type of arrangement to use for service delivery (Brown and Potoski, 2006). In addition Mody (1996) suggests that the involvement of private companies in infrastructure delivery necessitates that the activities, that are by their very nature open for competition, be separated (or "unbundled") from those that remain as "natural monopolies." The former can then be supplied through the market, while the latter will first need to be tendered competitively, and then be subject to continued public regulation. This is best done through a process that is "well-specified, inclusive, and ideally has some independent checks on the decisions—preferably by an office or organization with little to gain from the decision" (Wallin, 1997). The successful use of PPPs therefore requires new levels of strategic capacity, both for choosing the service and delivery vehicle, and to execute the unbundling process.

Executive capacity

Clearly this is the area of capacity that is most affected by the increased use of PPPs. The new role requires that the public sector is able to "orchestrate" a new network of players and stakeholders (including local and transnational NGOs) involved in service delivery. The public sector must be a "smart buyer" of services (Van Slyke, 2003) by being able to formulate contracts, tender them, evaluate different proposals, negotiate and bargain with the preferred bidder, and then roll out the appointment. In addition,

[6] Other variations include: "indirect provision" and "direct provision" (Batley and Larbi, 2004), and "management" and "production" (Brown and Potoski, 2006).

the new role requires regulatory capacity from the public sector – in the form of contract management, oversight, and auditing – to ensure the benefits of private provision are retained for the benefit of the public throughout the contract, and that private providers are treated equitably. In particular, the setting of tolls, water and power rates and other kinds of user fees or availability fees pits short and long term public interest against short and long term private concerns.

Political capacity

Lastly, using PPPs can impact the political capacity of the public sector in two ways. On the one hand it greatly complicates the political and institutional environment for public service delivery, which Wallin, 1997) describes as "bureaucratic intransigence, public union opposition, and partisan politics." Increased private sector involvement therefore requires the "necessary communication and political skills to manage programs with third parties in a complex political environment" (Van Slyke, 2003). In addition, the use of PPPs requires a supportive institutional environment to attain full public benefit (Mody, 1996). This includes functional financial markets (for financial accountability) and the political context that stimulates private (both local and international) investment.

In a number of countries the aforementioned capacities have been centralized in coordinating bodies, often referred to as "PPP Coordination Agencies." The benefit of centralizing these functions into one autonomous agency is that they "provide a consistent approach to involving the private sector and relevant public agencies in the evaluation, financing, procurement, maintenance, operation, and disposition of infrastructure assets" (Farrugia, et al., Forthcoming). In many cases these agencies are mandated to take an even wider role in promoting the use of PPPs, working with the other parts of the executive branch of government to identify and roll-out feasible projects (PPIAF, 2007). The role of these agencies is therefore predominantly focused on increasing the public sector's "strategic capacity" and "political capacity" while supporting the "executive capacity" of the executive branch.

Capacity embedded in the public sector level

Batley and Larbi (2004) provide a model definition for the second typology of public sector capacity, when they define capacity as "the factor that explains human performance within a given organizational framework and institutional environment." This approach recognizes capacity as being embedded in different levels of the public sector, and even beyond it, at an institutional level.

From our comparison of the literature on capacity in terms of public sector level in Table 2, we deduce three broad levels of capacity: (i) capacity embedded at the human level in the skills and capabilities of public sector employees; (ii) capacity at the organizational level contained in processes, structures, management systems and relationships; and (iii) capacity at an institutional level, consisting of both the rules, norms and standards of the public context, as well as the macroeconomic and political environment.

To date, the impact of PPPs (specifically for infrastructure provision) on public sector capacity at each of these levels has not been considered in the literature. However, a large body of extant literature analyzes the impacts of private provision of other public services, such as waste removal, recreational area management, and various social services.

Table 2 – Level classification of capacity

Level	Grindle and Hilderbrand (1995)	Franks (1999)	Levy (2007)	Research Gaps
Human level	Human resources – the capacity of the individual public sector employees	Human resource development	Service provision capability	Impact of PPPs on public staff retention
Organizational level	Organizations – the structures, processes, resources, and management styles of public sector organizations	Strengthening of managerial systems		Impacts of PPPs on the work processes, technology employed, and management styles of public authorities
	The task network – the set of organizations involved in accomplishing a given task.		Bureaucratic capability: both financial and administrative capability	
Institutional level	Rules and procedures set for the public sector, and the financial resources at its disposal (institutional context)	Institutional development, including community participation.	Investment climate	Impacts of PPPs on institutional capacity dimensions, such as corruption, creditworthiness, and social capital
	Economic, political and social milieus in which governments carry out their activities (action environment)	The creation of an enabling environment, with appropriate policy and legal frameworks	National checks & balances institutions; public attitudes toward private sector involvement in infrastructure	

In addition, the findings of the extensive literature on the impacts of "outsourcing" by private companies (mostly focussed at the organizational level) are also applicable to both the human and organizational levels. Contracting (or outsourcing) in this context is often viewed as the "disintegration" of non-core services to increase organizational focus, free up assets, and reduce costs (Harland, et al., 2005). Although there are many parallels, the impacts of outsourcing do differ from those of PPPs in a number of respects, including: PPPs are not aimed at increasing government competitiveness, the delivery of PPP services remains in the host country (outsourcing often takes delivery abroad), arguments of scale economies of suppliers is less relevant for PPPs, and the social and political implications (including issues such as public perceptions, political legitimacy, and social welfare) of PPPs are considerably greater. Still, this research is helpful for our current study. We consider these two research streams in terms of the three capacity levels identified above.

Human level

A number of authors have found that contracting in the social services sector decreases public sector capacity by reducing public staffing levels and hence public

sector human capital (Lawther, 1999; Milward and Provan, 2000; Van Slyke, 2003). This finding is unsurprising, as a reduction in the functions delivered by governments should lead to fewer staff being needed. In many contracting arrangements private providers re-employ the public employees who used to deliver the service. But even in these cases, their numbers are soon cut in pursuit of increased efficiency. However, if we focus more broadly than just on public service delivery capacity, contracting has been found to increase the managerial capacity of public authorities, as these arrangements allow public managers to focus more closely on their organization's core activities (Van Slyke and Hammonds, 2003).

The increased interaction of public and private players has also often been suggested to increase the likelihood of skilled public workers being "poached" or "siphoned off" to these private companies (see for instance UNDP, 1993). Cohen and Wheeler (1997) however found that the rate of retention of highly-qualified staff in Kenya was much higher than anecdotally suggested. More work is obviously needed to clarify the possible relationship between the use of PPPs and public sector staff employment and retention.

Organizational level

At an organization level, it has been suggested that the newly injected management capabilities of vendors may actually offset any loss in capacity experienced by the public authority (Brown and Potoski, 2006). Public agencies also address capacity shortfalls by "buying in" management expertise (Ibid.), but this remains a short-term solution, and these agencies need to address this shortfall to avoid long-term private sector dependence. It is interesting to note that Milward and Provan (2000) suggest that it is important that public agencies become not only buyers of services, but still continue to "produce" some services themselves. The reasoning is that producing some services helps the public authorities stay apprised of what the costs of production are, thereby enabling them to identify instances of overcharging or price-fixing by private providers.

Turning to the outsourcing literature, it has often been suggested that outsourcing increases organizational flexibility to meet the challenges of a changing business environment (see for instance Gilley and Rasheed, 2000). However, in-line with our discussion on the changing role of government, outsourcing in the private sector has been found to increase supply network complexity and therefore invariably requires increased managerial capacity from private firms that are outsourcing (Cox, 1996; Harland, et al., 2005). In addition, excessive contracting could lead to "hollowing out" at an organizational level which reduces the organization's capacity to learn (Lei and Hitt, 1995), and leads to declining rates of innovation (Kotabe, 1990).

Institutional level

At an institutional level it has been suggested that delegating authority for service delivery to non-governmental organizations might lead to a loss of the political legitimacy of "government action accomplished at arms length", specifically if the contract management of service delivery is also included (Milward and Provan, 2000). Public perceptions on the legitimacy of private firms providing public goods

(such as water supply from aquifers or surface runoff), further compounds these impacts. However, if the involvement of private providers increases the level of service provided to the public at reduced —or at least "reasonable"— costs to consumers of the service, the involvement of private providers could lead to increased political legitimacy.

Harland, et al. (2005) further suggest that extensive contracting (what they term "outsourcing") might lead to an erosion of the power of the public sector as it "creates powerful players who assimilate many independently arranged outsourcing contracts." However, they also propose that the objectivity brought by private providers might serve to challenge cultural constraints, established taboos, and entrenched attitudes, bringing in new creative ideas. This difference in institutions between the private provider and the public sector might however also lead to increased conflict (specifically in the case of non-local providers) if these institutional aspects are ingrained at a societal level.

Unfortunately the impacts on other aspects of the institutional environment, such as creditworthiness or corruption, have not been addressed in the literature. In addition, the interesting link between local government capacity and social capital (Wallis and Dollery, 2002) suggests that the impact of PPPs on social capital also merits investigation.

Conclusion and remaining questions

Our review of the impacts of PPPs on public sector capacity has revealed two broad areas of impact: (i) impacts on the role of the public sector and the functions that it needs to perform, and (ii) impacts on the capacity embedded in the human, organizational and institutional levels of the public sector. While the prior group of impacts have been studied quite comprehensively, a number of important questions remain in the latter group. These include:

1. At the *human level*, more work is needed to clarify the relationship between the use of PPPs and public sector staff retention. We would expect that the increased contact of public employees with private companies (who typically offer superior compensation packages for highly skilled and motivated employees) would lead to a transition of the best public workers to these companies. However, the impact of simplified work scope and civil service protections of public managers might offset the pull from the private sector. In addition, the economic impact of increased project flow might also impact the public sector employment conditions in the long run. In addition to staff retention, however, the possibility of skills transfer between private and public players also merits further work.
2. The impact of increased PPPs on capacity at the *organizational level* is largely contained in the changes to the role and functioning of the public sector. However, impacts on the work processes, technology employed, and management styles of public authorities warrant additional study.
3. In terms of the *institutional level*, research is needed to explore the impacts of PPPs on various institutional capacity dimensions, such as corruption,

creditworthiness, and social capital. There are credible arguments for ways in which each of these dimensions can be affected both positively and negatively by the use of PPPs.

References

Batley, R. and Larbi, G. A., (2004). "The Changing Role of Government: The Reform of Public Services in Developing Countries", Palgrave Macmillan,

Brown, T. and Potoski, M. (2006). "Contracting for Management: Assessing Management Capacity under Alternative Service Delivery Arrangements", Journal of Policy Analysis and Management, 25, 323-46.

Cohen, J. M. and Wheeler, J. R. (1997). "Building sustainable professional capacity in African public sectors: retention constraints in Kenya", Public Administration and Development, 17, 307-324.

Cox, A. (1996). "Relational competence and strategic procurement management Towards an entrepreneurial and contractual theory of the firm", European Journal of Purchasing and Supply Management, 2, 57-70.

Farrugia, C., Reynolds, T. and Orr, R. J., (Forthcoming). "Public-Private Partnership Coordination Agencies: A Global Perspective", Colaboratory for Research on Global Projects, Stanford.

Franks, T. (1999). "Capacity building and institutional development: reflections on water", Public Administration and Development, 19, 51-61.

Gilley, K. M. and Rasheed, A. (2000). "Making More by Doing Less: An Analysis of Outsourcing and its Effects on Firm Performance", Journal of Management, 26, 763.

Grindle, M. S. and Hilderbrand, M. E. (1995). "Building sustainable capacity in the public sector: what can be done", Public Administration and Development, 15, 441-463.

Grindle, M. S., (1997). "Getting good government: capacity building in the public sectors of developing countries", Harvard University Press,

Harland, C., Knight, L., Lamming, R. and Walker, H. (2005). "Outsourcing: assessing the risks and benefits for organisations, sectors and nations", International Journal for Operations and Production Management, 25, 831.

Hood, C. (1991). "A public management for all seasons", Public Administration, 69, 3-19.

Howitt, A. M., (1977). "Improving Public Management in Small Communities", Dept. of City and Regional Planning, Harvard University,

Kaul, M. (1997). "The New Public Administration: management innovations in government", Public Administration and Development, 17, 13-26.

Kotabe, M. (1990). "The Relationship Between offshore Souring and Innovativeness of US Multinational Firms: An Empirical Investigation", Contact, 21, 623-638.

Lawther, W. C. (1999). "The Role of Public Employees in the Privatization Process: Personnel and Transition Issues", Review of Public Personnel Administration, 19, 28-40.

Lei, D. and Hitt, M. A. (1995). "Strategic Restructuring and Outsourcing: The Effect of Mergers and Acquisitions and LBOs on Building Firm Skills and Capabilities", Journal of Management, 21, 835.

Levy, B., (2007). "Governance Reform: Bridging Monitoring and Action", World Bank Publications,

Lindley, C. (1975). "Changing Policy Management Responsibilities of Local Legislative Bodies", Public Administration Review, 35, 794-797.

Milward, H. B. and Provan, K. G. (2000). "Governing the Hollow State", J Public Adm Res Theory, 10, 359-380.

Mody, A., (1996). "Infrastructure Delivery: Private Initiative and the Public Good", World Bank Publications,

Osborne, D. and Gaebler, T., (1992). "Reinventing government: how the entrepreneurial spirit is transforming the public sector", Addison-Wesley,

Ostrom, V., Tiebout, C. M. and Warren, R. (1961). "The Organization of Government in Metropolitan Areas: A Theoretical Inquiry", The American Political Science Review, 55, 831-842.

Peters, B. G. and Pierre, J. (2002). "Governance Without Government? Rethinking Public Administration", Journal of Public Administration Research and Theory, 8, 223-243.

Polidano, C. (2000). "Measuring Public Sector Capacity", World Development, 28, 805-822.

PPIAF (2007). "Public-Private Partnership Units: Lessons for their Design and Use in Infrastructure", Washington, D.C., U.S.A., Public-Private Infrastructure Advisory Facility.

Salamon, L. M., (2002). "The tools of government: a guide to the new governance", Oxford University Press,

Savas, E. S., (1987). "Privatization: The Key to Better Government", Chatham House Pub,

UNDP, (1993). "Rethinking technical cooperation: reforms for capacity building in Africa", United Nations Development Programme - Regional Bureau for Africa,

Van Slyke, D. M. (2003). "The Mythology of Privatization in Contracting for Social Services", Public Administration Review, 63, 296-315.

Van Slyke, D. M. and Hammonds, C. A. (2003). "The Privatization Decision: Do Public Managers Make a Difference?" The American Review of Public Administration, 33, 146-163.

Wallin, B. A. (1997). "The need for a privatization process: Lessons from development and implementation", Public Administration Review, 57, 11-20.

Wallis, J. and Dollery, B. (2002). "Social Capital and Local Government Capacity", Australian Journal of Public Administration, 61, 76-85.

AUTOMATED DEFECT DETECTION IN URBAN WASTEWATER PIPES USING INVARIANT FEATURES FOUND IN VIDEO IMAGES

W Guo[1], L Soibelman[1], J H Garrett Jr.[1]

Dept. of Civil & Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA, 15213
PH: 412-268-2952 Fax: 412-268-7813 e-mail: lucio@andrew.cmu.edu

Abstract: This paper presents an innovative approach for condition assessment and defect reporting in wastewater infrastructure, enabling automatic detection of defects and patterns from inspection imagery in realistic settings. In this paper, we describe an automated three-step approach using local scale-orientation-illumination invariant features to detect surface defects and critical patterns from inspection imagery of wastewater pipelines. The invariant features were extracted by applying Scale Invariant Feature Transform (SIFT) algorithm developed by Lowe. The devised detection approach has been experimentally tested using a diverse collection of digital images acquired from real inspection scenarios. The evaluation results demonstrated that it is possible and feasible to use such an automated approach for defect reporting and condition assessment in wastewater pipe infrastructure.

1. Introduction

In our urban areas, most underground wastewater pipes are old and approaching their service lives (EPA 2006). With the promotion of sustainable wastewater infrastructure, it is important to conduct diagnostic inspection of those infrastructure systems and assess their conditions to ensure a sustainable future and efficient life-cycle cost. Currently, visual inspection is still widely used for inspection of those infrastructure systems. Video based inspection has been the predominant nondestructive method used for remote visual inspection of these pipelines in the United States (TTN 2002). However, the current video based inspection needs to be conducted by human inspectors, and the inspection process is time-consuming and error-prone (Tafuri and Selvakumar 2002). Hence, an automated approach for facilitating this labor intensive video inspection process is the focus of the research introduced in this paper. An automated approach will not only help to relieve human inspectors from the lengthy inspection process, but will also aid the development and employment of future autonomous robotic inspection platforms.

There exists a large ontology of types of defects or defect patterns in these stormwater and wastewater pipes (NASSCO 2001). Therefore, a critical challenge for

an automatic defect recognition capability is to extract features that are invariant to defect size, orientation, and illumination. Moreover, each defect may be of different sizes, colors, shapes within different pipes, and even in the same pipes but under different locations or conditions. Even the same defect recorded by a camera from an arbitrary viewpoint would look different. Pipe imagery taken during an inspection could be under inconsistent illumination conditions. In this paper, an innovative approach for automated defect detection in wastewater pipe inspection imagery using scale-orientation-illumination-invariant features is introduced. This approach is based on the Scale Invariant Feature Transform (SIFT) algorithm developed by Lowe (2004). The SIFT algorithm is described in Section 2. The proposed approach using this SIFT algorithm for defect detection and recognition for solving the particular problem in wastewater pipe inspection and condition assessment is described in Section 3. This proposed method is also illustrated using experimental testing results from real video inspection data acquired by Redzone Robotics Inc. The experimental testing methods and results are presented in Section 4.

2. Concept of Scale Invariant Feature Transform (SIFT)

Scale Invariant Feature Transform (SIFT) algorithm is able to find distinctive, scale and rotation invariant features in images (Lowe 1999). The SIFT features have been proved to be robust with respect to partial image noise, occlusion, change of viewpoint or perspective, and illumination changes. This property of the SIFT algorithm makes it extremely useful for tasks such as automatic image processing and object recognition where the objects in images have arbitrary appearances or the camera may be moving. The SIFT algorithm is built on a Difference-of-Gaussian (DOG) pyramid (Burt and Adelson 1983) in scale space. To generate the DOG pyramid, an input image is repeatedly blurred by a Gaussian filter; the difference between consecutive blurred images is computed and is one "octave" of the DOG pyramid. Then one of the blurred images is used to generate an image at a different scale. This can be done by downsampling the blurred image by a factor of 2.

The scale space DOG can be computed by subtracting two consecutive scale-space images (Lowe 2004), as shown in Equation 1.

$$D(x, y, \sigma) = L(x, y, k\sigma) - L(x, y, \sigma)$$

Equation 1 DOG Function (Lowe 2004)

In Equation 1, $L(x, y, \sigma)$ denotes a scale-space image (Equation 2), which is yielded by the convolution of a Gaussian function, $G(x, y, \sigma)$ (Equation 3), with an input image, $I(x, y)$.

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y)$$

Equation 2 Scale-space Image Function (Lowe 2004)

$$G(x,y,\sigma)=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Equation 3 Gaussian Function (Lowe 2004)

And $L(x,y,k\sigma)$ denotes another scale-space image (Equation 4), which is produced by the convolution of a Gaussian function, $G(x,y,k\sigma)$ (Equation 5), with an input image, $I(x,y)$.

$$L(x,y,k\sigma)=G(x,y,k\sigma)*I(x,y)$$

Equation 4 Scale-space Image Function (by factor k) (Lowe 2004)

$$G(x,y,k\sigma)=\frac{1}{2\pi(k\sigma)^2}e^{-\frac{x^2+y^2}{2(k\sigma)^2}}$$

Equation 5 Gaussian Function (by factor k) (Lowe 2004)

The two scale-space images are separated by a constant factor k. According to Lowe's, the value of factor k is chosen to be $2^{1/3}$ and σto be 1.6, in order to maximize the repeatability of the SIFT algorithm (Lowe 2004).

Furthermore, the extrema including both the maxima and minima of DOG function need to be located in the image scale space. The extrema are referred as *keypoints* in Lowe's paper. At each level of the DOG pyramid, the image gradient orientation, $\theta(x,y)$ (Equation 6), and gradient magnitude, $m(x,y)$ (Equation 7), can be produced at each pixel (Lowe 2004).

$$\theta(x,y)=\tan^{-1}((L(x,y+1)-L(x,y-1))/(L(x+1,y)-L(x-1,y)))$$

Equation 6 Gradient Orientation Assigned to Each Keypoint (Lowe 2004)

$$m(x,y)=\sqrt{(L(x+1,y)-L(x-1,y))^2+(L(x,y+1)-L(x,y-1))^2}$$

Equation 7 Gradient Magnitude Assigned to Each Keypoint (Lowe 2004)

Since an illumination change often has little impact on gradient orientation, Lowe has suggested assigning a gradient orientation as computed in Equation 6 to each keypoint, and thus achieve image rotation invariance. In order to reduce the impact of illumination changes, the gradient magnitude as computed in Equation 7 is thresholded to a small value to achieve illumination robustness (Lowe 1999). Finally, local image descriptors are produced at all the keypoints by sampling the image gradient magnitudes and orientations at each keypoint so that the descriptors are distinctive as well as invariant to illumination and 3D viewpoint (Lowe 2004).

The local feature descriptors provide a basis for image matching, image registration, and object recognition. The features extracted by using the SIFT algorithm invented by Lowe are invariant to image scale, rotation, and illumination

change. Hence, it is very useful in solving the particular detection problem of this research, in which the critical challenges are different defect sizes, orientations, colors, and viewpoints in pipe inspection imagery.

3. SIFT Approach for Defect Detection in Urban Wastewater Pipes

During a video inspection process, if a defect or anomaly occurs at a particular location, considering a video clip as a time series of image frames, the defect captured in the location should be shown in a series of successive image frames. As mentioned before, a critical challenge for an automatic defect recognition capability is to extract features that are invariant to defect size, orientation, and illumination and hence to provide robust detection of various defects. By using SIFT, a defect shown in two successive or bitemporal images can be matched, and then automatically detected. The steps of the proposed approach using a SIFT algorithm are described in the following subsections.

3.1 Generation of SIFT local feature descriptors

The method of generating the SIFT descriptors has been discussed in the Section 2. As illustrated graphically in Figure 1, a Difference-of-Gaussian (DOG) pyramid was produced by subtraction of nearby scale-space images. The keypoints were then located by finding the minima and maxima of DOG function from the DOG pyramid. The SIFT descriptors were generated at the keypoints. The arrows shown in the rightmost image represent keypoint descriptor vectors indicating location, scale, and orientation.

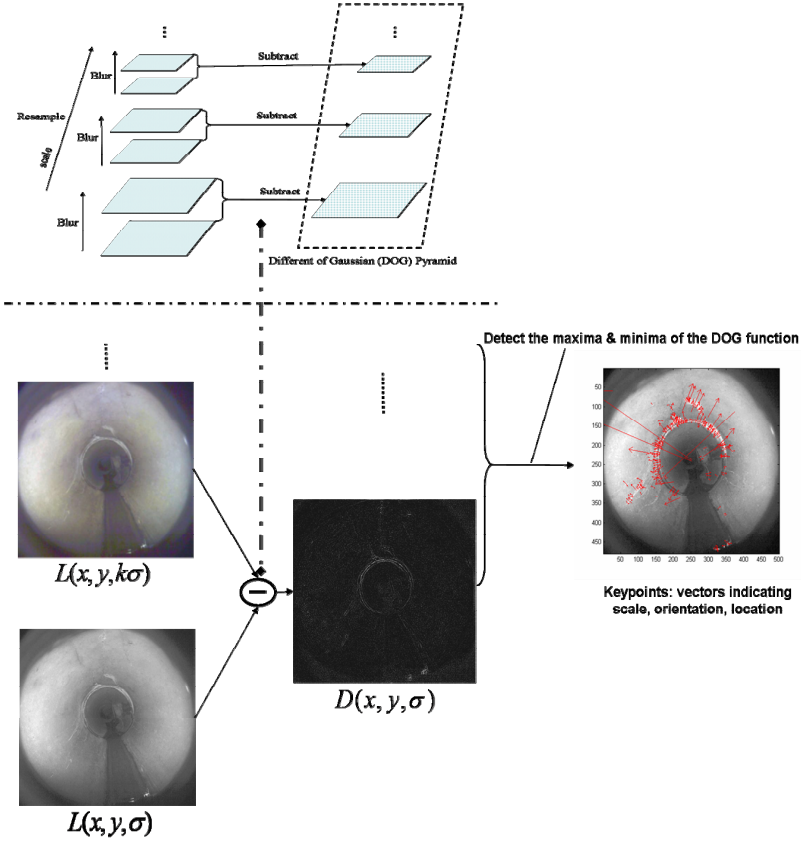


Figure 1. Generation of SIFT Local Feature Descriptors (Original Images from Redzone)

3.2 Feature Matching

Once keypoints have been located and their feature descriptors been generated in each image under analysis, the keypoints can be matched in the sequential images. An example is shown in Figure 2.

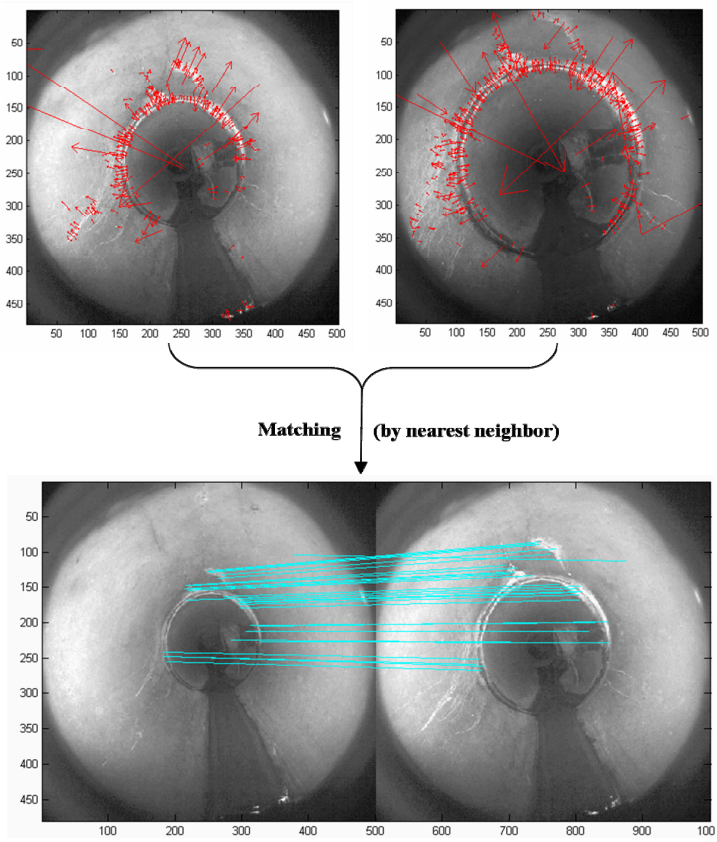


Figure 2. SIFT Feature Matching (Original Images from RedZone)

133 keypoints were found in the left image. 312 keypoints were found in the right image. The matches were determined by comparing the keypoints in two images and finding the similar ones and then matching them. The similarity of different image regions was defined by nearest neighbor of keypoints. The nearest neighbor, as used by Lowe in his work (Lowe 2004), is the minimum Euclidean distance between the SIFT descriptor vectors. As a result, keypoints in different images were matched. The number of matched keypoints in this example was 32, which is higher than the set threshold value in this experimental testing.

3.3 Pattern Detection

Based on the nature of video inspection for wastewater pipes, it is assumed that a defect or critical pipe pattern should occur in at least two successive image frames. Hence, a defect or pattern can be tracked by establishing the number of matched

keypoint pairs. If a defect or pattern exists in the consecutive images under analysis, the number of matched keypoints pairs should be larger than a threshold value; otherwise, no defect or pattern is considered in the images. For instance, in the example (Figure 2), the number of matched keypoints is larger than a threshold value, thus the existence and location of defects in the images can be identified. A larger number of matched keypoints indicates the existence of defect(s). The locations of the matched keypoints indicate the regions of interest (ROIs) such as defects or pipe landmark patterns.

If the existence of a defect or pattern is rejected mistakenly by the proposed detection approach, it could still be detected in another image frame or other image frames in which the defect may appear clearer and easier for detection. For example, in Figure 4, the defective joint shown in the left image was not detected by matching with the right image. However, this defective joint was able to be detected using its subsequent image frames containing the same joint.

On the other hand, the example shown in Figure 3 indicated that the right image was healthy since the number of matched keypoints was only 2, which is lower than the set threshold.

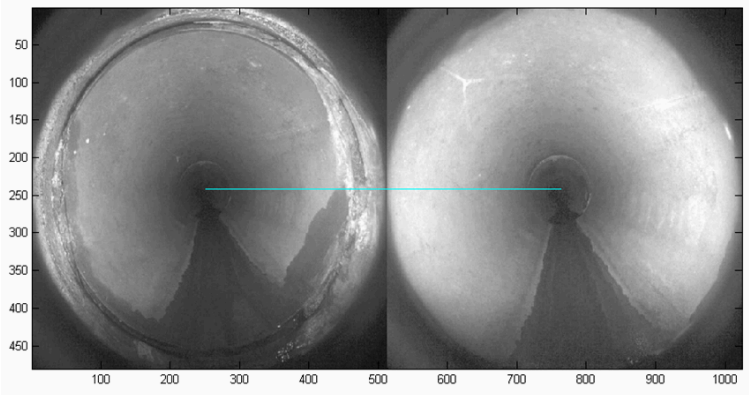


Figure 3. Example 2 of Pattern Detection (Original Images from RedZone)

In addition, the example shown in Figure 4 indicated that no defects or pipe landmarks have been detected in the two images since the number of matched keypoints was 6, which was below the set threshold.

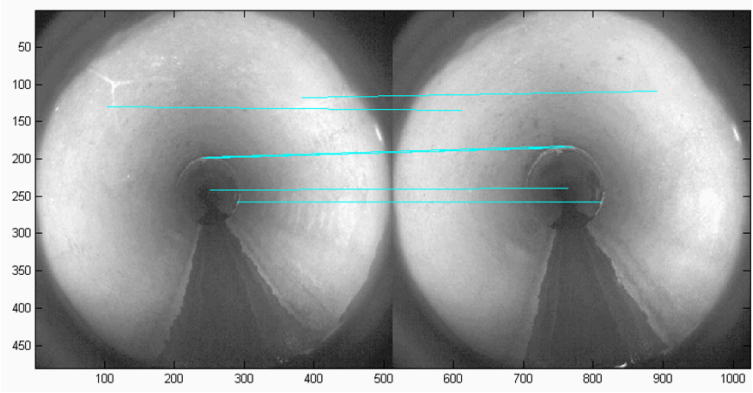


Figure 4. Example 3 of Pattern Detection (Original Images from RedZone)

4. Experimental Testing

The SIFT approach described in this paper has been tested using the high resolution images provided by Redzone and acquired by its Solo inspection platforms. Solo is a newly developed autonomous inspection platform (RedZone 2007a; RedZone 2007b). This inspection robot is able to navigate itself and acquire high resolution digital images for smaller diameter pipes (e.g., six to eighteen inches) for manhole to manhole inspection (RedZone 2007a; RedZone 2008).

In the testing data set, the inspected wastewater pipe is a 12 inch diameter Vitrified Clay Pipe (VCP) combined sewer. The inspection pipe length was 107.02 ft long. 192 inspection images were taken to record the pipe condition. Among those images, 44 defects, including joint offsets, deposits attached encrustation, cracks (longitudinal, multiple), and tap break-ins, were identified by the certified inspector as (RedZone 2007b). The results generated from the computer-assisted detection approach were compared with those conducted by certified human inspectors.

The confusion matrix generated from the experimental testing on the Solo dataset is shown in Table 1. There were 41 true positives, which were correctly detections, 12 false alarms, 3 missed defects, and 136 true negatives.

Data Set I	Defective (d)	Healthy (h)	Total
d'	41	12	53
h'	3	136	139
Total	44	148	192

Table 1 Testing Results Using SIFT Approach

The two major performance evaluation metrics considered in this research project are *accuracy* and *false alarm rate*. The accuracy refers to how well the described recognition approach correctly identifies objects of interest (OOIs) or excludes Non-OOIs. It is defined as the percentage of the correct detections,

including both correctly detected defects and non-defects, among all the images. In our testing, the accuracy was computed as 92%. The false alarm rate (FAR) refers to a percentage of Non-OOIs being mistakenly identified as OOIs. It shows the percentage of false alarms among all the actual healthy images. The false alarm rate was 8% for the testing dataset. The testing results demonstrated that the devised SIFT approach is practically feasible for automated detection of wastewater pipe defects or patterns. The good performance was mainly because the SIFT algorithm is invariant to illumination changes, sizes, shapes, viewpoints, and robust to image noise, which has been described in Section 2.

5 Conclusions and Discussions

The automated detection approach using SIFT features has been described in this paper. SIFT features are invariant to scale, rotation, and change in illumination. They can also tolerate some degree of affine or nonlinear geometric distortions, and image noise. In addition, images used for this SIFT approach do not have to be pre-processed, using processes such as cropping, normalization, noise removal, etc. The automatic visual pattern recognition approach using SIFT features in this paper has been evaluated using the actual images from inspections of VCP wastewater pipe segments. The experimental testing using real pipe inspection images has shown that the approach described in this paper using the SIFT algorithm is well suited to the problem for detecting defects in wastewater pipes. As future research, the devised approach will be tested using a more diversified set of inspection images and will be further adapted to other types of pipes. Lastly, it is worthwhile noting that this proposed approach can also be adopted for supporting automatic defect matching during an offline condition assessment process, or decision-making support during an inspection process.

6. Acknowledgements

The authors wish to thank RedZone Robotics Inc. for providing the high resolution images for experimental testing and funding for this research. The authors also acknowledge the funding support provided by the Innovative Management & Technology Services - National Aeronautics and Space Administration (IMTS-NASA) grant, and the Pennsylvania Infrastructure Technology Alliance.

7. References

Burt, P. J., and Adelson, E. (1983). "The Laplacian Pyramid as a compact image code." *IEEE Transactions on Communications, 31, 4 (1983), pp. 532540.*

EPA. (2006). "Asset Management for Sewer Collection Systems." *Fact Sheet, United States Environmental Protection Agency (EPA), Feb. 17, 2006.*

Lowe, D. G. (1999). "Object recognition from local scaleinvariant features." *Inernational Conference on Computer Vision (1999), 1150-1157.*

Lowe, D. G. (2004). "Distinctive image features from scale-invariant keypoints." *International Journal of Computer Vision 60 (2004), no. 2, 91-110.*

NASSCO. (2001). "Pipeline Assessment and Certification Program Manual." *Pipeline Assessment and Certification Program (PACP), Second Edition Reference Manual, NASSCO.*

Provost, F., and Kohavi, R. (1998). "On applied research in machine learning." *Machine Learning , 30, 127--132*.

RedZone. (2007a). "Meeting notes, RedZone Robotics Inc."

RedZone. (2007b). "RedZone Robotics West Homestead AIMP Inspection Report, 05.16.2007, RedZone Robotics Inc."

RedZone. (2008). *RedZone Robotics Inc., http://www.redzone.com/*.

Tafuri, A. N., and Selvakumar, A. (2002). "Wastewater Collection System Infrastructure Research Needs." U.S Environmental Protection Agency, Edison, NJ.

TTN. (2002). "Underground Mapping, Pipeline Location Technology and Condition Assessment." *Trenchless Technology Network (TTN), the University of Birmingham, Civil Engineering, Report - March 2002*.

Wickens, T. D. (2002). *Elementary Signal Detection Theory*, New York: Oxford University Press.

REAL-TIME CONCRETE DAMAGE VISUAL ASSESSMENT FOR FIRST RESPONDERS

Zhenhua Zhu[1], Ioannis Brilakis[2] and Gustavo Parra-Montesinos[3]

[1]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA. 30332-0355; email: zhzhu@umich.edu
[2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA. 30332-0355; PH (404) 894-9881; email: brilakis@gatech.edu
[3]Dept. of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI. 48109-2125; PH (734) 764-6576; email: gjpm@umich.edu

ABSTRACT

First responders are in danger when they perform tasks in damaged buildings after earthquakes. Structural collapse due to the failure of critical load bearing structural members (e.g. columns) during a post-earthquake event such as an aftershock can make first responders victims, considering they are unable to assess the impact of the damage inflicted in load bearing members. The writers here propose a method that can provide first responders with a crude but quick estimate of the damage inflicted in load bearing members. Under the proposed method, critical structural members (reinforced concrete columns in this study) are identified from digital visual data and the damage superimposed on these structural members is detected with the help of Visual Pattern Recognition techniques. The correlation of the two (e.g. the position, orientation and size of a crack on the surface of a column) is used to query a case-based reasoning knowledge base, which contains apriori classified states of columns according to the damage inflicted on them. When query results indicate the column's damage state is severe, the method assumes that a structural collapse is likely and first responders are warned to evacuate.

KEYWORDS: First responders, structural collapse, concrete columns, column recognition, damage detection, damage state estimation

1 INTRODUCTION

Earthquakes are devastating to individuals, communities and governments. They can cause hundreds of deaths or causalities and cost billions of dollars in the destruction of buildings and critical infrastructures. The magnitude 6.7 Northridge, California,

earthquake in January 1994, for example, killed 57 and injured more than 5,000 people; approximately 4,000 buildings were severely damaged or destroyed and another 8,500 were moderately damaged; the economic loss due to property damage was estimated at $20 billion (EERC, 2005; RMS, 2004).

Emergency response to earthquakes can greatly reduce their impact to a society. Fast rescuing speed is critical to save people's lives. According to an estimation from United Kingdom Fire Service Search and Rescue Team (UKFSSART, 2007), 91 percent of the people trapped in collapsed structures can survive when they are rescued within 30 minutes; the survival rate drops down to approximately 35% when they are trapped for two days. For this reason, teams of emergency responders (also called first responders), traditionally coming from the fire, the emergency medical services, and the police, are common in developed countries.

However, first responders are often in danger themselves when they perform emergency tasks. This is especially true for firefighters. As the principal rescue service, they have to enter dangerous buildings to suppress fires and to find and rescue trapped occupants. Any structural collapse of these buildings could make firefighters themselves victims, even if they are properly trained beforehand and safety precautions are taken. From 1989 to 1998, it was estimated that 18 percent of fire fighter deaths were due to structural collapse (NIOSH, 1999). On September 11, 2001, World Trade Center, New York City, the collapse of the towers killed 450 emergency responders who entered the towers to assist evacuation of the occupants and perform search and rescue and fire suppression activities (Jackson et al. 2002).

This paper discusses a novel method that can detect critical structural members in video frames, identify the damage inflicted on them and estimate the damage state of columns based on identified damage to assist in the automated prediction of potential structural collapse of concrete buildings for first responders after earthquakes. The emphasis of the research is placed on concrete columns, which play a key role in carrying the gravity load. The first step of the proposed method, the detection of vertical line pairs in video frames, was already implemented and tested.

2 RELATED WORK

2.1 Protection of First Responders from Structural Collapse

Protecting the safety of first responders from structural collapse is necessary, since structural collapse related injuries and deaths of first responders occur every year in disaster environments (NIOSH, 2007). One approach to protect first responders is to require that they wait a recommended period of time before entry into a building. After the main shock of an earthquake, Gallagher et al. (1999) suggested 1 to 8 days for emergency entry into a dangerous building depending on the magnitude of the main shock of the earthquake, as well as the expected time to be spent in the building. The recommended waiting time, however, is detrimental to the rapid response operations of first responders.

Another approach is by involving a civil engineer, particularly a structural engineer, into a first response team as the new fourth responder beyond the traditional triad of fire, police and emergency medical services (Prieto, 2002). The civil engineer would be responsible for identifying potential structural hazards in the area of first response team operations (FEMA, 2006). Although civil engineers are the most prepared personnel to deal with all aspects of the built environment (Aldunate et al. 2006), the value of adding civil engineers into first response teams is unclear. Collaboration-related problems between added civil engineers and other organizations involved in disaster relief efforts have been identified, considering that these organizations do not work together on a regular basis (Kostoulas et al. 2006). Also, first responders are hesitant to communicate and interact with others outside their own organizations (Aldunate et al. 2006 and Kostoulas et al. 2006), which significantly diminishes the effect of adding civil engineers.

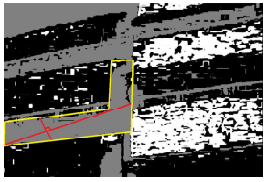
2.2 Structural Member Recognition in Images

The recognition of structural elements is an active research topic. Brilakis and Soibelman, (2008) initiated a preliminary study under which texture-based patterns were used to detect construction materials and their boundaries to infer the shape information of structural members. Their method based on two calculated dimensions (the maximum cluster dimension (MCD) and the maximum dimension along the perpendicular axis of MCD (PMCD)), and three assumptions: 1) if MCD is significantly larger than PMCD, then the object is linear; 2) if the object is linear, then the tangent of the MCD edge points represents its direction on the image plane; 3) if the computed direction is within 45° from the vertical (or horizontal) image axis then the linear object is a column (or beam).

Although the assumptions are valid in most framed structures, their method of depending on retrieved material information to infer the shape information of structural elements has a limitation. When one structural element (e.g. concrete column) is connected to another structural element with the same material (e.g. concrete beam), the method regards them as one single element instead of two separate elements (Figure 1).



(a) Original Image



(b) The merger of two structural elements

Figure 1: The limitation of detecting structural elements from material information

2.3 Automated Vision-Based Crack Detection

A large number of automated vision-based crack detection methods have been developed in recent years. For example, to detect cracks in unsupervised bridges, Abdel-Qader et al. (2006) proposed a principal component analysis (PCA) based recognition method. Dominant eigenvectors were first generated from a set of training data. Then, a concrete surface image was segmented into blocks. The filtering results of these blocks were directly projected onto these dominant eigenvectors to identify whether the block contained a crack or not. This way, cracks in an image can be detected sequentially on the basis of blocks. Besides PCA-based recognition, Abdel-Qader et al. (2003) compared four edge detection techniques and found that fast Haar transform was more reliable than the other three.

In sewer pipeline inspection and condition assessment, Sinha and Fieguth (2006) introduced two crack detectors to identify cracks in buried concrete pipes. Chae and Abraham (2001) relied on an artificial neural network for classifying pipe defects, where pipe image data was directly input and the attributes of defects (e.g. number for cracks and average width of cracks) were automatically retrieved for an overall pipe condition assessment.

For inspecting and measuring cracks in concrete tunnels, Yu et al. (2006) developed a mobile robot system, where concrete surface images of tunnels were captured. Edge detection techniques were used to retrieve crack information from these images. Then, the start and end points of a crack were manually given, so that the whole crack can be extracted through a graph search.

2.4 Safety Evaluation of Structural Elements after Earthquakes

Evaluating the safety of structures after earthquakes is a task of structural engineers and building inspectors. When earthquakes occur, reconnaissance teams comprised of two or more licensed inspectors per team are deployed to conduct manual inspections of buildings according to guidelines contained in ATC-20 (1989) and ATC-20-2 (1995). In both documents, columns are typically considered as the most critical elements for evaluation of gravity load carrying capacity of damaged structures. A cast-in-place concrete building is regarded as unsafe, when any of three conditions of its columns exists: 1) buckled or fractured column reinforcements; 2) massive concrete spalling and exposure of longitudinal column reinforcement; and 3) large diagonal cracks extending through columns (ATC-20, 1980).

Methods for automated evaluating the safety of a building after a disaster have been recently developed. Naeim et al. (2005) performed automated post-earthquake damage assessment and safety evaluation of around 70 buildings instrumented with sensor networks. The slow adoption of and the cost associated with instrumented sensor networks have significantly hindered their practical application for building damage detection. Kamat and El-Tawil (2007) proposed a method for estimating the safety of damaged buildings using augmented reality. They superimposed a CAD image over the user's view of the real world so that the deformed shape of a building component can be measured. However, research issues such as a prerequisite of CAD

models of buildings and known locations of fiducial marks for CAD image to superimpose have to be addressed (Kamat and El-Tawil, 2007).

Information from reinforced concrete column pseudo-static and dynamic tests may also be used for a crude evaluation of the likelihood of column collapse after an earthquake. Kato and Ohnishi (2002) and Elwood and Moehle (2003) noticed that a loss of axial load carrying capacity in reinforced concrete columns typically occurs after a nearly total loss of shear strength. Thus, if observed column damage (e.g. angle of inclination and width of cracks) is correlated with the occurrence of a shear failure, a quick estimation of whether column collapse is likely or not could be made. Based on the criterion suggested by Ohkubo (1991), crack widths of 0.2, 1.0, and 2.0 mm could be used as indicators of negligible, light, and moderate damage levels for reinforced concrete columns, respectively.

3 THE FRAMEWORK OF THE PROPOSED METHODOLOGY

Current possible solutions to protect first responders are either at the expense of first responders' fast rescuing time, or cause communication problems (e.g. lack of coordination, information sharing, trust and communication). Much work has been performed in damage detection and evaluation, but it is still far from reach for protecting first responders without inhibiting their operations. For these reasons, the writers here propose a method that would detect concrete columns in video frames, identify the cracks on them, and estimate the potential for structural collapse (Figure 2). A "digital hardhat" is suggested to be used. Similar to the device proposed by Liu (1997) to capture, store and retrieve construction information, a video camera is proposed to be attached to a first responder's hardhat. The video frames of the building the first responder enters after an earthquake are collected and processed in his/her portable computer.

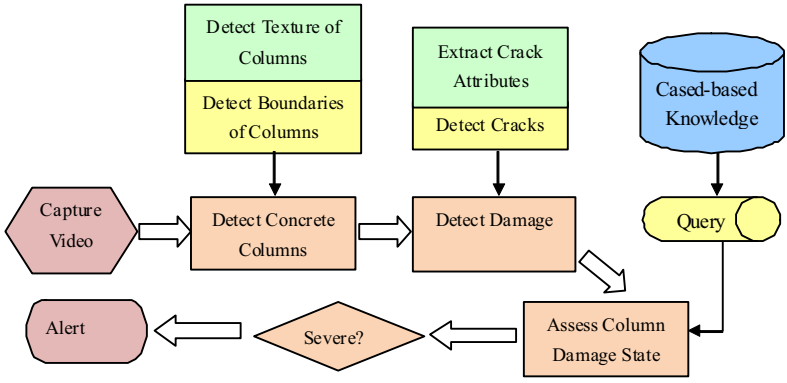


Figure 2: The proposed method

In the portable computer, concrete columns in each video frame are recognized

with the help of the column's visual characteristics. Damage inflicted on these columns is then detected and its attributes are calculated. Detected columns and damage are then correlated in the form of relative damage size, orientation and position. The correlation is used to query a case-based reasoning knowledge base which contains apriori classified damage states of columns. The query estimates the damage state of the column for any given damage inflicted on it. If the damage state is severe, the method will assume collapse is likely and an immediate evacuation warning will be given to first responders.

3.1 Concrete Column Detection

In order to detect concrete columns, the authors found that concrete columns typically have a) shapes dominated by long straight vertical lines and b) uniform texture and color patterns. As such, long vertical line pairs in a video frame are first detected. Canny edge detector (Canny, 1986) is used to produce an edge map and the Hough transform (Matas et al. 1998) is applied to retrieve long vertical line information in the edge map. Each retrieved vertical line is then compared to its neighboring vertical lines. If two vertical lines have similar size, they are regarded as one pair of vertical lines. The comparison is performed iteratively.

When all pairs of long vertical lines are found, a bounding rectangle for each pair of vertical lines is constructed. The texture contained in the bounding rectangle is then retrieved. The signature of the texture is calculated and compared with the signatures of traditional concrete textures. If the texture belongs to concrete, the region within the pair of long vertical lines is believed to be the boundary of one concrete structural element with long vertical lines such as concrete columns and walls; (beams are excluded since they do not have long vertical lines); else, the pair of long vertical lines is discarded. Then, the ratio of the width over the length of the remaining rectangles is calculated to indicate the structural element is concrete column if the ratio is small.

3.2 Damage Detection

For machine vision-based damage detection, the body of knowledge is already mature. Many methods based on image processing techniques such as thresholding, segmentation, and morphological transform have been developed. However the performance of the state-of-the-art algorithms is still unknown in this application environment, such as the speed of the damage recognition with limited processing capability. For these reasons, the authors will measure the performance of current damage detection algorithms in three aspects: 1) recognition precision (the amount of damage correctly detected over the amount of damage detected), 2) recognition recall (the amount of damage detected over the total real damage on the column), and 3) recognition speed. All results will be compared, so that the best performing damage recognition algorithm is selected for the application environment of this paper.

After the appropriate damage detection method is selected, the attributes of

existing damage can be measured from the detection results. These attributes include the size, width, orientation and position of the detected damage. The measurement of the attributes of damage is performed relatively to the dimension of the concrete column where the damage is inflicted on.

3.3 Concrete Column Damage Assessment

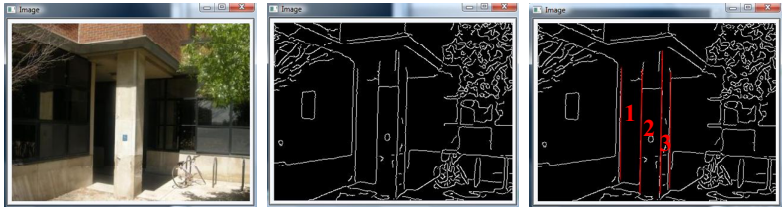
To visually assess concrete column damage, prior and current pictorial and video data from research on behavior of reinforced concrete columns under earthquake-induced deformations will be collected. In these visual data, the damage inflicted on the column during a test is recognized and its relation with the column's shear and axial load capacity is estimated. The information about the recognized damage and the estimated relation with residual strength is then stored in a common database.

The resulting database is further overlaid with a Case-Based Reasoning (CBR) interface. The query in the knowledge base can be performed through the CBR interface, when damage and concrete column information is given. In each query, the damage state of the concrete column is output to indicate whether the concrete column is severely damaged or not.

4 PRELIMINARY IMPLEMENTATION AND RESULTS

The methodology presented in this paper is gradually validated using a C++ based prototype. So far, the authors implemented the first step, the detection of vertical line pairs. The prototype was written in Microsoft Visual Studio 2005. OpenCV (Intel® Open Source Computer Vision Library) was used as the prototype's main image processing toolbox, which is free for both non-commercial and commercial use.

A series of screenshots (Figure 3) show the process of detecting vertical line pairs in an image using the prototype. Figure 3(a) shows that an original image. Figure 3(b) shows the edge map that was retrieved. Figure 3(c) shows the result of applying the Hough transform on the retrieved edge map and extracting the vertical line information. This information was used to find three line pairs.



(a) Original Image (b) Edge map (c) Vertical line pairs

Figure 3: The detection of vertical line pairs

The three line pairs identified in Figure 3 (c) constructed three regions (region 1, 2 and 3) in the image. Among these three regions, region 2 and 3 are concrete column's surfaces, while region 1 does not belong to any concrete structural members.

Texture both contained in region 2 and 3 is concrete. Therefore, the concrete column in the image can be recognized by further identifying whether the texture contained in these regions is concrete or not.

The currently developed method of detecting vertical line pairs can only locate concrete columns when at least one of their surfaces is visible. Also, when the method is applied in detecting multiple columns, distant concrete columns in an image are difficult to detect, since distant columns are small and their long vertical lines are not obvious. These two limitations, however, have no significant adverse effects on the proposed methodology, considering that damage on distant columns in an image cannot be detected using current image processing techniques. Also, the correlation of detected damage and columns like cracks' size vs. columns' size cannot be established when the size of concrete columns' surfaces is unavailable.

5 CONCLUSION

Structural collapses threaten first responders especially those who have to enter damaged buildings to perform essential emergency functions after a disaster. Protecting them from potential structural collapses is necessary and important. Current possible solutions cannot solve this problem effectively and efficiently. Letting first responders wait for a certain time will delay their emergency response. Adding a civil engineer to a first response team will result in collaboration problems between first responders and civil engineers.

In order to overcome limitations of current possible solutions, the writers propose a machine vision method to provide first responders an estimation of potential structural collapse hazards. The proposed method uses the video frames captured from a video camera attached on first responders' hard hat. In each video frame, concrete columns and damage inflicted on these columns are detected. The load carrying capacity of concrete columns is then assessed based on detected damage. When the damage state is severe, the proposed method assumes that structural collapse is likely and warns the first responder about it. In this way, first responders will be better protected from potential structural collapse. Currently, the first step of the proposed method, the detection of vertical line pairs in an image, has been validated. Future work will focus on implementing the remaining steps of the methods, such as comparing concrete textures, comparing existing crack detection algorithms, and creating the knowledge base of concrete columns' damage state.

REFERENCES

Abdel-Qader, I., Pashaie-Rad, S., Abudayyeh, O., and Yehia, S. (2006) PCA-Based algorithm for unsupervised bridge crack detection, Advances in Engineering Software, 2006, 37(12): 771-778

Abdel-Qader, I., Abudayyeh, O., and Kelly, M. E. (2003), "Analysis of Edge-Detection Techniques for Crack Identification in Bridges." Journal of Computation in Civil Engineering. 2003. 17(4): 255-263

Aldunate, R., Ochoa, S., Pena-Mora, F. and Nussbaum, M. (2006), "Robust Mobile Ad Hoc Space for Collaboration to Support Disaster Relief Efforts Involving Critical Physical Infrastructure", Journal of Computing in Civil Engineering, Vol. 20, No. 1, pp. 13-27

ATC-20 (1989), Procedures for Postearthquake Safety Evaluations of Buildings, Report ATC-20, Applied Technology Council. Redwood City, CA.

ATC-20-2 (1995), Addendum to ATC-20, Procedures for Postearthquake Safety Evaluations of Buildings, Report ATC-20, Applied Technology Council. Redwood City, California.

Brilakis, I. and Soibelman, L. (2008) "Shape-Based Retrieval of Construction Site Photographs", Journal of Computing in Civil Engineering, American Society of Civil Engineers, Volume 22, Issue 1, January/February 2008, Pages 14 – 20

Canny J. (1986), "A Computational Approach to Edge Detection", IEEE Trans. on Pattern Analysis and Machine Intelligence, 8(6), pp. 679-698.

Chae, M.J. and Abraham, D.M. Neuro-fuzzy approaches for sanitary sewer pipeline conditional assessment, J. of Computers in Civil Engineering, 2001, 15(1): 4–14.

Earthquake Engineering Research Center (EERC) (2005), "Northridge Earthquake", last visit: http://nisee.berkeley.edu/northridge/

Elwood, K. and Moehle, J., (2003), "Shake Table Tests and Analytical Studies on the Gravity Load Collapse of Reinforced Concrete Frames", PEER Report Series, November 2003/01.

Federal Emergency Management Agency (FEMA), (2006), "National Urban Search and Rescue Response System – Structure Specialist Position Description", last visit: www.disasterengineer.org/library/Struct%20Spec%20PD%20July%202006.pdf

Frosch, R., (1999), "Another Look at Cracking and Crack Control in Reinforced Concrete", ACI Structure Journal, Vol. 96, No. 3, pp. 437-442.

Gallagher, R., Reasenberg, P. and Poland, C. (1999), "Earthquake Aftershocks—Entering Damaged Buildings", ATC TechBrief 2, last visit: http://www.atcouncil.org/pdfs/atc35tb2.pdf

Jackson, B., Peterson, D., Bartis, J. LaTourrette, T., Brahmakulam, I., Houser, A. and Sollinger, J. (2002), "Protecting Emergency Responders: Lesson Learned from Terrorist Attacks", RAND Science and Technology Policy Institute, ISBN: 0-8330-3149-X, last visit: http://www.rand.org/pubs/conf_proceedings/CF176/

Kamat, V. and El-Tawil, S. (2007), "Evaluation of Augmented Reality for Rapid Assessment of Earthquake-Induced Building Damage", Journal of Computing in Civil Engineering, Volume 21, Issue 5, pp. 303-310.

Kato, D. and Ohnishi, K. (2002). "Axial Load Carrying Capacity of R/C Columns Under Lateral Load Reversals," Proceedings of the Third US-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced

Concrete Building Structures, Seattle, August 2001, Report PEER-2002/02, PEER, University of California, Berkeley, pp. 247-255.

Kostoulas, D., Aldunate, R., Peña-Mora, F. and Lakhera, S., (2006), "A Decentralized Trust Model to Reduce Information Unreliability in Complex Disaster Relief Operations", In Proc. 13th EG-ICE Workshop on Intelligent Computing in Engineering and Architecture, Ascona, Switzerland, June 25-30, 2006, LNCS 4200, pp. 383-407

Liu L. (1997), "Construction Field Data Collection using the Digital Hardhat", In: Proc. ASCE Construction Congress V. Minneapolis, MN, 399–404

Matas, J., Galambos, C. and Kittler, J. "Progressive Probabilistic Hough Transform". British Machine Vision Conference, 1998.

Naeim, F., Hagie, S., Alimoradi, A. and Miranda, E., (2006), "Automated Post-Earthquake Damage Assessment and Safety Evaluation of Instrumented Buildings", In: Advances in Earthquake Engineering for Urban Risk Reduction, Vol. 66, pp. 117-134.

National Institute for Occupational Safety and Health (NIOSH), (1999), "NIOSH Alert: Preventing Injuries and Deaths of Fire Fighters due to Structural Collapse", NIOSH Publication No. 99-146

National Institute for Occupational Safety and Health (NIOSH), (2007), "NIOSH Safety and Health Topic: Fire Fighter Fatality Investigation and Prevention Program", last visit: http://www.cdc.gov/niosh/fire/

Ohkubo M. (1991), "Current Japanese system on seismic capacity and retrofit techniques for existing reinforced concrete buildings and post-earthquake damage inspection and restoration", Techniques report no. SSRP-91/02. San Diego: University of California; 1991.

Prieto, R. (2002), "The 3Rs: lessons learned from September 11th", Royal Academy of Engineering, Chairman Emeritus of Parsons Brinckerhoff, Co-chair New York City Partnership Infrastructure Task Force, October.

Risk Management Solutions (RMS), (2004), "Northridge California Earthquake – RMS 10 Year Retrospective", last visit: http://www.rms.com/publications/northridgeeq_retro.pdf

Sezen, H., (2002), Seismic Response and Modeling of Reinforced Concrete Building Columns, Ph.D. Dissertation, Department of Civil and Environmental Engineering, University of California, Berkeley.

United Kingdom Fire Service Search and Rescue Team (UKFSSART), (2007), "Structure Collapse - A Guide for Emergency Personnel", last visit: http://www.ukfssart.org.uk/index.htm

Yu S.N., Jang, J.H., and Han C.S. Auto inspection system using a mobile robot for detecting concrete cracks in a tunnel, Automation in Construction, 2007, 16(3): 255-261

INTERACTIVE AUGMENTED REALITY VISUALIZATION FOR IMPROVED DAMAGE PREVENTION AND MAINTENANCE OF UNDERGROUND INFRASTRUCTURE

Amir H. Behzadan[1], and Vineet R. Kamat[2]

[1] Assistant Professor, Department of Construction Management and Civil Engineering Technology, The City University of New York, New York City College of Technology, 300 Jay Street, V-430, Brooklyn, NY 11201; PH (718)260-5578; e-mail: abehzadan@citytech.cuny.edu

[2] Assistant Professor, Department of Civil and Environmental Engineering, University of Michigan, 2350 Hayward Street, Suite 2340, Ann Arbor, MI 48109; PH (734)764-4325; FAX (734)764-4292; e-mail: vkamat@umich.edu

Abstract:

During a typical excavation operation, there is a high risk of inadvertently damaging the existing subsurface utilities. Such incidents cause significant financial loss to the project and can delay or abruptly halt ongoing construction. In many cases, they also pose a life threat and often result in accidental deaths. As a result, constructors are required to protect utility systems during excavation operations. In this paper, the applicability of advanced visualization and tracking technologies to improve work safety during urban construction projects by enhancing the visual perception of construction equipment operators is discussed. The integration of Augmented Reality (AR) visualization and the Global Positioning System (GPS) is explored to create real time views of an excavation site in which CAD models of the underground utilities can be accurately superimposed over live video streams of the real world with the resulting views being displayed to the equipment operator in real time.

INTRODUCTION

Underground utilities and installations (e.g. gas, data, sewer, fuel, electric, water) are vital components of urban infrastructure that are constantly exposed to inadvertent damage during construction or excavation operations. An accident causing damage to subsurface infrastructure can lead to significant loss of project financial resources and delay or abruptly halt ongoing construction. In addition, such incidents may pose a threat to human lives and often result in accidental deaths. Due to the high risks involved and in order to protect public and private utility systems and installations,

excavation contractors are encouraged and in most cases required to continuously follow federal and state regulations and practice adequate Subsurface Utility Engineering (SUE) methods during the actual excavation process. SUE is a process used to accurately identify and map underground utilities through the use of surface geophysics, surveying, data management and non-destructive excavation techniques. SUE has been recognized as the best available method to map underground infrastructure and is endorsed by a variety of organizations such as US Department of Transportation, National Transportation Safety Board, US Department of Energy, American Society of Civil Engineers, Associated General Contractors of America, and many universities and utility companies (ASCE 2003). The results of a study conducted by Purdue University for the Federal Highway Administration (FHWA) also indicated that for every $1 spent on SUE at least $4.62 was saved on the overall project (Purdue University 1999).

Existing regulations in many states require excavation and drilling contractors to contact local utility companies and request manual location marking of existing subsurface installations on the ground before they start excavating. As shown in Figure 1, a typical manual marking requires submitting written requests to local utility companies several days in advance of the actual excavation job.



Figure 1 – Process of Manually Marking the Underground Utility Lines

Once it is determined that markings are required, the request is assigned to a field locator, who will locate and mark the excavation site with paint, stakes and/or flags. The contractor can start the actual operations only after the locations of important underground utility lines are color marked on the ground (MISS DIG System 2007). However, manual marking of underground utility lines can be a time consuming and costly task. In addition, if sufficient care is not exercised, or if the congestion of

underground cables and pipes is high, a utility line may be overlooked or incorrectly marked in the marking process causing a potential catastrophic accident during the excavation process.

In this paper, research that explores the applicability of advanced visualization and tracking technologies to improve work safety in urban construction projects is discussed. The research objective is being pursued by exploring techniques of enhancing the knowledge and visual perception of construction equipment operators and other site personnel. This is achieved using Augmented Reality (AR) visualization and the Global Positioning System (GPS) to create real time views of an excavation or drilling site in which CAD models of the underground utility lines are accurately superimposed over live video streams of the jobsite. CAD data that represent existing subsurface infrastructure has to be integrated into the AR application. This data can be obtained from different sources including local utility companies. Real time views of the jobsite are captured using a video camera mounted on the construction equipment or a mobile user, whose position is continuously obtained from GPS and updated in the system. The final AR visualization can be displayed to the equipment operator through a display installed inside the cabin, or to site personnel using head-mounted or other display devices. Knowing the geometry of a construction or drilling equipment and its current configuration, forward kinematics can be used to continuously calculate the exact position of its digging implement. If this position is too close to an area occupied by existing underground utility lines, the operator can be visually and audibly warned to take the necessary precautions and prevent potential impact or damage.

The designed AR system can be integrated into all types of construction equipment (e.g. excavators, loaders, dozers, graders) to enhance subsurface infrastructure damage prevention during a typical excavation, drilling, road construction, or maintenance projects. What makes the application of the AR system highly appealing to contractors and local utility companies is that it can be easy to install and operate, requires less manual work, and at the same time, the required implementation cost is significantly lower than the potential savings in project time and financial resources that result from preventing accidents.

SYSTEM COMPONENTS AND DESIGN

As shown in Figure 2, two important sources of information are used in order to create and display the final augmented view of the excavation site to the equipment operator: Local utility company data, and tracking and video data. Local utility companies typically keep digital records of the location of subsurface utility lines. In order for such data to be used inside the visualization system, they have to be first converted to CAD models. This can be done through the geometric modeling step. The level of accuracy of the resulting CAD models is an important factor when determining how accurate and reliable the final augmented output of the visualization system is. Real world data is another important component of the system. It consists of live video streams of the excavation site and position of the excavation equipment.

A video camera installed on top of the equipment can be used to capture real time views of the surrounding environment while a GPS device mounted on the equipment collects and sends positional data (in form of longitude, latitude, and altitude) to the visualization system. The system can use this positional data to determine the portion of the excavation site currently accessible to the equipment. Appropriate CAD models of the existing utility lines within this portion of the site can then be loaded and superimposed on top of the real time views of the scene.

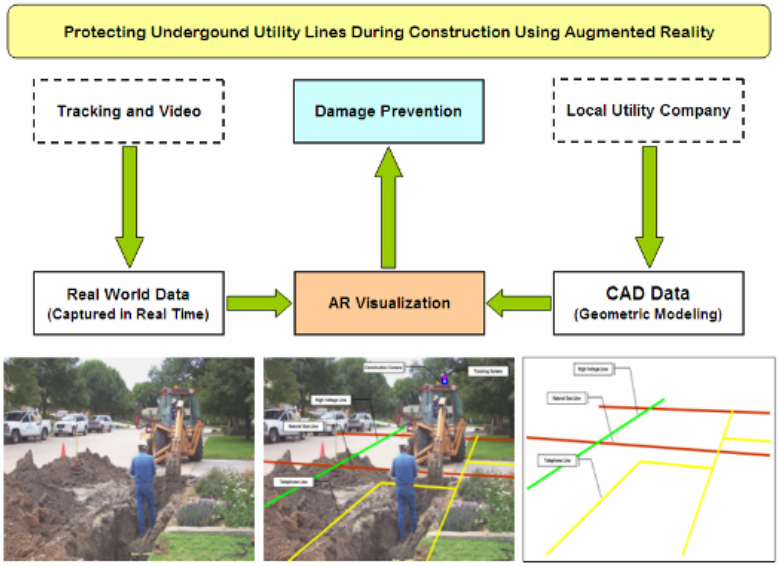


Figure 2 – Data Flow Diagram of the Designed System

As shown in Figure 3, the output of the visualization system consists of a mixed view of virtual utility lines and real excavation site which can be shown to the equipment operator in real time through an in-cabin mounted display. Figure 3 also shows another scenario in which a member of the site crew is looking at the same augmented scene though a Head Mounted Display (HMD). Having a non-operator person looking at the resulting views can significantly decrease the risk of hitting an actual utility line due to the equipment operator inadvertently ignoring a subsurface line being shown through the in-cabin display. The site person can be an excavation inspector who is equipped with a wearable computing platform. Inside this mobile apparatus, a laptop computer and a GPS receiver device can be installed and secured. A head orientation tracking device can also be installed inside the hardhat which sends three important pieces of data (yaw, pitch, and roll angles) to the system to determine the inspector's direction of look (i.e. line of sight). Together with positional data coming through the GPS device, head orientation data can be used to calculate the inspector's spatial context in the form of a viewing frustum and augment

appropriate CAD models. The final augmented view can then be displayed to the inspector through the HMD which is firmly installed in front of the hard hat.

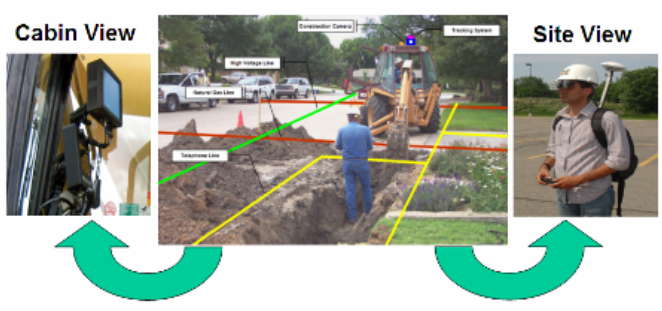


Figure 3 – Displaying the Final Augmented View to the Operator and Site Personnel

It is important to note that the accuracy level of the GPS device is also an important parameter when determining the position of the superimposed CAD models relative to the equipment. However, for the purpose of this research, GPS data with an accuracy of 50 centimeters or better can provide reliable results. The main reason is that according to excavation rules set by many states and counties, contractors are not allowed to use machine excavation in areas as close as 60 centimeters to existing utility lines (Buckeye Partners 2007). Depending on the field conditions at the project site, nature of the subsurface utility line, and the potential threat it may cause to the site personnel and neighborhoods, the clearance requirement can even increase to 1.5 meters.

In order to achieve higher accuracy levels especially in deeper excavations and trenches, GPS data communication techniques such as Real Time Kinematics (RTK) can be used. When used appropriately and in the absence of ambient radio signals, RTK improves the GPS accuracy level to a few centimeters (Ehsani et al. 2004). Figure 4 shows how an RTK-based GPS data communication can be integrated into the designed visualization system in this research. As shown in this Figure, a RTK base antenna and radio signal transmitter are first mounted on a remote spot with known global position. An RTK rover antenna together with a radio signal receiver, both mounted on top of the excavation equipment, continuously communicate with the base station. Knowing the speed of the radio signal and using the time of flight concept, the exact position of the RTK rover antenna (i.e. the equipment) can then be calculated and used inside the visualization system.

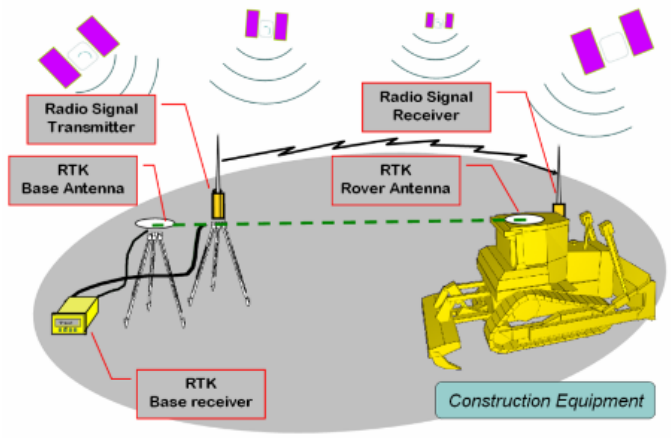


Figure 4 – Using RTK Communication to Improve GPS Data Accuracy

DESIGN OF AN AUTOMATED ALERT SYSTEM

Visual and/or audio alert systems are convenient means to enhance operator's perception of the excavation site. In the absence of such systems, the operator will have to constantly look at the display mounted inside the equipment cabin and interpret the augmented scene based on the contents of the AR visualization. Sometimes, the operator may overlook a certain CAD model or miscalculate the distance between the equipment implement and the subsurface lines. In order to avoid such cases, the visualization system must be accompanied by an automated alert system. The system should constantly calculate the distance between the equipment endpoint (e.g. shovel, blade, and scoop) and CAD models of the utility lines being visualized. If the calculated distance is less than a threshold value initially specified to the system, an alert message can be sounded for the operator.

The automated alert system introduced in this research, works on the basis of forward kinematics (Crane and Duffy 2008, Kamat and Martinez 2005). As shown in Figure 5, at each instant of time, the position of the equipment's implement can be calculated based on the global position of the GPS device (mounted on top of the equipment) and current equipment configuration. As shown in this Figure, if the position of the cabin top is known (using the incoming GPS data), the only required parameters to calculate the exact position of the shovel using forward kinematics will be the cabin height (d_1), boom length (d_2), stick length (d_3), shovel depth (d_4), boom angle (α_1), stick angle (α_2), and shovel angle (α_3). The shovel position can be calculated as follows:

$$T_{Shovel}^{Cabin} = T_{Boom}^{Cabin} \times T_{Stick}^{Boom} \times T_{Shovel}^{Stick}$$

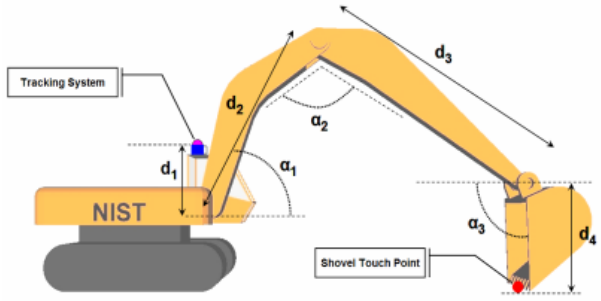


Figure 5 – Using Forward Kinematics to Calculate the Implement Position

In which T_{child}^{parent} is a 4x4 matrix representing the transformation (position, orientation, and scale) of the *child* node relative to the *parent* node. Having calculated the position of the shovel relative to the cabin and knowing the global position of the cabin top, the same value for the shovel can also be determined (Behzadan 2008). When compared to the global position of the underground utility lines (known to the system from the geometric modeling step), the bucket's teeth position can determine if the equipment is too close to a utility line. Appropriate warning messages can then be sounded for the operator. A significant advantage of this alert system is that the output can be used inside a mechanical feedback loop which can override the operator and potentially stop the equipment in case of a real life threatening emergency.

VALIDATION RESULTS

The presented work is part of a larger ongoing research project that explores the use of AR visualization in supporting the planning and design of construction operations. The authors have successfully developed and tested the mobile apparatus illustrated in Figure 3 which enables a site engineer to "look" at underground utility lines in locations where actual excavation operations take place (Behzadan et al. 2008, Behzadan and Kamat 2007). The design of this AR visualization system is generic and it can be used to visualize any type of operations and display the results to a freely moving user in real time. Several proof-of-concept experiments using different operational scenarios have been conducted to validate the functionality of the designed visualization system (Behzadan 2008).

Figure 6 shows an AR visualization scene of a steel erection operation created by the mobile AR visualization system. The virtual elements of the visualized scene depicted in this Figure are CAD models of columns and beams, as well as a tower crane. The user of the system is equipped with the designed mobile AR apparatus and is able to navigate inside the visualization and look at the superimposed graphics from different perspectives and positions. While this Figure illustrates how the designed system can be used to visualize an operation above the ground level, the same setup can be

effectively used with CAD models of subsurface utility lines to visualize an underground environment such as a trench excavation.

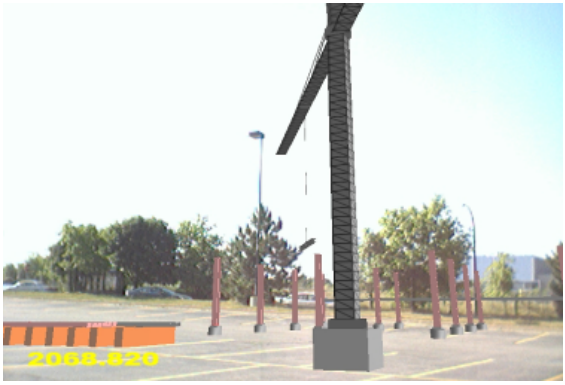


Figure 6 – An Augmented Reality Animation of a Steel Erection Operation

CONCLUSION AND FUTURE WORK

In this paper, the critical need of protecting underground facilities during a typical excavation process was highlighted. Design and implementation of an AR visualization system which enables equipment operators as well as other site personnel to look at virtual models of subsurface utility lines at the excavation site was also discussed in detail. Experiments with the designed hardware and software system prove the feasibility of the idea of creating real time visualizations of computer models on top of live video backgrounds. Such visual information support can significantly reduce the risk of damaging hidden utilities by enhancing the operator's perception of the environment in which the actual operation takes place.

The authors are currently working on the design of a safe and secure method of mounting tracking and video devices on typical construction equipment. The design must enable continuous data transmission between the construction machinery and the visualization system without limiting the equipment's motion and exposure to the elements of the excavation site. In addition, work is in progress to develop robust forward kinematics algorithms to calculate the exact position of the equipment implement based on the incoming data of the GPS device. This also requires installing motion sensors and orientation trackers on moving parts of the construction equipment (e.g. boom, stick) to provide the system with real time configuration and angular motion data.

ACKNOWLEDGMENTS

The presented work has been supported by the National Science Foundation (NSF) through grant CMS-0448762. The authors gratefully acknowledge the support of the

NSF. Any opinions, findings, conclusions, and recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the NSF.

REFERENCES

American Society of Civil Engineers (2003). "Standard guideline for the collection and depiction of existing subsurface utility data." ASCE Construction Institute 30-02.

Behzadan, A. H. (2008). "ARVISCOPE: Georeferenced visualization of dynamic construction processes in three-dimensional outdoor augmented reality." Ph.D. Dissertation, Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI.

Behzadan, A. H., Timm, B. W., and Kamat, V.R. (2008), "General purpose modular hardware and software framework for mobile outdoor augmented reality applications in engineering." Journal of Advanced Engineering Informatics, 22(1), Elsevier Science, New York, NY, 90-105.

Behzadan, A. H., and Kamat, V. R. (2007). "Enabling smooth and scalable dynamic 3D visualization of discrete-event construction simulations in outdoor augmented reality.' Proceedings of the 2007 Winter Simulation Conference, Washington, DC.

Buckeye Partners, L.P. and Affiliates (2007). "Right-of-way use restrictions specification." Breinigsville, PA, 18031.

Crane, C. D., and Duffy, J. (2008). "Kinematic analysis of robot manipulators." Cambridge University Press, Cambridge, UK, ISBN 978-0-521-04793-7.

Ehsani, M. R., Upadhyaya, S. K., and Mattson, M. L. (2004). "Seed location mapping using RTK GPS." Transactions of the ASABE, 47(3), American Society of Agricultural and Biological Engineers, St. Joseph, MI, 909-914.

Kamat, V. R., and Martinez, J. C. (2005). "Dynamic 3D visualization of articulated construction equipment." Journal of Computing in Civil Engineering, 19(4), American Society of Civil Engineers, Reston, VA, 356-368.

Purdue University (1999). "Cost savings on highway projects utilizing subsurface utility engineering." FHWA Contract Number DTFH61-96-00090.
MISS DIG System (2007). "One call excavation handbook." Auburn Hills, MI, 48326.

COLLABORATIVE TUNNELING SIMULATION USING SYNTHETIC ENVIRONMENTS

S.M. AbouRizk[1], S. Hague[2] M. Al-Bataineh[3] S. Fernando[4]

Abstract

Project managers can use simulation tools during the pre-construction planning phase to coordinate human and material resources and weigh alternative scenarios proposed for a specific project, define activities, create schedules, predict completion dates, and calculate costs. Tunneling is a good test case for simulation due to its repetitive and sequential activities. Unfortunately, current simulation techniques are only effective when the models can be limited in scope and are limited to single users, as original construction simulation frameworks were meant to tackle processes and operations rather than integrate projects within collaborative, multi-user environments. Furthermore, current simulation environments fail when the interactions involve different models. This paper discusses a proposed system for the development of a multi-user decision support framework to improve the planning phase of construction. The framework is designed to house a collaborative environment in construction and will be informed by the Construction Synthetic Environment (CoSyE) method based on High Level Architecture (HLA).

1. Introduction

The prevalent approach for simulating construction operations has typically been process interaction simulation. Using this approach, a simulationist creates a model of a construction operation using specific modeling constructs. Much advancement has

[1] Hole School of Construction Engineering, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2G7; PH (780) 492-8096; FAX (780) 492-0249; e-mail: abourizk@ualberta.ca
[2] Hole School of Construction Engineering, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada, T6G 2G7; PH (780) 492-0596; FAX (780) 492-0249); e-mail: hague@construction.ualberta.ca
[3] SMA Consulting Ltd., #305 8702 Meadowlark Road, Edmonton, Alberta, Canada T5R 5W5; PH (780) 484-3313; FAX (780) 483-7303; e-mail: mohammed@smaconsulting.ca
[4] City of Edmonton Asset Management and Public Works, Drainage Services, Design and Construction, 3rd Floor, Century Place, 9803 -102A Avenue, Edmonton, Alberta, Canada T5J 3A3; e-mail: siri.fernando@gov.edmonton.ab.ca

taken place to apply process interaction simulation in construction. CYCLONE (Halpin 1977) fostered a wide range of construction simulation research efforts. Chang (1987) introduced object-oriented concepts to construction simulation modeling. Object-oriented simulation models resemble their real-life counterparts. Using the object-oriented approach leads to reduced coding and improved simulation model readability, as demonstrated by Oloufa (1993). Martinez and Ioannou (1994) introduced STROBOSCOPE as a modeling and simulation language capable of modeling a wide variety of systems. It contains implementations of CYCLONE and an open platform for creating models using source code in its open environment. Hajjar and AbouRizk (2002) introduced *Simphony* both as a platform for developing customized simulation tools for construction application as well as for use as a general purpose simulator.

Current simulation techniques are effective when the models can be limited in scope and are not set in a collaborative environment. This inherited deficiency arises from original construction simulation frameworks that were meant to tackle processes and operations rather than integrated projects with multi user environments.

2. Distributed Simulation

Distributed simulation surfaced in the 1970s and has matured over the last few decades. Currently, it is used for many applications, such as military training, analysis of communication networks, and air-control systems. Distributed simulation runs a simulation model on a number of geographically scattered computers linked by a network connection such as the internet, in which interactions take more time and occur less often.

There are two major categories of application for the distributed simulation. The first category is concerned with the analysis of a particular system (e.g. comparing a number of alternatives for a complex system, such as air-traffic control). In this case, we are interested in computing the results of the model as fast as possible to use the simulation in an effective manner. For example, by evaluating the available actions as quickly as possible for an air-traffic network, delays due to inclement weather could be reduced. The second category is concerned with developing virtual environments and 3D visualizations for training, entertainment, and evaluation of devices. This category is widely used in military training because it is safe and cost-effective.

Distributed simulation provides numerous benefits compared to classic simulation programs (Fujimoto 2001):

1. By dividing the simulation model among a number of computers, the execution time for analytical simulation is reduced. The simulation time can also be reduced by a factor equal to the number of processors used in the simulation. This is clearly an important advantage of distributed simulation in comparison to other types, some of which require several days to run a complex simulation model.
2. In online and real-time simulation, quick executions are important since there is ordinarily little time to make decisions. It is important for the virtual environment to execute in real time.

3. A distributed virtual environment can be achieved by using distributed simulation.
4. Machines from different manufacturers can be integrated using distributed simulation. For example, the flight simulators among different aircrafts.
5. Multiple development teams.
6. Independent but interoperable model development.
7. Joining and resigning running simulation models.
8. Different simulation algorithms.
9. Human/hardware-in-the-loop capability.
10. Large scale modeling capability.
11. Support for intelligent agents.

3. High Level Architecture (HLA)

HLA is a set of general rules created to manage the development of distributed simulation environments. It was first developed by the U.S. Department of Defence (DoD). The HLA approach supports complex, multi-layer, multi-user applications, such as those in the construction industry. HLA supports complex virtual environments (federations) using distributed simulation technologies. Also, it provides the rules to develop individual components (federates) of such environments by different developers while maintaining interoperability between them. HLA standards facilitate the reusability of the developed components. These standards consist of three main components: HLA rules, interface specifications, and the Object Model Template (OMT). HLA rules must be enforced if a federate or federation is to be regarded as HLA. The interface specification defines the functional interface between federate and run-time infrastructure (RTI). The RTI is software that conforms to the HLA specifications and provides software services, such as synchronization, communication, and data exchange between federates to support an HLA-compliant simulation.

These services fall into six main areas:

- Time management
- Object management
- Declaration management
- Federation management
- Ownership management
- Data distribution management

To promote collaborative modeling, reusability, and interoperability, all objects and interactions managed by a federate and visible outside the federate should be specified in detail under a common format. The Object Model Template (OMT) provides standards for documenting HLA object modeling information and consists of three parts: Federation Object Model (FOM), Simulation Object Model (SOM), and Management Object Model (MOM).

To develop a comprehensive collaborative construction simulation framework, we will use HLA concepts; since HLA does not support hierarchy, we will use Ziegler's (2000) abstraction concept to present hierarchy in our framework.

4. Collaborative Construction Simulation

Facilities are built through the collaboration of multiple stakeholders. Different participants in the project at different times operate within different levels of the project hierarchy and engage with different facets of the project. They provide input, make decisions and interact with the design and the built facility. This often leads to many challenges and problems that are not reconcilable with today's technologies.

To facilitate interactions between participants in a loose network approach, we intend to build our framework to make use of the services and methods available through HLA. HLA supports building complex virtual environments (called federations) using distributed simulation technologies. It provides standards for building the individual components (federates) of such environments by different developers while maintaining interoperability between them. HLA standards consist of three main components: the HLA rules (IEEE 1516), the interface specifications (IEEE 1516.1), and the Object Model Template (OMT) (IEEE 1516.2). A conceptual model of the proposed research in the context of the hierarchical concepts and the HLA standard is provided in Figure 1 above.

The processes required to build facilities are simulated through a myriad of abstractions and representations. Those representations evolve, change and mature from one stage of the life cycle to the next. Henderson (2002) argues that "stakeholders have their specific roles in a project, and their responsibilities change when their roles change." In different roles, various stakeholders may work at different levels of the job hierarchy and require differently detailed information from operational processes, i.e. relating to strategy, tactics, or total operations, both when setting up and executing a process.

5. Framework Overview

The framework presented in this paper incorporates a number of components to help understand and simulate construction projects, especially tunneling. This framework will help researchers to develop a generic multi-user based model for any construction project. Figure 2 shows the tunneling construction framework.

Even though our focus will be on tunneling projects, this framework can be generalized for any construction project. In the following section, we will describe each of the framework components.

6. Framework Components

The proposed framework consists of a number of components that will integrate together. This integration will facilitate the development of a multi-user simulation-based model for tunneling operations.

These components will help to develop a better understanding of the construction process under consideration, in our case tunneling; also, they will help define the company hierarchy. A CoSyE simulation environment based on HLA concepts is another component of this framework, which will be used to develop the simulation models. Meanwhile, Ziegler's abstraction concept will be used to represent the hierarchy in the simulation model, as HLA doesn't support hierarchy.

A detailed description of the framework components is presented below.

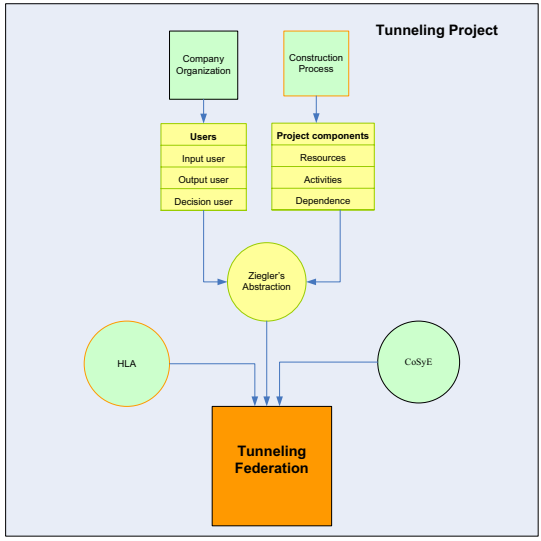


Figure 1 Multi-user framework for tunneling construction

6.01 Process study

To be able to understand the complexity of a given construction process, it should be studied and documented closely. To achieve that, a number of site visits should be scheduled. In our case, the focus was on tunneling operations. To understand more about the process, we visited a number of sites in Edmonton, Canada over the course of our research. During these visits, we recorded the process activities and their durations.

From this component, a number of issues should be highlighted, such as: resources, processes, activities, materials, outcome, upper management input, weather effects, and material delivery impact. The idea behind this is to define the information exchanged between the site and the company, and also other parties involved in the project such as consultant, designer, etc.

6.02 Company organization

This component will present us with the different users involved in the project and their levels of involvement. That will help us to define our system users: the input user will input data to the system and update project status; the output user will receive outputs based on the input data from the input user, analyze them, and make recommendations based on that. Lastly, the decision-making user, which is the highest user level, will set the actions and strategies.

6.03 Ziegler's abstraction

To represent hierarchy in the framework, we used Ziegler's concept of abstraction. Abstraction, in this sense, refers to "applying a method to a model to reduce its complexity while maintaining its validity in the context of the simulation exercise." As the model is abstracted to higher levels, it is reduced (coupled with other models) and consequently becomes less complex. The essential steps include partitioning the models and coupling them in the process of reduction, thus creating higher level models (Ziegler 2000). To facilitate collaboration, we maintained lower level models with appropriate flexible configurations for operational use, while abstracting the higher level models for managerial purposes and for scenario-based planning.

6.04 High Level Architecture

Current simulation techniques do not allow developers to combine a number of computer simulation models into a larger simulation. The developer is forced to recreate the overall simulation model, which adds additional time and cost to the process. HLA provides the link that will allow developers to combine these simulation models.

In HLA terminology, the combined simulation model is called a federation, and each simulation model included in the simulation is called a federate. Each federation needs a Run Time Interface (RTI), which is supporting software used to control the data flow between federates, and a Federation Object Model (FOM), which contains the common object model for the data exchanged between federates in a federation (Kuhl et al. 1999).

6.05 Construction Synthetic Environment (CoSyE)

The CoSyE (AbouRizk 2006) simulation environment is based on HLA rules and consists of three major components (see Figure 2):

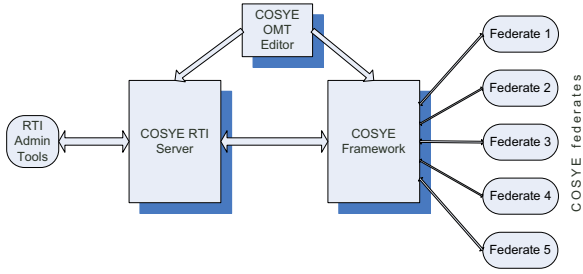


Figure 2 CoSyE architecture with the modeling federates

1. CoSyE RTI Server, a .NET implementation of IEEE standards 1516-2000. Currently, the CoSyE RTI server has implemented 50% of the standards and

provides services, such as federation, declaration, object, ownership, and time management.

2. Object Modeling Template (OMT) editor, used to define objects and their attributes. It defines the structure of the Federation Object Model (FOM) for the federation. The FOM for a single federation defines the communication language through which federates included in the federation speak with each other, including the names of things and occurrences. The OMT editor is integrated into Microsoft Visual Studio.NET.
3. CoSyE Framework, an application programming framework that allows developers to create federates, handle details of communication with the RTI, integrate with code generated by the OMT editor, and use many of the visual programming features supported by Visual Studio. In addition, the framework supports both discrete-event and time-stepped federates.

7. Tunneling federation

7.01 Developing a synthetic environment

The synthetic environment we are planning to develop for tunneling simulation will mirror the real company hierarchy, in which each user will have a different level of detail required to represent his/her level in the company hierarchy.

Figure 3 illustrates the mapping between the company hierarchy and the tunneling federation we intend to build. Please note the segment of the federation that utilizes the CoSyE federation detailed above. To overcome HLA's lack of support for hierarchy, we used abstraction to represent the hierarchy in the context of a higher level user, represented by a higher level of abstraction and fewer details.

The following list provides the federates that will be included in our federation:

1. Excavation Federate: Responsible for excavation of the tunnel segments, loading of the dirt onto the train, performing lining operations, and installing the tracks.
2. Geotech Federate: Carries the ground profile and produces the penetration rate for the TBM.
3. Statistics Federate: Used to collect statistics for the operation, such as production rate, resource usage, and project duration.
4. Breakdown Federates: Predicts the breakdown of different machinery, estimates the duration of the breakdown, and the time required to fix it.
5. Viewer Federate: 3-D animation of the entire operation.
6. Shift Federate: Manages shifts properties such as the duration of the shift, lunch break, etc.
7. Real time Federate: Responsible for real time update data from the site.
8. Shaft Construction Federate: Used to simulate shaft excavation for tunneling. The shaft can be represented as working shaft, removal shaft, and emergency shaft.

9. Material Delivery Federate: This federate is responsible for simulating material delivery to the project. This material can be lining, mechanical parts, electrical parts, etc.
10. Earth Moving Federate: Used to simulate the removal of the excavated dirt form site to dumping area.
11. Weather Federate: Used to predict the weather parameters during the simulation period for a site location.
12. Engineer Federate: Responsible for producing reports for the project manager, such as updates to the schedule, and cost estimates.
13. Director Federate: Used for high level users to help them run scenarios and come up with the best approach to achieve their goals.

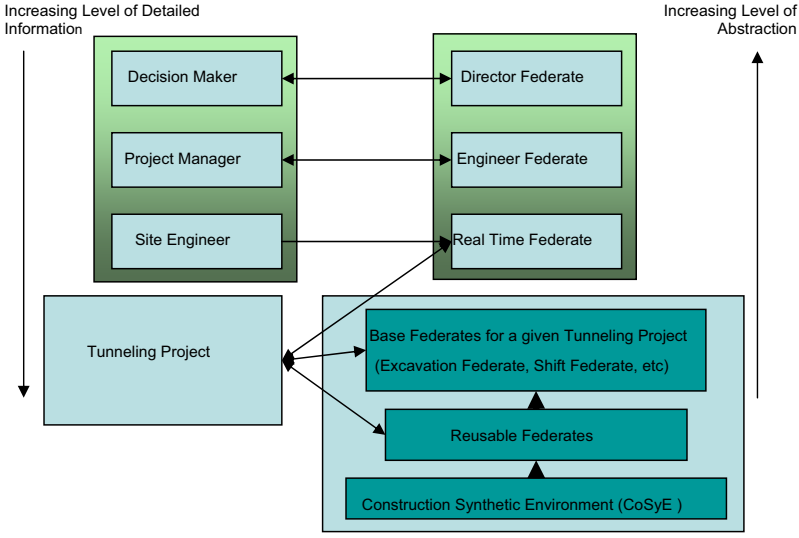


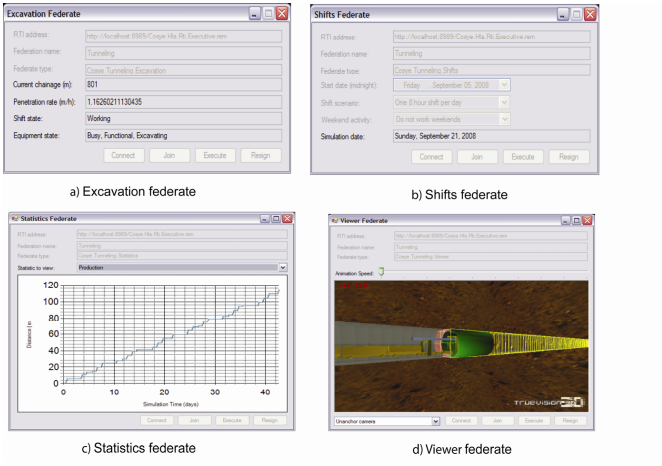
Figure 3 Tunneling federation vs. company hierarchy

During execution of the simulation, federates will be responsible for creating object instances of the object classes we defined in the FOM. Also, federates can publish and subscribe to an object instance attribute; for example, a federate can subscribe to the diameter of tunnel section, or it can publish the tunnel section diameter. Some federates can publish and subscribe, publish only, or subscribe only.

A federate will be interested in publishing an attribute if it updates its value; for example, Excavation Federate updates the TrainState. A federate will be interested in subscribing to an object class instance attribute if it triggers an action; for example, Excavation Federate will subscribe to TBMState because if the TBMState is 'Down', no excavation can be done until the TBMState changes to 'Functional'.

7.02 Federation outputs

The tunneling federation has a number of outputs. Utilizing a Bayesian updating technique, we were able to introduce real-time updating for the TBM advanced rate using data collected on site. Using the TBM advance rate, the federation produces the production rate for ground excavation in m/hr. This production rate will be transferred to the schedule using the services provided by the Shift federate. The Statistic federate will provide the manager with TBM statistics, which show the percentage of time TBM is working, down, or idle. As well, the federation can produce 3D graphic outputs for the model in order to improve visualization. Based on these outputs, the project manager will be able to understand the status of the project and build a plan for the future.



a) Excavation federate b) Shifts federate

c) Statistics federate d) Viewer federate

Figure 4 Current tunneling federation

7.03 Current state of the tunneling federation

Figure 4 shows the current state of the tunneling federation. At this stage, excavation, shift, statistics, and viewer federates have been partially developed. Each federate is an individual simulation model with its own resources; it is at a different simulation time in each captured snapshot. The federates have been developed using Visual Studio 2008 and the CoSyE framework.

8. Summary

In this paper, we present a proposed future implementation for simulating multiple users in tunneling operations. Our analysis has shown that current simulation environments are not capable of handling multi-user multi-layer problems. In this project, every time a change was requested, the simulation model had to be altered and re-run. The project team was unable to use the simulation environment concurrently, which cost us a lot of time and effort in finishing the job. Running the

models showed that this program is efficient during pre-construction estimating, but once construction is underway, a number of users with competing interests will be involved in the simulation. For example, senior managers will be interested in end results per day, while site engineers will be interested in low-level detailed information so that they can make a decision based on this data. Considering the previous limitations, a new method of simulation needs to be developed to further support specific requirements. To address these issues, we have presented a tunneling simulation using CoSyE.

9. References

AbouRizk, S. (2006). "Collaborative Simulation Framework for Multi-user Support in Construction." Discovery Grant Proposal.

Fujimoto R. M.. (2001), "Parallel and Distributed Simulation Systems." Proceedings of the 2001 Winter Simulation Conference, Florida, 147-157.

Oloufa, A. (1993). "Modeling operational Activities in Object-Oriented Simulation." Journal of Computing in Civil Engineering, ASCE, 7(1), 94-106.

Martinez, J. and P. G. Ioannou (1994). "General Purpose Simulation with Stroboscope." Proceedings of Winter Simulation Conference, ASCE, 1159-1166

Hajjar, D. and AbouRizk, S. (2002). "Unified modeling methodology for construction simulation." Journal of Construction Engineering and Management. 128(2), 174-185.

Halpin, D. W. (1977). "CYCLONE: Method for Modeling of Job Site Processes" Journal of the Construction Division, ASCE, 103(3):489-499

Chang, D.Y. and Carr, R.I. (1987). "RESQUE: A Resource Oriented Simulation System for Multiple Resource Constrained Processes." Proceedings of the 1987 PMI Seminar/Symposium, Milwaukee, Wisconsin, 4-19.

Kamat, V. R., and Martinez, J. C. (2001). "Visualizing Simulated Construction Operations in 3D", Journal of Computing in Civil Engineering, Vol. 15, No. 4, American Society of Civil Engineers, Reston, VA, 329-337.

Zeigler, B. P., T. G. Kim, and H. Praehofer. (2000). "Theory of Modeling and Simulation." New York, NY, Academic Press.

Kuhl, F., Weatherly, R., and Dahmann, J. (1999) "Creating Computer Simulation System an Introduction to High Level Architecture", Prentice-Hall Inc., Upper Saddle River, NJ, USA.

Henderson, P. (2002). "Systems Engineering for Business Process Change: new directions", Springer, London, UK.

DEVELOPMENT OF A NUMERICAL MODEL FOR PREDICTING PULLING LOADS ON FUSIBLE PVC PIPE

Samuel T. Ariaratnam[1], Arnab Ghosh[2], Richard (Bo) Botteicher[3], and Siggi Finnsson[4]

[1]Professor, Ira A Fulton School of Engineering, Arizona State University, Tempe, Arizona; PH (480) 965-7399; FAX (480) 965-1769; email: ariaratnam@asu.edu
[2]Graduate Research Assistant, Ira A. Fulton School of Engineering, Arizona State University, Tempe, Arizona; email: arnab.ghosh@asu.edu
[3]Senior Product Engineer, Underground Solutions Inc., Denver, Colorado; email: bbotteicher@undergroundsolutions.com
[4]Engineer, Digital Control Inc., Kent, Washington; email: siggif@digital-control.com

Abstract:

Design engineers are continually evaluating alternative pipe and construction options for addressing their municipal infrastructure needs. Today, the use of trenchless technologies such as Horizontal Directional Drilling (HDD) in the municipal sector has increased significantly as an alternative construction method. The nature of the HDD process necessitates the use of continuously joined pipe products capable of being pulled in, as opposed to pushed in by segmental installations. Fusible PVC™ (FPVC™) pipe is one such material for installation of water and wastewater, pressure and non-pressure infrastructure using HDD. While maximum safe pull load criteria have been developed for this material, the present pull load predictive tools for the HDD process are highly variable and, in some cases, overly conservative in evaluating safe pull loads. This paper describes the results of research to develop a predictive model for HDD installations specific to FPVC™. A three step process was used to define the methodology of predicting safe pull load. The first step was the development of empirical equations based on existing methodologies, experience, and PVC-specific material properties. The second step involved field measurement of pipe pull loads during HDD installations. Finally, the field data was compared to the calculated data and the predictive equations were modified accordingly. This design model, calibrated by field verified data, enables a more accurate determination of required safe pull load for any given HDD installation.

1. INTRODUCTION

The conventional method for construction, replacement, and repair of underground utilities has been trenching or open-cut. This method includes installation of utility systems into open-cut trenches. Open-cut method involves digging a trench along the length of the proposed pipeline, placing the pipe in the trench and then backfilling. Often, the construction effort is concentrated on activities such as detouring roads, managing traffic flow, trench excavation and shoring, dewatering, backfilling and compaction operations. Subsequently, this often results in a small part of the construction effort actually being focused on the final product (i.e. the installation of the product pipe). In some cases, the backfilling and compaction, and reinstatement of groundwater and pavement alone amount to 70% of the total cost of the project (Najafi and Gokhale, 2005). When traditional open-cut method is not acceptable or desirable, Horizontal Directional Drilling practices can be applied. In situations with high investments in surface infrastructure, congested utilities, and where the social costs such as commuter traffic and businesses are affected, HDD is a more desirable choice (Lueke and Ariaratnam, 2005).

Currently, there are numerous alternative pipe products to choose from for installations using trenchless methods such as Horizontal Directional Drilling (HDD). FPVC™ pipe has proven to be a feasible alternative to other options including: high density polyethylene (HDPE); ductile iron; and gasketed or jointed PVC. Favorable material properties inherent to PVC include: (1) durability; (2) corrosion resistance; (3) resistance to chemicals; (4) high tensile strength; and (5) cost-competitiveness. However, development of analytical procedures to determine design characteristics of this product is imperative to broadening its use. An analytical procedure for determining safe pulling forces and associated Factor of Safety would aid engineers and contractors in selecting FPVC™ for Horizontal Directional Drilling projects as a viable and economical option. A logical approach to evaluation of design methodology is important to ensure that basic engineering principles are met during installation and to satisfy the requirements of municipal agencies.

Established equations for calculating pull loads during HDD installations were developed in ASTM F1962-05 *Standard Guide for the Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit under Obstacles, Including Rivers* (ASTM, 2005). The equations developed in ASTM F1962-05 were used as a basis and modified for calculating pull loads using FPVC™ pipe. The calculations were compared to actual pipe loads captured during field installations of FPVC™ pipe using in-line measuring devices. This paper presents results of safe pulling loads from two of six projects studied. It should be noted that research is on-going to compare predicted vs. actual pull loads on HDD projects.

2. EQUATIONS TO PREDICT PIPE PULL LOADS

The design approach in the ASTM F1962-05 Standards was used as a foundation for the prediction of pulling loads for the projects monitored. The equations for predicting the loads are mainly performed for the four critical points A, B, C, and D

as illustrated in Figure 1. The equations to predict the pulling loads for the FPVC™ pipes are divided into two different design methods depending on the method of pipe installation. The method of installation of FPVC™ can be either continuous pull or sectional pull.

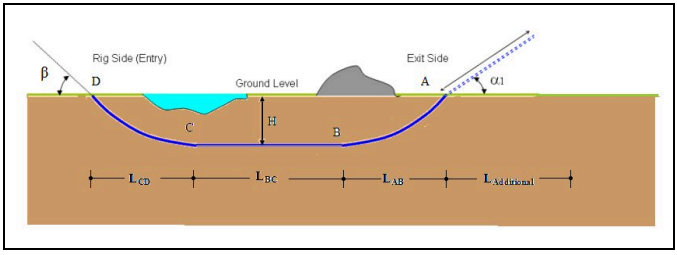


Figure 1. General Borepath Schematic of a Typical HDD Installation

2.1 Case 1: Continuous Pull (pre-fused pipe before installation)

In this method, all pipe sections are fused together to make a continuous string of pipe to be installed in one continuous operation. ASTM F1962-05 equations are used to determine the pulling loads at points along the borepath. These are shown in Equations 1 to 4.

$$T_A = \exp(\nu_a \alpha)\,[\nu_a w_a (L_1 + L_2 + L_3 + L_4)] \quad (1)$$

$$T_B = \exp(\nu_b \alpha)\,[T_A + \nu_b |w_b| L_2 + w_b H - \nu_a w_a L_2 \exp(\nu_a \alpha)] \quad (2)$$

$$T_C = T_B + \nu_b |w_b| L_3 - \exp(\nu_b \alpha)\,[\nu_a w_a L_3 \exp(\nu_a \alpha)] \quad (3)$$

$$T_D = \exp(\nu_b \beta)\,\{T_C + \nu_b |w_b| L_4 - w_b H - \exp(\nu_a \alpha)\,[\nu_a w_a L_4 \exp(\nu_a \alpha)]\} \quad (4)$$

Where,
T_A = Pull force on pipe at point A, lbf (N)
T_B = Pull force on pipe at point B, lbf (N)
T_C = Pull force on pipe at point C, lbf (N)
T_D = Pull force on pipe at point D, lbf (N)
L_1 = Additional length of pipe required for handling and thermal contraction, ft (m)
L_2 = Horizontal distance to achieve desired depth, ft (m)
L_3 = Additional distance traversed at desired depth, ft (m)
L_4 = Horizontal distance to rise to surface, ft (m)
H = Depth of bore from ground surface, ft (m)
$\exp(x) = e^x$, where, e = natural logarithm base (e = 2.71828)
ν_a = Coefficient of friction applicable at the surface before the pipe entering bore hole
ν_b = Coefficient of friction applicable within the lubricated borehole or after the wet pipe exits

w_a = Weight of empty pipe, lbf/ft (N/m)
w_b = Net upward buoyant force on pipe in borehole, lbf/ft (N/m)
α = Borehole angle at pipe entry (or HDD exit, at side opposite drill rig), radians
β = Borehole angle at pipe exit (or HDD entry, at same side as drill rig), radians

2.2 Case 2: Sectional Pull (pre-fusing longer sections & joining during pullback)

In this case, the shorter sections of pre-fused pipe lengths are fused simultaneously to obtain a longer length of pipe during pipe pulling. This may be done in circumstances where site conditions restrict the ability to layout longer sections of fused pipe string. ASTM F1962-05 equations are modified and used for the prediction of the pulling forces during this kind of installation. The ASTM equations were modified to obtain the pull forces at the four given points. Figures 2a to 2d illustrate the advancement of the pipe in the borehole and the corresponding Equations 5 to 8.

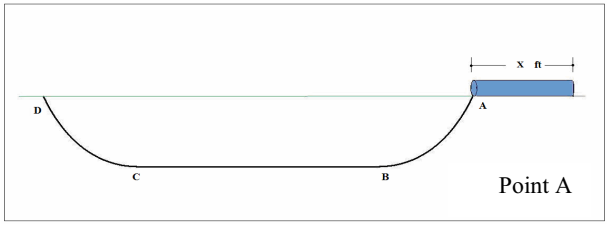


Figure 2a. Point A along the Borepath

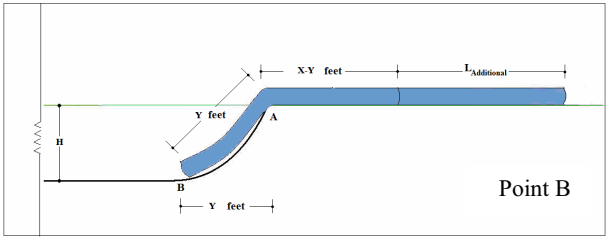


Figure 2b. Point B along the Borepath

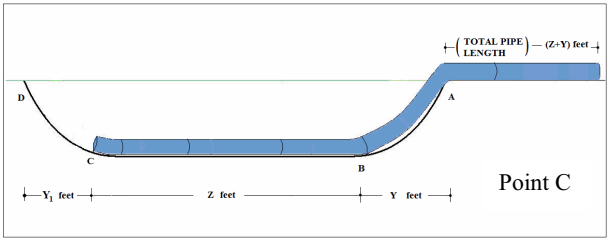


Figure 2c. Point C along the Borepath

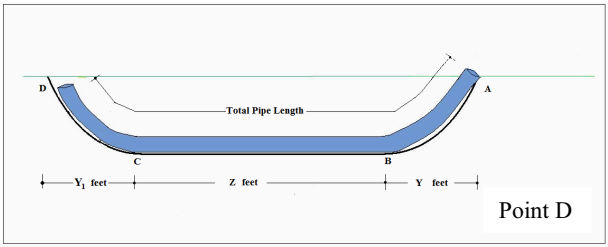


Figure 2d. Point D along the Borepath

$$T_A = (v_a * w_a * L_{X\ feet}) \quad (5)$$

$$T_B = T_A + [\exp(v_b * \alpha) v_b * W_b * Ly\ ] + [\ v_a * w_a * L_{(X-Y)+(Laddditional)\ feet}\ ] + (W_b * H) \quad (6)$$

$$T_C = T_B + (\ v_b * w_b * L_{\ Z\ feet}) + (\ v_a * w_a * L_{Surface\ feet}) \quad (7)$$

$$T_D = T_C + \exp(v_b * \beta) v_b * W_b * L_{Y1\ feet} - (w_b * H) \quad (8)$$

2.3 Hydrokinetic Force

During pullback, the movement of the pipe is resisted by the drag force of the drilling fluid. The hydrokinetic force (Equation 9) depends primarily on the drilling slurry, slurry flow rate and the borehole and pipe sizes. This must be added to the maximum calculated pull load to obtain the "true" maximum prediction.

$$T_{HK} = q*(\pi/8)*(D_H^2 - OD^2) \quad (9)$$

Where,
q = Hydrokinetic Pressure (=10 psi)
D_H = Borehole Diameter
OD = Pipe Outside Diameter

3. FIELD PROJECTS USING FUSIBLE PVC™ PIPE

3.1 Secession Reclaimed Water Main Project, South Carolina

3.1.1 Project Background

The Beaufort Jasper Water and Sewer Authority (BJWSA) is a non-profit, non-taxing public service organization that provides water and sewer service to an area of approximately 750 square miles including two counties in South Carolina. The BJSWA Port Royal Wastewater Reclamation Facility produces a reclaimed water quality effluent, which allows it to be used for mostly unrestricted irrigation purposes.

The Secession Golf Course could be tied into the Port Royal WRF effluent force main on Port Royal Island near McTeer Bridge, which traverses the Beaufort River from Port Royal Island to Lady's Island.

The Secession Reclaimed Water Main project involved installing a 250mm (10") nominal diameter DR 14 Fusible PVC™ pipe to complete the crossing. The initial bore path was back reamed in a single pass with a 445mm (17.5") diameter back reamer over a five day period. During this process, the HDD contractor utilized a second 60,000 pound drill rig, located on the west side of the river. The function of the second rig was to exert tension on the drill pipe string while the primary 330,000 pound rig provided rotation.

Site limitations required pre-fusion of pipe sections to facilitate installation of the FPVC™ pipe string. Each shorter length of the pre-fused pipe was made into 300m (1000 ft) strings of pipe. This left four intermediate fusions to be performed during the pullback. The total length of pipe installed was 1.56km (5,120 ft). During the fusion process, the external bead was removed form the pipe to reduce drag during pullback. In keeping with good practices, rollers were used to minimize frictional forces acting on the pipe while outside of the borehole. The main pull-in with pipe exiting the alignment on the east side took approx 17¼ hours. Removal of reamer and final positioning took an additional 1¼ hours for a total of 18½ hours.

3.1.2 In-Line Pull Force Monitoring Device

Pull force was monitored in two ways for this installation. First, for each drill rod segment, the hydraulic pressure and gear used at the drill rig were recorded. This captured the pull force based on the machine hydraulics that was required to move the drill stem, back reamer, drill mud, spoils, as well as the pipe. The approximate conversion factor from gauge pressure to pull force was coordinated and verified by the contractor. The second measurement was taken from an in-line pull force monitoring device rented from Horizontal Technologies of Houston, TX. This device was developed to record downhole information as it relates to the pipe and the borehole. The device was connected between the swivel and the back reamer with a standard threaded connection that matched up to the drill stem, reamer, and swivel threaded connections. All data were recorded for the entire length and duration of the pull, even though it lasted over 18 hours. The device measured tensile force, external mud pressure, drilling fluid pressure in the drill stem, and torsion forces translated to the pipe. Data points were recorded every 10 seconds, and stored on board the device. After the pullback was complete, the device was returned for data retrieval. This data allowed for comparison of pull force at the pipe to the pull force at the machine moving the drill stem, back reamer, and the pipe.

3.1.3 Predicted Design Calculations

Equations 5 to 8 were used to estimate the pull loads because this project was performed by a sectional pull method. In the calculations, X is 30m (100 ft), Y and Y_1 are 200m (600 ft) and Z is 1000m (3,300 ft) as per Figure 2.

$$T_A = (0.1 * 16.97 * 1000) = 1{,}697 \text{ lbs} \quad (5)$$

T_B = 1697 + [exp (0.3 * 0.2) 0.3 * 15.12 * 600] + [0.1 * 16.97 * 1400) + (15.12 * 60]
= 7,870 lbs (6)

T_C= 7870 + (0.3*15.12*3900)+(0.1*16.97*500)+[exp(0.3*0.5253)0.3*15.12*800]
= 30,656 lbs (7)

T_D = 30,656+[(exp(0.3*0.2)0.3*15.12*500]+[exp(0.3*0.44)*0.3*15.12*200]-(15.12*
60 = 33,192 lbs (8)

Total Pull Force (Predicted) = Max force + Hydrokinetic Force (T_{HK})
= 33,192 lbs+ 605 lbs = 33,797 lbs

Total Pull Force (Actual) = 39,493 lbs (between points C and D, at a horizontal distance of 1.52 km or 4,991 feet from A)

Figure 3 illustrates the actual vs. predicted pull force values at the four different points along the borepath. The values have a close correspondence with the predicted being slightly more conservative.

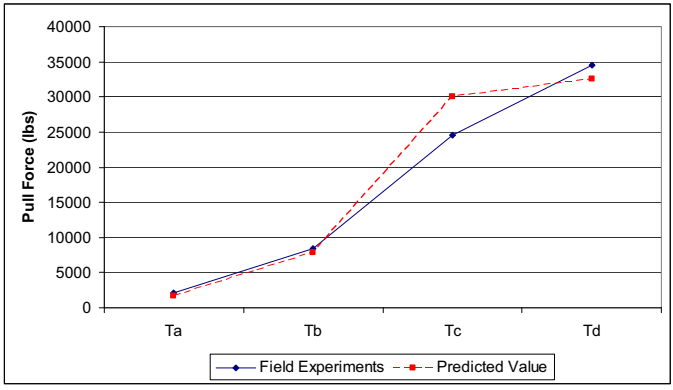


Figure 3. Predicted vs. Actual Pull Loads for the Secession HDD Project

3.2 Broomfield (Phase II - Pull II), Broomfield, CO

3.2.1 Project Background

The City and County of Broomfield, Colorado is a municipality located between Denver and Boulder that needed to upsize and replace an existing waterline under a busy service road in an area of small industrial and commercial businesses for fire flow and other service reasons. Industrial Road, though only a two lane thoroughfare, sees substantial traffic flow. Subsequently, city officials decided to install a new line using HDD technology and FPVC™ as the product pipe.

The pipe being installed was a 300mm (12") DR 18 purple color, FPVC™ pipe. The pipes as delivered on site were 20 lengths of 12m (40 ft) each. The pipes were fused prior to the installation and then installed in one continuous pull. The project had to cross a number of existing underground utilities, ones a 600mm (24") Reinforced Concrete Pipe (RCP) storm culvert. The depth of installation was maintained at 2.4m (8 ft) and the whole of the pull was along 144th avenue. A Ditch Witch JT4020 drill rig was used to perform the drilling and pullback operations.

3.2.2 In-Line Pull Force Monitoring Device

An in-line pull force monitoring device developed by Digital Control Inc. was used to capture pull load data on the pipe during installation. The TensiTrak™ tension load and drilling fluid pressure monitoring device included a strain gauge and a pressure-measuring device, which were connected to a transmitter. The transmitter transmits load and pressure readings in real time on the frequency used by the Eclipse® locating system. The information transmitted included instantaneous pull force, maximum pull force, drilling fluid pressure, transmitter temperature, transmitter battery life and a magnetic signal, which can be used to locate the depth and direction of the TensiTrak device should this be desired. The instantaneous pull loads and drilling fluid pressures were also transmitted in real time by the Eclipse receiver to a remote device positioned on the drill rig.

The TensiTrak monitor was connected to a swivel between the reamer and the product pipe being installed to ensure that only the load on the product pipe itself was measured. This is important since traditionally there is no method to gauge whether increased pulling loads are caused by reamer loads (i.e. in harder ground conditions), loads of the product pipe, or a combination of both.

3.2.3. Predicted Design Calculations

This project was performed by a continuous pull method. Equations 1 to 4 were used in the design calculations.

$$T_A = \exp(0.1 * 0.070)\,[0.1 * 19.3\,(0 + 200 + 500 + 200)] = 1{,}749 \text{ lbs} \quad (1)$$

$$T_B = \exp(0.3*0.070)[1749 + 0.3*69.65*200 + 69.65*7 - 0.1*19.3*200*\exp(0.1*0.070)] = 6{,}155 \text{ lbs} \quad (2)$$

$$T_C = 6155 + 0.3*69.65*500 - \exp(0.3*0.070)\,[0.1*19.3*500\,\exp(0.1*0.070)] = 15{,}610 \text{ lbs} \quad (3)$$

$$T_D = \exp(0.3*0.070)\,\{15{,}610 + 0.3*69.65*200 - 69.65*7 - \exp(0.1*0.070)\,[0.1*19.3*200\,\exp(0.1*0.070)]\} = 19{,}306 \text{ lbs} \quad (4)$$

Total Pull Force Required (Actual) = <u>20,280 lbs</u>

Total Pull Force Required (Predicted) = Max. Pull force + Hydrokinetic energy
= 19,306 + 855 = <u>20,161 lbs</u>

Figure 4 illustrates the actual vs. predicted pull force values at the four different points along the borepath. The values have a close correspondence with the predicted being slightly more conservative.

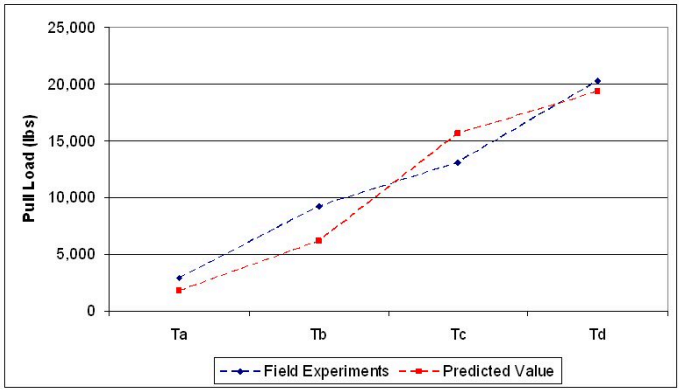


Figure 4. Predicted vs. Actual Pull Loads for Broomfield Phase II – Pull II

4. CONCLUSIONS

This paper presents a methodology for gathering and analysis of pull load data for the prediction of FPVC™ pipes during Horizontal Directional Drilling installations. In the past, several models have been developed to predict the pulling loads for pipes during HDD installations; however, these existing models are specific to HDPE and steel pipes for HDD installations. Numerous field tests have been conducted with Fusible PVC™ pipes during Horizontal Directional Drilling operations. The loads were predicted using the model presented and then compared with the actual field pull data gathered.

The paper describes two of six HDD projects that have been studied to date. The comparisons of results of the maximum pull forces of all field projects are presented in Table 1. The results reveal a 16.8% difference between the maximum predicted (33,797 lbs) to an actual (39,493 lbs) pull loads for the Secession Reclaimed Water Main Project employing a sectional pull method. These equations were modified from those used to design projects using a continuous pull method. The five other projects studied employed a continuous pull method. These results varied from a 58% (Broomfield Phase I project) to a 0.59% (Broomfield Phase II - Pull II project) difference in predicted vs. the actual loads. The difference reveals a maximum Factor of Safety of 1.6 between the predicted and the actual force, with the predicted results being conservative.

Admittedly, only six field projects have been used for comparison; however, the results presented in this paper demonstrate the need for designers and contractors to capture field data using in-line pull force monitoring devices to better calibrate their

predictive models. Continued research is underway to capture field results from in-line monitoring devices installed in additional field projects using Fusible PVC™. This will further improve the accuracy of predictive models and aid designer and contractors in determining maximum safe pulling loads on such projects.

Table 1. Comparison of Actual vs. Predicted Maximum Pull Load Values

Project	Actual (lbs)	Predicted (lbs)	% Difference
Broomfield, CO Industrial Lane Phase I project	22,710	35,893	58% more than actual (over-predicted)
Broomfield, CO Industrial Lane, Phase II, Pull I project	19,200	23,545	22% more than actual (over-predicted)
Broomfield, CO Industrial Lane, Phase II, Pull II project	20,280	20,161	-0.59% i.e. 0.59% less than actual (under-predicted)
Broomfield, CO Industrial Lane, Phase II, Pull IV project	21,780	25,980	19% more than actual (over-predicted)
Albuquerque, NM Rio Rancho Well No. 21	17,355	22,776	31% more than actual (over-predicted)
Beaufort-Jasper, SC Secession Golf Course Effluent Main	39,493	33,797	-14% i.e. 14% less than predicted (under-predicted)

5. REFERENCES

ASTM Standard F1962-05 (2005). "Standard Guide for the Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings", ASTM International, West Conshohocken, PA

Lueke, J.S. and Ariaratnam, S.T. (2005), "Surface heave mechanisms in horizontal directional drilling", Journal of Construction Engineering and Management, ASCE, 131(5): 540-547.

Najafi, M. and Gokhale. S. (2005). "Trenchless Technology - Pipeline and Utility, Design, Construction, and Renewal", McGraw Hill, New York.

HORIZONTAL DIRECTIONAL DRILLING ON THE SNOQUALMIE RIVER: A CASE STUDY

Kimberlie Staheli, PhD, P.E.[1], Michelle Ramos, L.E.G., P.E.[1]

[1] Staheli Trenchless Consultants, Bothell, Washington

Abstract

The Kimball Creek project was a 1,000-foot long crossing of the Snoqualmie River near Snoqualmie, Washington. The 16-inch diameter DR-9 HDPE pipe was installed by Horizontal Directional Drilling (HDD). Staheli Trenchless Consultants (STC) provided submittal review and full time consultation during construction. As part of the submittal review, STC independently checked the contractor's estimated pullback forces for the pipe length, diameter, and type. During construction, actual pullback forces were recorded and were later compared to both STC's and the contractor's predicted pullback forces. This paper discusses the construction for this project and compares actual pullback forces to the contractor's and engineer's predictions.

INTRODUCTION

The Kimball Creek HDD involved roughly 1,000 linear feet of directional drilling beneath the Snoqualmie River just upstream of Snoqualmie Falls (Figure 1). The HDD portion of the project was initiated on July 18, 2007 and was completed on August 15, 2007 when the 16-inch HDPE pipe was successfully pulled from the south side of the river to the north side.

Prior to initiating HDD construction, Staheli Trenchless Consultants (STC) completed pipe pullback calculations to estimate the maximum pullback force on the pipe and to confirm the HDD drill rig was adequately sized for the project. During construction, STC was on-site recording measurements of pilot bore advancement, reaming, swabbing and pipe pullback. The following sections summarize the construction process that occurred during the pilot bore drilling and pipe installation. The actual forces required for pullback of the HDPE pipe into the prepared borehole are then compared to the estimated forces.



Figure 1: The Snoqualmie River near the HDD crossing



Figure 2: HDD drill rig

SETUP AND PILOT BORE

Setup for drilling began on July 18, 2007 with site grading and set-up of the wire-line tracking system which was used to locate and guide the pilot bore. Setup was completed on July 19 and the pilot bore was initiated. The pilot bore was drilled with an American Augers HDD rig (Figure 2). The pilot bore was advanced approximately 13 feet to check that the downhole assembly was functioning properly.

Drilling of the pilot bore began on July 20 and continued into July 21 when bit advancement was halted after approximately 360 feet. The drilling crew suspected that difficult ground conditions had halted advancement. When the drill string was pulled out, it was discovered that the bit and sub-saver attachment behind it were

broken off. Thread failure was suspected for the broken bit (Figure 3).

On July 23, a new bit was attached and drilled down the existing hole with the intent of establishing a new borehole, steering around the lost bit. After some difficulty retrieving the drill steel out of the first borehole, a second borehole was established. After advancing the new pilot hole approximately 300 feet, the signal from the Down Hole Assembly was lost. Removing the pipe from the borehole, they found both the bit and steering sub were missing, leaving only the stainless steel sub attached to the drill string.



Figure 3: First drill rod – thread failure

Following the loss of the second drill bit, the contractor elected to change drill rig operators and re-started drilling operations with a new Down Hole Assembly. By end of day on July 25, 2007, approximately 120 feet of pipe were drilled in the third attempt of the pilot bore. Pilot bore drilling continued through the evening of July 28, when the pilot bore was completed and the drill bit punched out on the exit side.

Reaming and Swabbing

Reaming was completed in 3 passes with 13-inch, 20-inch, and 26-inch diameter reamers (Figure 4). The original 13-inch diameter reamer was damaged during reaming before the full reaming pass could be completed. The 13-inch reamer was then replaced by a 14-inch reamer, which finished the reaming pass. During the 20-inch and 26-inch reaming passes there were several sections of difficult advancement; however, the bore was successfully reamed without any damage to the reaming assemblies.



Figure 4: 26-inch Reamer

When the 26-inch reamer completed the reaming pass, a large cluster of cobbles was pulled out of the borehole, suggesting multiple cobbley sections along the alignment. Two swabbing runs were conducted using an 18-inch swab and 24-inch reamer to ensure the hole remained open and clear before pullback of the pipe was initiated (Figure 5). The swabbing pass encountered minimal resistance.



Figure 5: Swab head

PIPE PULLBACK

Pipe pullback commenced with an 18-inch reamer leading the pulling head and assembly (Figure 6). The pullback operation went smoothly. Pullback forces were converted from the hydraulic pressure gauges read at the control panel using a pre-calibrated conversion table provided by American Augers. During rods which had variable pullback resistance, an average value was recorded due to the step function nature of the conversion table. The average force on the pipe during pullback was 40,800 lbs. A brief section of the pipe had elevated pullback forces of 60,980 lbs, which then dropped back down to 40,800 lbs shortly thereafter. The rise in pullback pressures coincided with emerging from the second bend in the bore geometry and likely reflected additional frictional resistance by the pipe as it was advanced through the curve and pulled uphill. The pipe emerged on the north side at 13:00. A pullback



Figure 6: Reamer in front of pulling head

force graph compares the anticipated pullback forces to the actual (Figure 7).

Calculations of the expected pullback force during pipe installation by STC predicted a maximum load of approximately 36,000 lbs. For a 30-foot section of the borehole, the total weight of mud was roughly 10,000 lbs. The pullback process is often affected by a number of variables, many of which are difficult to observe inside the borehole. It is the opinion of STC that the pullback loading recorded was not outside of reasonable expectations and the basic load of approximately 40,000 lbs was a product of the frictional loading on the pipe, the weight of fluid displacement and potential wedging of the pipe in rougher cobbly ground.

The ramping up of pullback forces near the end of installation correlated with the pipe emerging from the second curved portion of the alignment which began 519 feet out from the drill rig and entered the straight section 305 feet away. The additional force

required as the pipe ascended to the surface was likely the result of increased friction through the two curved sections of the borehole and the additional gravitational resistance to pulling the pipe up the straight section.

The predicted pullback loading submitted by the contractor was 18,574 lbs, roughly 42,000 lbs less than the force observed during the pullback operation. However, the drill rig capacity of 140,000 lbs pullback force provided ample force to complete the bore.

CONCLUSIONS

Predicting pullback forces for HDD construction is a complicated process with many variables that are difficult to quantify. The natural environment rarely provides uniform properties, soil layers and geologic conditions for modeling soil response and borehole condition. Additionally, quantifying bore hole integrity is difficult when contractor's means and methods can create a multitude of borehole scenarios.

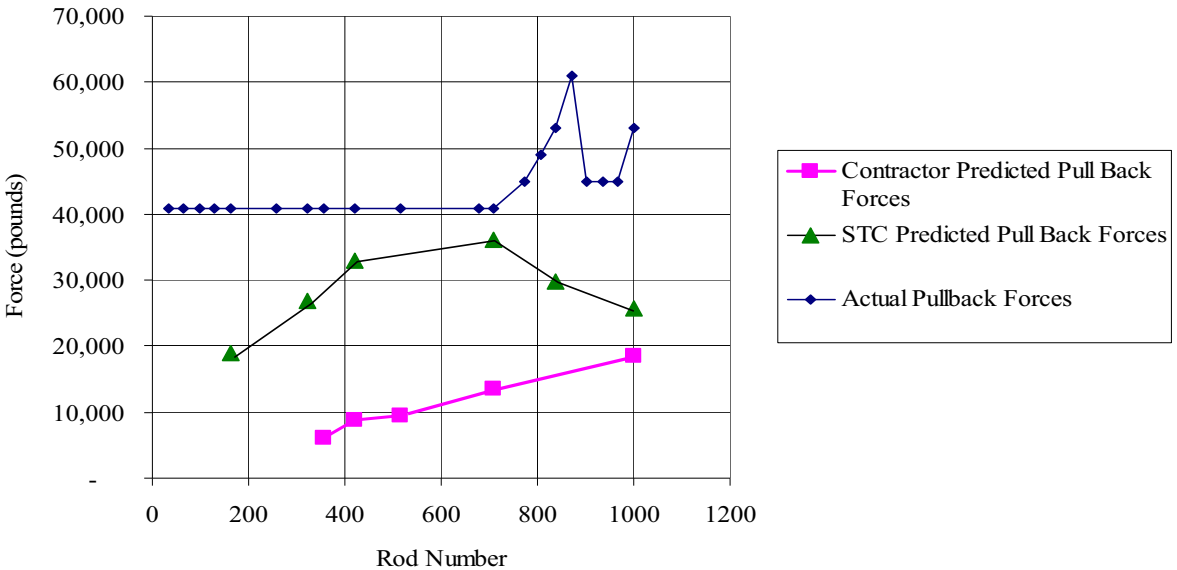


Figure 7: Comparison of actual to predicted pullback force

RISK ALLOCATION IN STANDARD FORMS OF GENERAL CONDITIONS FOR TUNNELING CONTRACTS

Veerasak Likhitruangsilp[1] and Photios G. Ioannou[2]

[1]Ph.D., Assistant Professor, Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand; PH (66-02) 218-6460; FAX (66-02) 251-7304; e-mail: VeerasakL@gmail.com
[2]Ph.D., Professor, Civil and Environmental Engineering Department, University of Michigan, Ann Arbor, MI, USA; PH (734) 764-3369; FAX (734) 764-4292; e-mail: photios@umich.edu

ABSTRACT

A construction contract is the primary tool for allocating risk among the contracting parties in the project, especially the owner and the contractor. Presently, many tunneling contracts are prepared by adopting or modifying standard forms of general conditions, which were not designed primarily for tunneling work, leading to contractual disputes among the parties. This paper examines risk allocation in standard forms of general conditions as applied to tunneling projects. Tunneling risk factors were first identified based on literature, analyses, and interviews with experienced tunnel engineers. We then investigated the general conditions of actual tunneling contracts, including the standard forms of general conditions prepared by the International Federation of Consulting Engineers (FIDIC) in order to analyze and compare their risk allocation schemes. The results show that some tunneling risk factors are not included, whereas some are not clearly or appropriately allocated in such contracts. The paper finally discusses some important considerations on improving the risk allocation in the standard forms of tunneling contracts based on the International Tunneling Association (ITA) recommendations.

INTRODUCTION

The construction of a tunnel is typically a large, complex, and expensive infrastructure undertaking that encompasses significant risks throughout the project's life cycle. Successful tunneling project management requires a risk management program that can identify, analyze and respond to the associated risks systematically and effectively (Altabba et al. 2004).

In most cases, the primary tool for risk allocation between the owner and the contractor is the contract for construction. Of the various contract documents, the

general conditions (or *general provisions*) *of the contract* are the main document that stipulates the contractual obligations of each party in a construction project. Instead of developing a new document, most construction projects use one of several *standard forms of general conditions* that have been developed for this purpose by professional organizations, such as the AIA, AGC, and ASCE. Project-specific modifications to the standard general conditions are issued as *supplementary conditions*. At present, the standard general conditions prepared by the International Federation of Consulting Engineers (FIDIC) are widely used in all types of construction projects. In fact, many tunneling contracts worldwide are prepared by adopting or modifying this standard form. Since these documents were not primarily designed for tunneling projects, their direct application to underground work often leads to contractual disputes among the parties (Choothom 2006; Tochaiwat 2001). This paper presents an investigation into risk allocation for tunneling projects that use standard forms of general conditions and presents possible areas for equitable improvement and the minimization of contractual disputes.

TUNNELING RISK MANAGEMENT

In general, construction risk can be defined as an exposure to the possibility of loss or gain as a consequence of a possible or an unforeseen occurrence (Carr 1989; Ioannou 1984). Tunneling risk can therefore be viewed as exposure to a favorable or an unfavorable effect on the project's cost, time, or quality that results from a possible or unforeseen incident. Underground construction involves various types of risks that do not exist or are not as important in other more conventional construction work. The primary source of risk in underground work is geologic uncertainty. Subsurface conditions cannot be identified with certainty, regardless of how sophisticated the adopted site exploration programs may be (Likhitruangsilp and Ioannou 2005). Additionally, the perceived tunneling risks are also influenced by such factors as the spatial geologic variability of subsurface conditions, uncertain ground behavior, and the contracting parties' risk sensitivity (Likhitruangsilp 2003).

The concept of risk management is commonly applied to eliminate or mitigate the impacts of risk in construction projects. A construction risk management system consists of four main interdependent components: risk identification, risk analysis, risk response, and risk monitoring and evaluation (Flanagan and Norman 1993; Smith 1999; Likhitruangsilp and Putthividhya 2008b).

Risk identification entails defining four risk components, namely, sources of risk, risk factors, risk events, and risk impact. Once risk factors have been identified, their risk impacts can be analyzed in a qualitative or quantitative manner to yield the criticality (degree) of each risk factor. An appropriate risk response method for each risk factor is then chosen based on its criticality and the decision maker's risk tolerance. Risk response methods can be categorized into four measures: risk retention, risk reduction, risk transfer, and risk avoidance. For example, the contractor may use subcontracting to transfer some critical risks to others or buy insurance to protect against undesirable risk outcomes. Risk response methods should be monitored during construction to evaluate their performance. If risks are not eliminated or mitigated as planned, the risk management system needs to be partially or entirely revised (Likhitruangsilp and Putthividhya 2008a).

The concept of risk management can be applied throughout the life cycle of a tunneling project, namely, the design phase, the bidding phase, and the construction phase. Table 1 summarizes the owner's and the contractor's risk management tasks in each phase of the project. As can be seen, both parties need to be involved in tunneling risk management. This is especially true for the owner, who usually has a leading role from the outset. Among these risk management tasks, the preparation of contract documents is usually considered the most important.

TUNNELING CONTRACTS

A construction contract is an agreement between the owner and the contractor creating rights and obligations that are enforceable or recognizable at law (Garner 2004). This set of legal documents is the primary tool for allocating risks between the owner and the contractor, and its preparation must explicitly take into account the concepts of risk management.

With the assistance of the designer or construction management professional, the preparation of tunneling contracts mainly entails understanding the owner's risk tolerance (i.e., the owner's risk attitude), identifying tunneling risks, and determining the most feasible, reasonable, and realistic approach to respond to those risks. This information is then used in allocating risks in contract documents. Likewise, the contractor needs to identify and assess potential tunneling risks, and use this information to evaluate the risk allocation in the contract documents provided by the owner before submitting its bid proposal (Abbott 1998).

Table 1. Risk management tasks for owner and contractor [Modified from Eskesen et al. (2004)]

Phase	Owner	Contractor
Design	• Establish risk policy • Perform qualitative and quantitative risk assessment • Register tunneling risk • Investigate site • Communicate results to contractors through bidding documents	
Bidding	• Prepare bidding documents, including describe significant risks • Prepare bidding documents by considering risk clauses • Select contractors, including evaluate the contractor's proposed risk management system • Request insurance certificates and bonds before notice to proceed.	• Prepare bid proposal, including risk management program
Construction	• Supervise and support the contractor's risk management program • Assess and mitigate its own risk • Verify and approve the contractor's proposed risk response methods	• Establish risk management system • Perform detailed risk assessment • Propose risk response methods • Implement risk response methods approved by the owner

The general conditions are part of construction contract documents principally stipulating the contractual obligations of each party in a construction project. Proven to be equitable and applicable, the standard forms of general conditions have been developed by various professional, business, and public organizations in the construction industry (Clough et al. 2005), including the American Institute of Architects (AIA), the Associated General Contractors of America (AGC), and the International Federation of Consulting Engineers (FIDIC). In present, the standard forms of general conditions prepared by FIDIC are widely used in various types of civil engineering projects, particularly tunneling. Many tunneling contracts, especially where tenders are invited on an international basis, are often prepared by adopting or modifying such standard forms as the Conditions of Contract for Works of Civil Engineering Construction (FIDIC 1987) and the Conditions of Contract for Construction (FIDIC 1999). Table 2 shows the main provisions of both standard forms of general conditions by FIDIC. Even though the provisions in both versions look different, their overall contents are quite similar. The Conditions of Contract for Construction (FIDIC 1999), however, seem to be friendlier for engineers who are not familiar with the legal terms used in the Conditions of Contract for Works of Civil Engineering Construction (FIDIC 1987).

Table 2. Main provisions of FIDIC standard forms of general conditions

FIDIC (1987)	FIDIC (1999)
• Definitions and Interpretation • Engineer and Engineer's Representative • Assignment and Contracting • Contract Documents • General Obligations • Labour • Materials, Plant and Workmanship • Suspension • Commencement and Delays • Defects Liability • Alterations, Additions and Omissions • Procedure of Claims • Contractor's Equipment, Temporary Works and Materials • Measurement • Provisional Sums • Nominated Subcontractors • Certificates and Payment • Remedies • Special Risks • Release from Performance • Settlement of Disputes • Notices • Default of Employer • Changes in Cost and Legislation • Currency and Rates of Exchange	• General Provisions • The Employer • The Engineer • The Contractor • Nominated Subcontractors • Staff and Labour • Plant, Materials and Workmanship • Commencement, Delays and Suspension • Tests on Completion • Employer's Taking Over • Defects Liability • Measurement and Evaluation • Variations and Adjustments • Contract Price and Payment • Termination by Employer • Suspension and Termination by Contractor • Risk and Responsibility • Insurance • Force Majeure • Claims, Disputes and Arbitration

To examine risk allocation in tunneling contracts, we analyzed the contracts for five tunneling projects located in Bangkok, Thailand, and owned by three government agencies. Table 3 shows general information about these projects and their respective owners. Our findings indicate that the general conditions for projects having the same owner were quite similar. Consequently, the general conditions for these five projects were categorized into three formats:

- Format I: General conditions based on the Standard Form of General Conditions for Government Procurement prepared by the Office of the Prime Minister of Thailand,
- Format II: General conditions modified from the Conditions of Contract for Works of Civil Engineering Construction by FIDIC, and
- Format III: General conditions mainly based on the Conditions of Contract for Works of Civil Engineering Construction by FIDIC.

Even though this paper primarily focuses on the general conditions for tunneling contracts, we also investigated other contract documents related to contractual risk allocation, including supplementary (special or particular) conditions and technical specifications.

TUNNELING RISK FACTORS

Prior to analyzing risk allocation in the three formats of general conditions, tunneling risk factors were first identified by reviewing literature [e.g., Ahmed et al. (1999); Ghosh and Jintanapakanont (2004); and Likhitruangsilp (2003)]. Analytical tools such as cause-effect diagrams, influence diagrams, and risk breakdown structures (Hillson 2002) were used to identify tunneling risk factors which were then verified by interviewing nine experienced tunnel engineers.

Figure 1 shows 34 risk factors for tunneling projects obtained from the above analyses. These tunneling risk factors can be categorized into seven groups: (1) economics, politics, and laws (2) force majeure, (3) physical and construction site, (4) project personnel, (5) construction operation and technique, (6) design, and (7) construction contract.

The tunneling risk factors shown in Figure 1 can also be categorized into two types: external factors and internal factors. The external factors include all the risk factors in Groups F1 and F2 as well as some risk factors in Group F3 (e.g., unforeseen site conditions), whereas the rest are considered internal factors.

Table 3. General information of the case studies

Information	Project 1	Project 2	Project 3	Project 4	Project 5
Type	Water Drainage Tunnel (I)	Water Drainage Tunnel (II)	Water Transmission Tunnel (I)	Water Transmission Tunnel (II)	Underground Transmission Line Tunnel
Owner	Bangkok Metropolitan Authority	Bangkok Metropolitan Authority	Metropolitan Waterworks Authority	Metropolitan Waterworks Authority	Metropolitan Electricity Authority
Duration (day)	1,440	1,440	790	730	1,430
Price (Million USD)	59.9	61.9	52.5	18.9	85.7
Inner Diameter (m)	5.00	4.60	2.80	2.50 and 2.00	2.62
Total Length (km)	5.30	6.20	17.543	3.33 and 2.70	7.00

Note: 1 USD = 35 THB (Thai Baht)

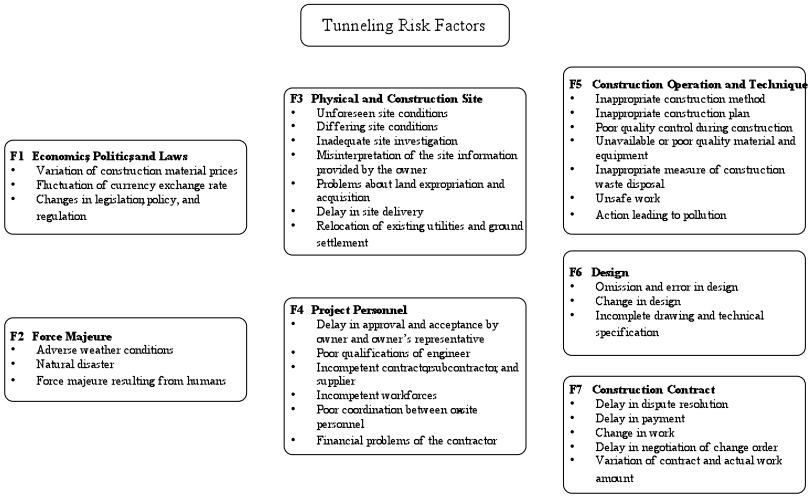


Figure 1. Categorization of tunneling risk factors

TUNNELING RISK ALLOCATION

After the tunneling risk factors had been identified, each of the tunneling contracts was analyzed to examine the allocation of risks among the contracting parties. We first determined whether or not each risk factor was stipulated in the contract documents, especially the general conditions. For the risk factors stipulated in the contract, we then identified the contracting party responsible for such risk factor. In every tunneling contract, five forms of risk allocation were found:

(1) Risk factors allocated to the owner (employer)
(2) Risk factors allocated to the contractor
(3) Risk factors shared between the owner and contractor
(4) Risk factors stipulated in the contract but with unspecified allocation, and
(5) Risk factors not stipulated in the contract documents.

Table 4 illustrates the risk allocation matrix for the three formats of tunneling contracts. As can be seen, all three formats encompass most of the tunneling risk factors. However, for Format II and Format III, which are based on the standard forms of general conditions by FIDIC, two and three risk factors, respectively, are not stipulated. These factors are *variation of construction material price* (F11), *fluctuation of currency exchange rate* (F12), and *changes in design* (F62). It should also be noted that some risk factors that are stipulated in the contract are not allocated to any contracting party, especially those in Group F7 (Construction Contract), namely, *delay in dispute resolution* (F71), *changes in work* (F73), and *delay in negotiation of change order* (F74).

Table 5 compares the results from the assessment of risk allocation in the three contractual formats. As can be expected, most tunneling risk factors are allocated to the contractor (53-65 percent), whereas only three or four risk factors (about 10 percent) are allocated to the owner. Moreover, there are a significant number of risk factors (eight risk factors in Format I and six risk factors in Formats II and III) that are either not stipulated in the contract documents at all, or stipulated in the contract without being allocated to any contracting party. To avoid any contractual dispute during construction, both issues need to be addressed while preparing the contract.

Table 4. Risk allocation matrix for three formats of tunneling contracts

Group	Code	Risk Factors	Contractual Risk Allocation		
			Format I	Format II	Format III
F1		Economics, Politics, and Laws			
	F11	Variation of construction material price	S	S	-
	F12	Fluctuation of currency exchange rate	-	-	C
	F13	Changes in legislation, policy, and regulation	C	C	C
F2		Force Majeure			
	F21	Adverse weather condition	S	S	S
	F22	Natural disaster	S	S	S
	F23	Force majeure resulting from humans (e.g., war, revolution, or civil disorder)	S	S	S
F3		Physical and Construction Site			
	F31	Unforeseen site conditions	-	C	C
	F32	Differing site conditions	C	C	C
	F33	Inadequate site investigation	C	C	C
	F34	Misinterpretation of the site information provided by the owner	-	C	C
	F35	Problems about land expropriation and acquisition	C	C	C
	F36	Delay in site delivery	C	S	-
	F37	Relocation of existing utilities and ground settlement	C	C	C
F4		Project Personnel			
	F41	Delay in approval and acceptance by owner or owner's representative	E	E	E
	F42	Poor qualifcations of engineer	E	E	E
	F43	Incompetent contractor, subcontractor, and supplier	C	C	C
	F44	Incompetent workforces	C	C	C
	F45	Poor coordination between on-site personnel	-	C	C
	F46	Financial problems of the contractor	C	C	C
F5		Construction Operation and Technique			
	F51	Inappropriate construction method	C	C	C
	F52	Inappropriate construction plan	C	C	C
	F53	Poor quality control during construction	C	C	C
	F54	Unavailabe or poor quality material and equipment	C	C	C
	F55	Inappropriate measure of construction waste disposal	C	C	C
	F56	Unsafe work	C	C	C
	F57	Action leading to pollution	C	C	C
F6		Design			
	F61	Omission and error in design	C	E	C
	F62	Change in design	-	-	-
	F63	Incomplete drawing and technical specification	C	I	C
F7		Construction Contract			
	F71	Delay in dispute resolution	I	I	I
	F72	Delay in payment	E	E	E
	F73	Change in work	I	I	I
	F74	Delay in negotiation of change order	I	I	I
	F75	Variation of contract and actual work amount	S	C	C

Note: E = Employer's risk factor
C = Contractor's risk factor
S = Risk factor shared between the Employer and Contractor
I = Risk factor stipuated in the contract without specifying allocation
- = Risk not stipuated in the contract

Table 5. Comparison of risk allocation in three formats of contracts

Risk Allocation	Number of Risk Factors		
	Format I	Format II	Format III
Risk factors stipulated in the contract			
Owner	3	4	3
Contractor	18	19	22
Share	5	5	3
Not stipulating risk allocation	3	4	3
Risk factors not stipulated in the contract	5	2	3
Total	**34**	**34**	**34**

RECOMMENDATIONS ON TUNNELING RISK ALLOCATION

The International Tunnelling Association (ITA) established a working group for contractual sharing of risks in 1977. Its main tasks were examining the means by which underground construction risks are customarily shared and making recommendations to promote more equitable and efficient risk sharing. A total of 25 recommendations were summarized and published in several reports such as ITA (1988, 1990, 1992a, 1992b). A comparison of contractual risk allocation practices in our case studies with ITA recommendations revealed several discrepancies, especially for risk factors in Group F3 (physical and construction site). ITA recommends that several risk factors in Group F3 be shared between the owner and the contractor, namely, unforeseen site conditions (F31), differing site conditions (F32), and inadequate site investigation (F33). However, the tunneling contracts in all case studies assign these risk factors to the contractor, as shown in Table 4. Such contractual risk sharing practices certainly do not benefit the owner because the owner must pay a large amount of contingency sums the contractor includes in the bid price to cover its risk of encountering adverse ground conditions, even though normal ground conditions might actually prevail during construction. Detailed discussions on the other recommendations can be found in Choothom (2006).

CONCLUSION

This paper presents risk allocation practices for tunneling contracts that adopt or modify standard forms of general conditions. Thirty-four tunneling risk factors were identified and categorized into seven groups. The actual construction contracts for five tunneling projects were analyzed to investigate how risk factors were allocated to the contracting parties. The results show that some tunneling risk factors were omitted from the contract documents, some were not allocated to any party, and some were allocated inappropriately. These results can assist owners, designers, and contractors to prepare better contract documents and allocate tunneling risks equitably.

ACKNOWLEDGMENTS

The authors wish to thank Ms. Sudarat Choothom for assisting in preparing this paper and Chulalongkorn University for financially supporting the work presented here.

Any opinions, findings, conclusions, or recommendations in this paper are those of the authors and do not reflect the views of the grantor.

REFERENCES

Abbott, E. L. (1998). Subsurface Conditions: Risk Management for Design and Construction Management Professionals. Chapter 4 Preparation of Contract Documents for Subsurface Projects, John Wiley & Sons, Inc., USA.

Ahmed, S. M., Ahmad, R., and Saram, D. D. (1999). "Risk Management Trends in the Hong Kong Construction Industry: A Comparison of Contractors and Owners' Perceptions." Engineering, Construction and Architectural Management, 6(3), 225-234.

Altabba, B., Einstein, H., and Caspe, H. (2004). "An Economic Approach to Risk Management for Tunnels." Proc. of the North American Tunneling Conference 2004, April 17-22, 2004, Atlanta, Georgia, USA.

Carr, R. I. (1989). "Cost Estimating Principles." Journal of Construction Engineering and Management, ASCE, 115(4), 545-551.

Choothom, S. (2006). "Risk Allocation in Tunneling Contracts Using Tunnel Boring Machines," thesis submitted to Chulalongkorn University, Bangkok, Thailand, in partial fulfillment of the requirements for the degree of Master of Engineering in Civil Engineering (in Thai).

Clough, R. H., Sears, G. A., and Sears, S. K. (2005). Construction Contracting (seventh edition). John Wiley & Sons, USA.

Eskesen, S. D., Tengborg, P., Kampmann, J., and Veicherts, T. H. (2004). "Guidelines for Tunnelling Risk Management: International Tunnelling Association, Working Group No. 2." Tunnelling and Underground Space Technology, 19(2004), 217-237.

Flanagan, R., and Norman, G. (1993). Risk Management and Construction. Blackwell Scientific Publications, Great Britain.

Garner, B. A., Editor in Chief (2004). Black's Law Dictionary (eighth edition). Thomson, USA.

Ghosh, S., and Jintananpakanont, J. (2004). "Identifying and Assessing the Critical Risk Factors in an Underground Rail in Thailand: A Factor Analysis Approach." International Journal of Project Management, 22, 633-643.

Hillson, D. (2002). "Use a Risk Breakdown Structure (RBS) to Understand Your Risks." Proc. of the Project Management Institute Annual Seminars & Symposium, October 3-10, 2002, San Antonio, Texas, USA.

International Federation of Consulting Engineers: FIDIC (1987). Conditions of Contract for Works of Civil Engineering Construction (fourth edition). Lausanne, Switzerland.

International Federation of Consulting Engineers: FIDIC (1999). Conditions of Contract for Construction for Building and Engineering Works Designed by the Employer. Lausanne, Switzerland.

Ioannou, P. G. (1984). "The Economic Value of Geologic Exploration as a Risk Reduction Strategy in Underground Construction," thesis presented to the Massachusetts Institute of Technology, at Cambridge, MA, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

ITA Working Group on Contractual Sharing of Risks (1988). "ITA Recommendations on Contractual Sharing of Risk (Propositions I to XIX)." Tunnelling and Underground Space Technology, 3(2), 103-140.

ITA Working Group on Contractual Sharing of Risks (1990). "ITA Recommendations on Contractual Sharing of Risk (Recommendations XX and XXI)." Tunnelling and Underground Space Technology, 5(4), 337-341.

ITA Working Group on Contractual Sharing of Risks (1992a). "ITA Recommendations on Contractual Sharing of Risk (Recommendations XXII and XXIIII)." Tunnelling and Underground Space Technology, 7(1), 5-8.

ITA Working Group on Contractual Sharing of Risks (1992b). "ITA Recommendations on Contractual Sharing of Risk (Recommendations XXIV and XXV)." Tunnelling and Underground Space Technology, 7(4), 393-397.

Likhitruangsilp, V. (2003). "A Risk-Based Dynamic Decision Support System for Tunnel Construction," thesis presented to the University of Michigan, at Ann Arbor, MI., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Likhitruangsilp, V., and Ioannou, P. G. (2005). "Economic Assessment of Site Exploration Programs Using Stochastic Dynamic Programming." Proc. of Construction Research Congress 2005, April 5-7, 2005. San Diego, CA, USA.

Likhitruangsilp, V., and Putthividhya, A. (2008a). "Preliminary Groundwater Risk Assessment Framework: A Case Study of Groundwater Contamination in Thailand." Proc. of the 12th International Conference on Integrated Diffuse Pollution Management (IWA DIPCON) 2008, August 25-29, 2008, Khon Kaen, Thailand.

Likhitruangsilp, V., and Putthividhya, A. (2008b). "A Risk-Based Decision Support System for Groundwater Remediation." Proc. of the XXXVI Integrating Groundwater Science and Human Well-Being (IAH) Congress 2008, October 28-November 1, 2008, Toyama, Japan.

Smith, N. J., Editor (1999). Managing Risk in Construction Projects. Blackwell Science, Great Britain.

Tochaiwat, K. (2001). "A Study of FIDIC Contract Applicability in Thai Construction Industry," thesis submitted to Chulalongkorn University, Bangkok, Thailand, in partial fulfillment of the requirements for the degree of Master of Engineering in Civil Engineering (in Thai).

TRENCHLESS IN ANCHORAGE – CASE STUDIES

Michelle Ramos, P.E.[1], Brian Gastrock, P.E.[2]

[1] Staheli Trenchless Consultants, Bothell, Washington
[2] Stephl Engineering, LLC, Anchorage, Alaska

1. ABSTRACT

This paper presents case studies involving trenchless construction in Anchorage, Alaska. Like many cities around the nation, Anchorage is growing beyond the capacity of their infrastructure. Much of the infrastructure for downtown Anchorage was installed in the early 1900's and is in need of repair or replacement. Because the city has grown and developed around the infrastructure, it is difficult to repair or replace the utilities using conventional open-cut construction.

The following case histories highlight different trenchless technologies and how the technologies are being applied within Anchorage. The trenchless technologies include horizontal directional drilling (HDD), sliplining, Cured-in-Place Pipe (CIPP) and guided boring (also known as pilot tube microtunneling).

One project involved installation of over 1,100 feet of water line within a narrow utility-congested alley. Guided boring or pilot tube microtunneling (PTMT), was specified by the design engineer and was modified during construction by the contractor. The contractor proposed a hybrid PTMT and HDD installation method that utilized the pilot phase of PTMT with the reaming and pullback phases of HDD. The case history will detail the project design, the intent of the engineer, and how the contractor-made modifications to the design performed during construction.

An HDD case history is discussed involving installation of an approximately 280-foot HDD up a steep slope to install a 10-inch sewer line.

Other projects will discuss the state of Cured-in-Place Pipe (CIPP) in Anchorage with case histories involving over 1,300-feet of 10-inch sewer re-lining and over 2,300 feet of 24-inch sewer line relining in downtown Anchorage. The latter of the two projects also included a 620-foot HDD crossing of a salmon-bearing stream by a 10-inch water main. A slip lining project will also be reviewed. This project is currently in construction with 1,450 feet of 21-inch CMP sewer line being sliplined with 14-inch HDPE. The project is located in wetlands, along a small tributary stream with some locations buried beneath 20 feet of backfill.

2. INTRODUCTION

Similar to many cities, portions of the utility pipelines in and around the city of Anchorage are undersized for the current population or are beyond their useful design life. Because many of these pipelines were installed before the city grew up around them or when there were fewer surface conflicts, they are often difficult to access for open-cut replacement. Additionally, many fish-bearing drainages cut through Anchorage, which limit open-cut applications. As such, trenchless technologies are being more and more utilized for renovation or replacement of water and sewer pipelines.

This paper will discuss four trenchless case histories located at various project sites across Anchorage (see Figure 1).



Figure 1: Vicinity Map

3. G/H ALLEY PROJECT

Project Summary:

Existing Pipe : 6-inch wire-wrapped wood stave pipe

New Pipe: 8-inch DR-11 HDPE pipe (OD 10.75 inch), 1158 feet long (3 runs)

Installation Method: Guided Boring/PTMT and HDD Hybrid

3.1 BACKGROUND

This project was severely constrained by existing utilities and home accesses. The residences in this area all face the main streets (G Street and H Street) with driveway access through the rear alley. The alley contains utility main lines and service lines, including an existing 6-inch diameter wire-wrapped wood stave pipe that has

experienced recent failures (Figure 2).

Anchorage Water and Wastewater Utility needed to install a new 8-inch diameter pipe along the G/H Alley right-of-way (r.o.w.) to replace the existing wood stave pipe. The r.o.w. is only 20 feet wide, is the main access for the homes along the alley, and contains four below-grade utilities as well as overhead power. The water line is located 10 to 11 feet below grade. Various trenchless construction options including HDD, auger boring, pipe bursting and PTMT were considered due to the



Figure 2: Wire-wrapped wood stave pipe

presence of many utilities, the lack of available room within the narrow r.o.w. to perform open-cut work, and the regular use of the alley by neighboring residents.

The soil was reported to be poorly graded sand with gravel at the depth of the waterline. No groundwater was reported.

3.2 TRENCHLESS ALTERNATIVES AND FEASIBILITY

Pipe bursting, HDD, auger boring, and PTMT were considered to replace the existing 6-inch wire-wrapped wood stave pipe.

Pipe bursting was eliminated as it is known to be incompatible with wire-wrapped wood stave pipe. The wire wraps around the bursting head creating "bird-nests" making the bursting head ineffectual. A static bursting test project done in Anchorage in 2004 on a similar wood stave pipe was not successful due to wire binding and was abandoned. The wire-wrapping of the wood stave pipe combined with the small diameter of the host pipe, the competent soil around the pipe and the required upsize of the pipe all indicated a low likelihood of success.

HDD was also considered to replace the existing water line. However, because of both the line and grade control needed to install the water line in close proximity to the other utilities in the r.o.w. and the frac-out potential, HDD was not selected as the preferred construction method for this project.

Replacement of the water line by auger boring construction was also considered for this project. However, because the alley contains many utilities, there was insufficient space to install the size jacking and receiving pits required without temporarily relocating many of the existing utilities. A significant constraint imposed by one of the utilities would have required a complete replacement of the entire length of their pipeline for any portion moved, therefore, auger boring was not chosen as the best trenchless option for this project.

PTMT uses a small diameter, displacement pilot head with a guidance system to achieve precise line and grade. It is typically used to install concrete, clay, polycrete, or steel pipe. PTMT uses a compact jacking unit to install a small diameter steerable pilot bore from the jacking shaft to the reception shaft. The shafts are much smaller than commonly used for auger boring. Once the pilot bore is installed to the reception shaft, short pieces of casing with internal augers are advanced along the pilot bore path. The pilot bore rods are removed from the reception shaft as casing is advanced from the launch shaft. Product pipe is installed from the launch shaft as casing is removed at the reception shaft.

The ground and groundwater conditions were favorable for PTMT since the soils were competent and above the water table. Line and grade control tolerances are generally about ½-inch over 300 feet.

3.3 RECOMMENDED TRENCHLESS OPTION

As HDPE pipe does not respond well to compression, we recommended pulling HDPE pipe into place using the casing pipe as a pulling head (also known as "hybrid PTMT").

After the casing is pushed to the reception shaft, the HDPE product pipe is attached to the casing and pulled back to the insertion pit. The larger diameter bore left by the casing allows for the HDPE pipe to be pulled in without exceeding its load rating. The hybrid method requires fusing the entire HDPE pipe string together prior to commencing pullback. In order to accommodate the bend radius of the HDPE pipe, a narrow "runway" is needed to insert the HDPE pipe into the reception shaft. Typically the width of the runway is about 2 feet.

For up to about 10-inch diameter pipe, bore lengths can exceed 500 feet. Because of the limited overcut of the auger head, the lack of pressurized drilling fluid and the tight installation tolerances, pipelines can be installed by PTMT in close proximity to other utilities and without frac-out concern. As such, hybrid PTMT was recommended to install the new 10-inch diameter water line.

3.4 CONSTRUCTION

This project was constructed in the summer of 2008. The contractor proposed an alternative construction process in which the pilot bore was installed on line and grade using a guided boring system (Figure 3). Once the pilot bore was established, a surface mounted HDD rig drilled to the reception pit and connected to a horizontal directional drill stem that had been pulled back through the pilot bore (Figure 4). A reamer was attached at the launch pit, and the alignment was back reamed and forward reamed using the HDD rig (Figure 5). Once the bore was reamed to 15



Figure 3: Guided Boring Machine



Figure 4: HDD rod coming out of pit

inches, the pre-fused HDPE pipe was pulled into the bore using the HDD rig (Figure 6). This allowed the contractor to ensure line and grade using the guided boring



Figure 5: HDD rig set-up



Figure 6: Pulling in HDPE pipe

system. Once line and grade was set, the guided boring system was free to move onto the next run. Typically with PTMT, the slowest part is the excavation and advancement of the casing. By switching over to the HDD system for reaming and pullback, the contractor was able to speed up these steps.

4. GAMBELL CIPP AND HDD PROJECT

Project Summary:

Existing Pipe: 24-inch (sewer) and 8-inch (water) ductile iron pipe

New Pipe: 2,400 feet of 16.5mm resin-impregnated felt & 600 feet of 10-inch HDPE

Installation Method: Combination of CIPP and HDD

4.1 BACKGROUND

The project was located in an area of high traffic and public use. Open cut, removal and replacement of the pipe was not recommended due to the impacts to the public use of the adjacent facilities. The surrounding buildings were used for conventions, college hockey games, and high school football games. The sewer pipe crossed the parking lot for the facilities, along with a major roadway artery (Figure 7).

The original pipe was installed in the late 1970's and the project was needed because of severe corrosion. The existing water main crossing Chester Creek was known to have holes, and had been abandoned, closing off the loop. Anchorage Water and Wastewater Utility (AWWU) needed to install a water main under the creek to re-connect the loop to ensure adequate water service. Additionally, the potential for pipe failure due to the corrosion of the sewer main needed to be addressed. The pipe had been inspected and was found to have severe external pitting. AWWU needed to rehabilitate the sewer main across the roadway and through the parking lot.

The soils in the areas were reported to be sands and gravels with silts, along with areas of organics and a dense clay layer near the creek. The water table varied along the project from 4 to 12 feet below the ground surface

4.2 TRENCHLESS ALTERNATIVES AND FEASIBILITY

Open-cut remove and replace, sliplining, and CIPP were considered to rehabilitate the existing sewer. HDD, auger boring and CIPP were considered for the replacement or rehabilitation of the water main.

For the sewer main, open-cut remove and replace was eliminated due to the potential impacts to the surrounding facilities and the crossing of Chester Creek. Chester Creek is a fish-bearing stream. Coordinating the work with the public facilities and the agencies for the creek crossing made the project cost prohibitive.

Sliplining of the sewer main was eliminated due to the cost and potential impacts to the facilities. The insertion pits would have needed to be in areas of high traffic, making this alternative infeasible.

For the water main, CIPP was eliminated due to the higher cost and not knowing the exact condition of the existing pipe. If the pipe was collapsed, the CIPP alternative would not have been possible.

4.3 RECOMMENDED TRENCHLESS OPTION

For this project, CIPP of the existing 24-inch sewer main and HDD for the new 10-inch HDPE water main were chosen because of the minimal surface impacts and time of construction. Additionally the products' resistance to corrosion helped to ensure a longer design life of the pipelines.

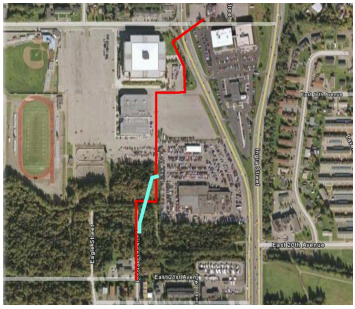


Figure 7: Project alignment



Figure 8: HDD rig set-up

4.4 CONSTRUCTION

This project was constructed in the later summer through fall of 2007. The contractor was able to install the HDD under Chester Creek per the design, and within the anticipated schedule (Figure 8).

The CIPP was installed per the design, with the exception of a curing malfunction that occurred in the pipe segment the crossed Chester Creek. Because of the over capacity of the pipe, the Contractor was able to re-install a custom CIPP liner that was reduced in inside diameter, but still met the design requirements.

5. C-5-1 SLIPLINING PROJECT

Project Summary:

Existing Pipe : 21-inch corrugated metal pipe

New Pipe: 1,450 feet of 14-inch HDPE in two segments

Installation Method: Sliplining

5.1 BACKGROUND

The project consisted of approximately 1,450 feet of 21-inch corrugated metal pipe (CMP) that generally follows an unnamed tributary that feeds Campbell Lake. The pipe is located at varying depths ranging from 10 to 20 or more feet. The pipe was originally designed to convey more flow than current conditions, but the flows were diverted to a larger sewer main in the 1970's. The reduced flow rates, along with significant humps and bellies caused problematic flow characteristics in the pipe



Figure 3: Manhole condition

(Figure 9). Additionally, the existing pipe showed signs of collapse, indicated by ovality in the pipe and offset joints.

The proximity of the tributary and wetlands along with the depth of backfill over the pipe required AWWU to consider a trenchless alternative to rehabilitate the existing sewer main.

The soil varied along the alignment, but was generally silty sands overlaying clays, with the water table generally between 7 and 11 feet below the ground surface.

5.2 TRENCHLESS ALTERNATIVES AND FEASIBILITY

CIPP and sliplining were considered to rehabilitated the existing 21-inch CMP. However, CIPP was eliminated due to the over-capacity of the existing pipe, along with the estimated construction costs of CIPP in that diameter.

5.3 RECOMMENDED TRENCHLESS OPTION

Sliplining was the preferred alternative because of the anticipated construction cost and the reduction of the pipe diameter to improve the flow characteristics.

Sliplining is a method where an insertion pit is excavated and an HDPE pipe is pulled, pushed, or a combination of both to install the smaller pipe inside the existing host pipe. The annular space between the new HDPE and the original host pipe is then filled with a grout mixture to support the HDPE from collapse.

Sliplining can be done in longer lengths, depending on the angle of the pipe through manholes. For the C-5-1 project, the design used one excavation pit, located approximately two-thirds of the way along the alignment. This then required only one excavation, thus minimizing the surface impacts.

This project is scheduled for construction in early spring 2009.

6. GOVERNMENT HILL SEWER PROJECT

Project Summary:

New Pipe: 280 feet long (modified to 195’ by the contractor), 10-inch DR 11 HDPE pipe

Installation Method: HDD

6.1 BACKGROUND

The purpose of the Government Hill Sewer project was to consolidate two sanitary sewer lines into a single 10-inch O.D. (nominal 8 inch I.D.) HDPE pipe. This pipe will carry effluent halfway down a steep slope to an existing main sewer line which continues parallel to the slope to wastewater treatment facilities. The steep slope was of particular concern since portions of the slope to the north-west had slid during the 1964 Good Friday Anchorage earthquake.

6.2 TRENCHLESS ALTERNATIVES AND FEASIBILITY

Both auger boring and HDD were considered for this project. However, due to the availability of staging area for setting up equipment, slope of the installation and the potential for perched groundwater, auger boring was ruled out in favor of HDD.

To facilitate HDD installation, reaming, and spoils excavation, the design called for HDD construction to commence at the bottom of the slope with pipe fusing and layout in an open space at the top of the slope.

6.3 CONSTRUCTION

The contractor proposed a number of design modifications during the submittal process. He proposed drilling from the top of the hill, excavating the manhole location prior to HDD drilling, and modifying the slope of the drill path to reduce the depth of the manhole (MH) excavation. While this increased the risk of difficulties during pipe pullback through a dry bore, it decreased the mud pressure within the borehole by essentially providing an intermediate mud pit at the MH location and reducing the length of reaming and pullback to 195 feet from the design length of 280 feet. Other complexities regarding the contractor's proposed design modifications



Figure 4: HDD drill rig set-up

arose from pipe handling and layout area on the steep slope and setting up the drill rig in tight quarters (Figure 10).

Pilot bore construction started on August 18th. The 105 foot pilot bore from the entrance to the MH excavation was completed in 2 hours. On August 19th, the pilot bore from the MH excavation to the exit location was completed in approximately 3 hours. No frac-outs or inadvertent returns were observed between the MH and the exit location. A small frac-out occurred near the drill rig but was cleaned up and did not impact the remainder of the drilling. Once the pilot bore was complete, a 16-inch reamer was attached at the exit location and back reamed (Figure 11). The bore hole was back reamed and forward reamed with mud returns exiting into the prepared pit at the bottom of the bore. Spoils were continuously removed by vac-truck stationed at the bottom of the steep slope with over 100 feet of flexible hose running from the pit to the vac-truck. The back ream and forward ream were completed in approximately 3 hours.



Figure 5: Reamer attached to drill rods

Once the pipe was fused, it was moved into position. Due to the steepness of the slope, moving the pipe into position was challenging. Once pullback started, it took 36 minutes to complete. The driller averaged 2 minutes per 10' drill rod while continuously pumping mud into the dry bore. The average pullback force was 8,000 pounds except for one instance when the driller stopped pullback to wait for mud. Pipe pullback was stopped for about 4 minutes and the pullback force increased to 12,000 pounds. Pipe pullback continued without complications. Mud flow continued down hill until the pipe was within 40 feet of the MH excavation.

7. CONCLUSIONS

Use of trenchless technologies in Alaska is growing in number and complexity. As the city expands, the infrastructure ages and the comfort-level with trenchless technology increases, there will be more call for this technology.

INTEGRATED SIMULATION-BASED SCHEDULING FOR MODULE ASSEMBLY YARD

H. Taghaddos[1]; S. AbouRizk[2]; Y. Mohamed[3]; R. Hermann[4]

Abstract

Producing a schedule for industrial construction that optimizes resource utilization and meets the delivery dates of competing projects is a complicated task. The scheduler must consider several constraints and uncertainties including limited space, crew skill, and shipment processes in the module yard. This paper presents an integrated simulation-based scheduling framework that pulls the data from a database interface, runs the simulation model, and provides different graphical reports to the user. Although this model has been implemented successfully in the industry, some challenges are not yet solved. A distributed simulation system using High Level Architecture (HLA) is proposed to break down the simulation into a number of components to enhance the performance of the system. This system also helps to reuse these components in future projects and to facilitate the expansion of the model, enabling more complicated process simulations.

Keywords: Construction simulation; resource constraint; construction scheduling; module yard planning; High Level Architecture

1. Introduction

Simulation modeling has become a reputable tool for managing resources in the planning and execution phases of construction projects. Simulation is not just a tool to mimic the real world, but it is also a powerful technique for developing production

[1] PhD Student, Department of Civil & Environmental Engineering, Hole School of Construction, University of Alberta, Edmonton, AB, Canada; PH (780) 492-8096; FAX (780) 492-0249; e-mail: hosein@ualberta.ca
[2] Professor, Department of Civil & Environmental Engineering, University of Alberta, Edmonton, AB. Canada T6G 2W2; PH (780) 492-8999; FAX (780) 492-0249; e-mail: abourizk@ualberta.ca
[3] Assistant Professor, Department of Civil & Environmental Engineering, Hole School of Construction, University of Alberta, Edmonton, AB, Canada; PH (780) 492-1321; FAX (780) 492-0249; e-mail: ymohamed@construction.ualberta.ca
[4] Senior Construction Engineer, PCL Industrial Management Inc., 5404-99 ST, Edmonton, AB. Canada; PH (780) 733-5514; e-mail: RHHermann@pcl.com

schedules (Gupta and Sivakumar 2002). This paper presents a simulation-based scheduling (SBS) approach for pipe spool module assembly, which represents a multi-unit industrial construction project. Developing a realistic schedule for a module assembly yard that satisfies the project constraints and uncertainties is a complicated task. The schedule must also reflect changes in the supply date of materials coming from the fabrication shop and other suppliers. There are many other uncertain factors affecting the schedule such as weather conditions and changes in the desired delivery dates based on field progress.

The SBS model has been developed based on an actual case study for PCL Industrial in Edmonton, Alberta. This model provides an interface in Microsoft Access for reading the input data, including project specifications, constraints, and heuristic rules. The model is both a scheduling system and a tracking system; i.e. the model feeds actual data into the database as the project is progressing. A discrete event simulation model simulates the overall process and generates various graphical output data, including module location and resource utilization, which enable the analysis of pertinent decisions.

Although this model has been implemented successfully in the industry, we have further ambitions to expand its flexibilityl. High Level Architecture (HLA) is proposed to break the simulation into a number of smaller components. This strategy is very useful for linking the simulation model of the module yard to that of the fabrication shop. Currently, these models work separately and the link must be created manually. Moreover, the developed components can be reused in future projects.

2. Module Assembly

Modular construction has become very popular in the Alberta oil sands region. It not only minimizes the time and cost to construct on site in northern Alberta's harsh weather conditions, but also improves the safety and quality of the project (SCHIMMOLLER 1998; Burke and Miller 1998; Maru and Kawahata 2002). In construction, a "module" refers to a unit that can easily be connected to make a structure (i.e. refineries and oil-processing plants, building). It is usually made of pre-assembled components such as structural steel frames, racks of pipes, cables, equipment, or a combination of miscellaneous components. Its dimension is designed to fit in a truck for transfer to the construction site (Davila Borrego 2004; Mohamed et al. 2007).

Every module represents a unique construction project with its own internal design and components. Pipe spool modules are usually assembled off-site in the module assembly yard near spool fabrication areas. A typical module yard is divided into a number of areas, which are called "lots." Each lot is composed of a number of rows, which are called "bays," and each module occupies a fraction of a bay. The assembly process can be started whenever the required components are prepared by the fabrication shop and supply changes in the module yard (Taghaddos et al. 2008). The assembly process starts by locating a suitable space in the yard. Then, a number of activities must take place to finish the assembly process.

3. Scheduling Module Assembly Yard

Scheduling the module assembly yard involves a number of uncertain factors and constraints. Each module cannot be started earlier than a given date based on the availability of spools and other required equipment. It should be also delivered by a certain date depending on the client request and progress in the field. These dates vary according to the capacity of the fabrication shop and the other supply changes. The scheduler should also consider the limited amount of resources in the yard (i.e. space, skilled crew, crane, trucks).

A typical module assembly yard may contain a few hundred modules when it faces a high workload. Scheduling the module assembly in the yard with CPM-based techniques is a tedious exercise. More importantly, adjusting the schedule because of any changes in the progress of the work or resource availability is very difficult. Finally, it does not provide a flexible model for optimization purposes such as resource leveling or shipping based only on time (Mohamed et al. 2007). In this paper, a simulation-based approach is introduced for scheduling and tracking the processes in the module assembly yard. The input data is provided through a database interface, developed in Microsoft Access 2007 (Figure 1).

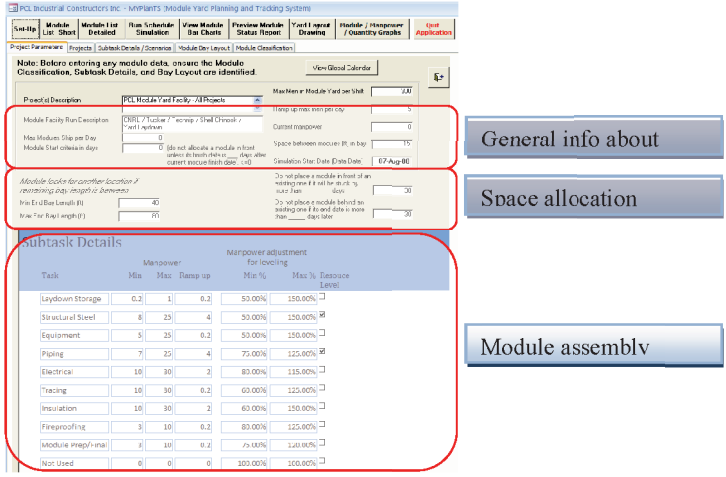


Figure 1. Scheduling and tracking in Microsoft Access

3.01 Database interface

The user interface has been provided in database interface by using VBA language. The "Set Up" menu contains information about the simulation parameters, projects, scenarios, layout (i.e. number of bays, their size and location) and classification of modules. The user must define general information about simulation, space allocation parameters, and module assembly as the required parameters (Figure 2). Module assembly parameters include the list of the activities and the range of crew in the

yards. Ramp up determines the maximum amount of people that the company can hire to reach the maximum number of resources.

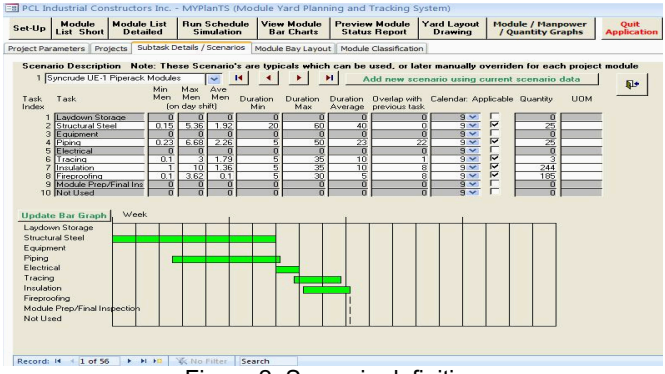


Figure 2. Scenario definition

Figure 3 shows other required information that the user must provide, such as module dimensions, lot order, and preferred bay. Lot order determines the order of preference in allocating the module in different lots. For example, the superintendent may prefer to send pipe rack modules to lot A, and if there is not enough space available in lot A, then send them to lot B, and so on. The system also has the flexibility to define a number of bays in a group and force the simulation model to allocate the module in that group. The other flexibility of this system is that we can activate the lots for a specific period (Figure 4). This feature is beneficial for taking into account the future expansion of the yard.

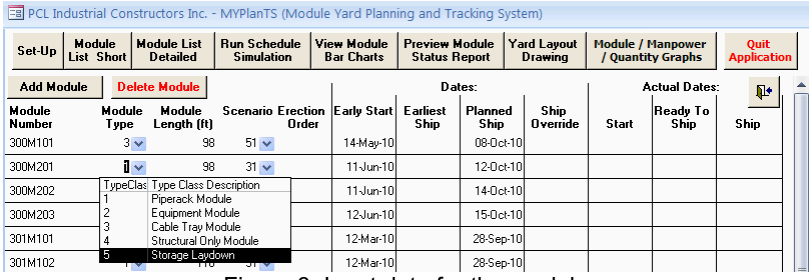


Figure 3. Input data for the module

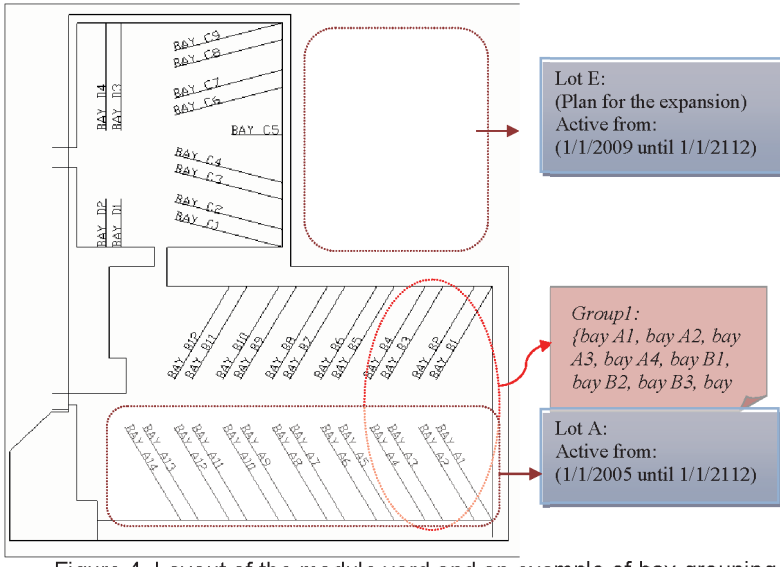


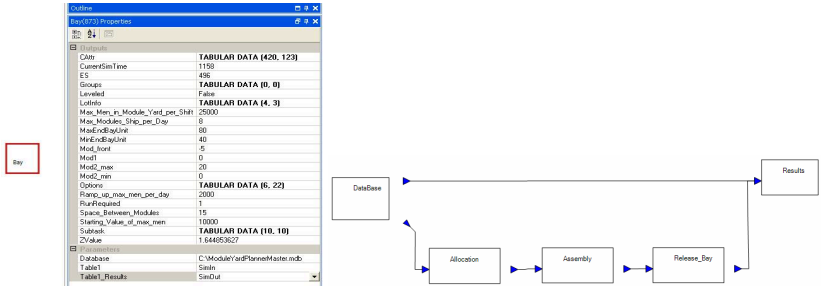
Figure 4. Layout of the module yard and an example of bay grouping

3.02 Simulation model

The discrete-event simulation model in this study is developed within the Simphony.NET (version 1.1.3.11) simulation environment (AbouRizk and Hajjar 1998). *Simphony* allows a developer to build hierarchical models using a language similar to VB.Net. In the developed model, the parent element (Figure 5a) reads the required data from the Access database and provides access to the data for all the elements in the child level. The simulation model assigns resources (i.e. space, skilled crew, truck) based on a minimum slack algorithm (Russell and Norvig 2003). This method is an heuristic planning method used for job shop scheduling with a resource constraint. This method gives priority to the task with the least remaining slack and then updates the slack of all other tasks. The priority in this approach is defined by the free float of the activities (Davila Borrego 2004; Mohamed et al. 2007).

The logic of the entire simulation model is depicted in Figure 5b. First, the model reads the required information from the database; then, an entity (corresponding to a module) with an initial priority is produced at the early start time (or actual start time) of each module. The initial priority of the modules is calculated according to their free float—planned ship date minus early start date minus duration. If the module is already completed, the corresponding entity is sent directly to the last element to populate the results into the database. Otherwise, the entity is sent to the Space Allocation, Assembly, and Release elements, consecutively.

In Space Allocation elements, the time and space criteria are defined as two heuristic rules to optimize the use of space. The time criterion is needed to place modules in order so that a module is not trapped by another module because of its late finish date.



a) Parent level b) Child level Figure 5. Simulation model

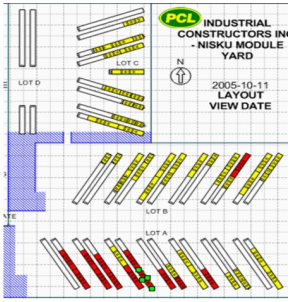
This criterion is satisfied by having a rough estimate of the finish time of the modules in the bay, and putting the modules that will be finished later behind the other modules that will be finished earlier. However, the finish time at the space allocation phase is just an estimate, and it will change according the resource limitations. The space criterion places modules so that remaining space in the back of the bay will be small enough (i.e. less than 20 feet) or big enough to place another module in the back of the bay (i.e. more than 80 feet). However, if no space is found according to the space criteria, it will be ignored. These two criteria help to improve the space utilization in the yard.

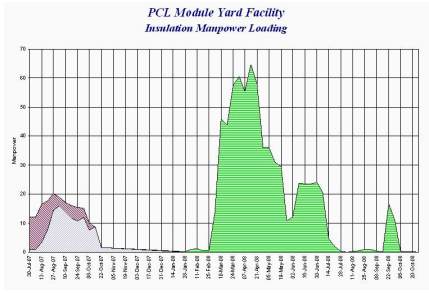
In Assembly elements, a number of activities with specific durations and manpower are performed. First the early start dates of activities are estimated according to the Critical Path Method (CPM) without considering the resource limitation. If the required skilled crew for the first activity is available, the first activity starts, and the second task is scheduled. Otherwise, the module waits in the queue until enough resources become available. As the module waits in the queue, its priority increases accordingly.

After performing all the required activities, the module waits be shipped. However, the space in front of the module should be empty in order to ship the module by truck. For some specific modules, the superintendent may allow the module to be shipped by crane, even if the space in front of the bay is not empty. If the number of requests for shipment are less than the available trucks per day, the module must be shipped and the space in the bay is released. Otherwise, modules with lower priority have to wait to be shipped on the next day.

3.03 Graphical output

When the simulation model finishes its run and populates the data into the database, the results are presented to the user in various formats. The user can see the allocation of the module in the yard at any point of time (Figure 6a). He/she also can compare the planned shipping date of the module with the simulation finish date. Moreover, a number of reports are provided for the company, including loading report for the total manpower and skilled crew in different disciplines as well as the loading reports of the modules (Figure 6b). The scheduler should play with the model, modify its parameters, and simulate new scenarios to reach the most favorable results.





a) modules location in the yard b) resources utilization

Figure 6. Graphical output data

3.04 Limitations

Shortage of skilled crew members is a key issue for the Alberta construction industry. Therefore, optimizing human resource utilization is vital for managers. Resource leveling is one of the main challenges of multi-unit projects. In this method, a two-pass discrete-event simulation method is employed to level the utilization of resources (Taghaddos et al. 2008). Although this heuristic approach produces significant improvement in the results, the results can still be improved by employing intelligent agent theory for resource allocation in the next phase of this project.

The other challenge of this project is to link the simulation model of the module yard to the simulation model of the fabrication shop. In practice, a module assembly process in the module yard starts whenever the required components are fabricated in the shop. Currently, these two models work independently, although the shop and yard belong to the same company. The scheduler has to link them manually and re-enter the changes whenever there is a delay in the fabrication shop.

4. Distributed Simulation System Using HLA

The described model has been developed in the industry, and our partner company is impressed by the results. However, we have ambitions to expand the flexibility of the model by employing HLA to develop an independent component for the resource allocation for reuse in other projects. This approach also allows us to build two simulation models for the module yard and fabrication shop from different simulators and to combine them easily.

4.01 High Level Architecture (HLA)

High Level Architecture (HLA) is an approach for integrating separate components of a simulation model, referred to as federates, into a single distributed simulation model, called a federation (Fujimoto 2003; Kuhl et al. 1999). The main intent of HLA is to promote interoperability between simulations and to aid in the reuse of models in different contexts, ultimately reducing the time and cost required to create a new environment (Fujimoto 2003; Kuhl et al. 1999; Shahin 2007). These features significantly improve the development of construction simulations since simulation models of different construction applications share a number of common

components. This strategy also helps to develop each federate separately with a different simulator and then to combine them (Kuhl et al. 1999).

4.02 Scheduling module assembly yard using HLA

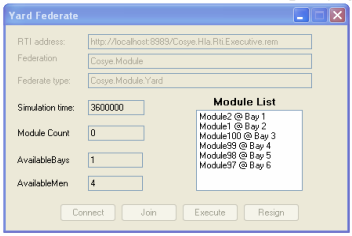
This study uses the Construction Simulation Environment (COSYE) software environment. COSYE (AbouRizk et al. 2006; AbouRizk and Robinson 2006) is an HLA-based simulation environment, developed at the University of Alberta. In this project, we plan to design the following federates to enhance the performance of the system. These federates will be reusable in the future projects.

1. Module yard federate: This federate is similar to the simulation model described in the previous section. However, the resource allocation part of the model is developed as a generic federate. This federate is already developed.
2. Resource allocation federate: This federate acts as an "intelligent observer" placed within the model to watch the model's performance and resource utilization. This federate will be developed as an intelligent agent based on the resource leveling methods in job shop scheduling (Gopalakrishnan 1998; Karumanasseri and AbouRizk 2002), as well as our results from the previous experience (Taghaddos et al. 2008). If more than one type of resource exists, different instances of this agent must be cloned to correspond to different resources.
3. Weather generation federate: This federate is designed to consider the effect of weather conditions on the module assembly yard. In regions such as Alberta, cold (or warm) weather can significantly affect the schedule. This federate helps to develop a realistic schedule that takes into consideration the time of year, the location of the project, and the impact of weather on productivity. This federate has already been developed by Shahin (2007).
4. Calendar federate: This is a generic federate applicable to many construction projects. It takes into consideration national holidays and long weekends according to the location (country) of the project.
5. Real-time graphical federate: This federate can connect to graphic software to show the module location and activities graphically while the simulation federate is running. This federate methodology also has sufficient flexibility to allow the simulator to incorporate the model and apply his/her decisions while it is running (i.e. the user can allocate the module to a specific bay independently).
6. Spool fabrication shop federate: This federate will be developed to model procedures in the spool fabrication shop. This federate is partially developed, bust has to be expanded to model the fabrication shop accurately and estimate the availability time of the spools.

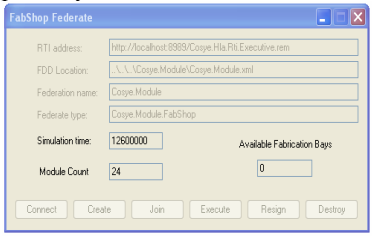
4.03 Current framework

Figure 7 shows the current stage of module yard federation. At this stage, fabrication shop, module yard, and graphical federates have been partially developed. Each federate is an individual simulation model with its own resources; it is at a different simulation time in each captured snapshot. The real-time graphical federate is developed using Visual Studio 2005 Tools for Office (VSTO). This federate connects to Microsoft Visio 2007 and shows the module location while the module yard

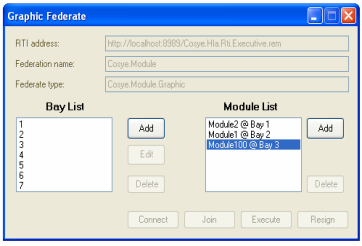
federate is running (Figure 7). This federate demonstrates the capability of this system to collaborate with a third-party graphical system.



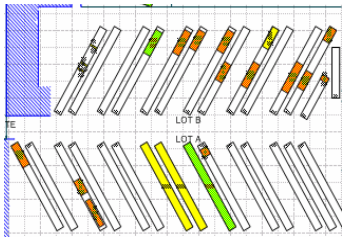
a) Fabrication shop federate



b) Module yard federate



c) Graphical federate



d) Real-time graphical representation

Figure 7 The current stage of module yard federation

5. Conclusions

Producing a realistic schedule for multi-unit industrial construction that optimizes resource utilization and satisfies project constraints is very complicated. This paper implements a simulation-based scheduling framework for an actual case study in a module assembly yard. The developed model pulls the data from a database interface, runs the simulation model, allocates resources (i.e. space, crew) to the modules based on minimum slack algorithm, and finally provides different graphical reports to enable the analysis of pertinent decisions.

This model is expanded by employing High Level Architecture (HLA). This methodology splits the model into various components and links them in a structural format. These components may break into smaller components as needed. This framework allows us to develop an independent component for the resource allocation and to reuse it in future projects. It also helps us to expand the model by linking the yard model to the fabrication shop model. As a bonus, this integrated simulation-based framework has enabled us to develop some other useful federates including weather generation, calendar and real-time graphical federates.

6. Acknowledgements

The authors wish to acknowledge and thank our partner company PCL Industrial for their kind collaboration.

7. References

AbouRizk, S. M., Al-Hussein, M., and Mohamed, Y. (2006). "Development of Synthetic Environments for Select Construction Applications." Collaborative Research and Development Grant, Feb. 2006.

AbouRizk, S. M., and Robinson, F. A. (2006). "Synthetic Environments for Construction Planning and Control." NSERC Industrial Research Chair Research Program, Feb. 2006.

AbouRizk, S. M., and Hajjar, D. (1998). "A framework for applying simulation in construction." *Canadian Journal of Civil Engineering,* 25(3), 604-617.

Burke, G. P., and Miller, R. C. (1998). "Modularization Speeds Construction." *Power Engineering Magazine,* 102(1), 20-22.

Davila Borrego, L. F. 2004. "Simulation-based scheduling of module assembly yards with logical and physical constraints." M.Sc. thesis, University of Alberta, Canada.

Fujimoto, R. M. (2003). "Distributed simulation systems." *Proceedings of the 35th conference on Winter simulation,* 124–134.

Gopalakrishnan, K. N. (1998). "Design and development of a decision support system for scheduling steel fabrication projects." PhD thesis, University of Alberta, Canada.

Gupta, A. K., and Sivakumar, A. I. (2002). "Simulation based multiobjective schedule optimization in semiconductor manufacturing." *Proceedings of the 34th conference on Winter simulation,* 1862-1870.

Karumanasseri, G., and AbouRizk, S. M. (2002). "Decision support system for scheduling steel fabrication projects." *Journal of Construction Engineering and Management,* 128(5), 392-399.

Kuhl, F., Weatherly, R., and Dahmann, J. (1999). "*Creating Computer Simulation Systems: An Introduction to the High Level Architecture"* Prentice Hall.

Maru, A., and Kawahata, J. (2002). "Hitachi Modularization Technology." *Nuclear Plant Journal,* 20(5), 39.

Mohamed, Y., Borrego, D., Francisco, L., Al-Hussein, M., Abourizk, S., and Hermann, U. (2007). "Simulation-based scheduling of module assembly yards: Case study." *Engineering, Construction and Architectural Management,* 14(3), 293-311.

Russell, S. J., and Norvig, P. (2003). "*Artificial intelligence: a modern approach."* Prentice Hall/Pearson Education, c2003.

SCHIMMOLLER, B. K. (1998). "Power plants go modular." *Power Engineering Magazine,* 102(1), 14-19.

Shahin, A. A. (2007). "A framework for cold weather construction simulation." PhD thesis, University of Alberta, Canada.

Taghaddos, H., AbouRizk, S. M., Mohamed, Y., and Hermann, U. (2008). "Simulation-Based Resource Leveling in Multi-Project Construction." *CSCE 2008 Annual General Meeting & Conference,* GC424-1-GC424-10.

Wyman, F. P. (1991). "Common features of simulation based scheduling." Proceedings of the 23rd conference on Winter simulation*,* 341-347.

INTEGRATING AGENT-BASED SIMULATION WITH GAME THEORY TO INVESTIGATE THE HOLD-UP PROBLEM IN PROJECT NETWORKS

H. I. Unsal[1] and J. E. Taylor[2]

Abstract
Subcontractor selection strategies employed by contractors can significantly impact short-term project and long-term organizational success. Existing research on subcontractor selection strategy focuses mainly on the evaluation of subcontractors. We extend this perspective by integrating an agent-based simulation model with game theory to examine whether partner selection strategies that do not consider subcontractor selection as a repeated game may lead to a version of the hold-up problem. The hold-up problem we investigate centers around relationship-specific investments in learning following the introduction of an innovation or organizational change across a project network. We find that a minimum total cost strategy may decelerate the rate of adaptation to an innovation or organizational change. The findings contribute to subcontractor selection strategy literature by simulating the impact of the hold-up problem in project networks, distinguishing task interdependence as a moderating variable, and identifying that the minimum total cost strategy is a suboptimal strategy for project networks adapting to systemic changes.

Introduction

Selection of subcontractors is one of the crucial parameters for project success. Since subcontractors can account for up to 90% of the total value of a project (Kumaraswamy and Matthews 2000) the right subcontractor selection strategy can offer great potential savings. Existing research on subcontractor selection strategy focuses mainly on the evaluation of the subcontractors (Russell et al. 1990; Holt 1998). There are several models that support decision making during subcontracting by optimizing an objective function of the contractor in terms of both cost and financial risk (Elazouni and Metwally 2000; Tserng and Lin 2002; Topcu 2004).

[1] Graduate Research Assistant, Department of Civil Engineering and Engineering Mechanics, Columbia University, 610 S.W. Mudd Bldg., 500 West 120th Street, New York, NY 10027; PH (212) 854-3143; FAX (212) 854-6267; e-mail: hiu2001@columbia.edu.

[2] Assistant Professor, Department of Civil Engineering and Engineering Mechanics, Columbia University, 618 S.W. Mudd Bldg., 500 West 120th Street, New York, NY 10027; PH (212) 854-1182; FAX (212) 854-6267; e-mail: taylor@civil.columbia.edu.

Often overlooked in studies of subcontractor selection strategy is the effect of inter-organizational learning. The assumption is that a contractor makes a subcontractor selection decision based on criteria that depend solely on price and characteristics of the subcontractor such as experience, technical expertise, and financial stability. However there are other factors that do not necessarily depend on the subcontractor such as the alignment with the long-term corporate strategy, the business environment, or the relation of the contractor with the subcontractors. For example, if a contractor adopted a new technology they might tend to work with same subcontractor repeated over a number of successive projects to maximize the benefits of learning. We need research to understand this post-innovation subcontractor selection strategy since the design and construction community is offered a steady stream of new technologies to adopt by technology vendors. Increasing attention on partnering which aims to minimize transaction costs in a project network also suggests the need for consideration beyond the existing subcontractor selection strategy literature. The analysis of Tserng (2002, p.107) regarding traditional subcontractor selection methods points out the critical need to understand subcontractor selection strategies in the post-innovation context as follows:

> *"Due to long-term cooperative relations between the general contractor and subcontractor, the force of personal relationships can easily turn into a managerial bottleneck; additionally, the more the general contractor depends on the technical skills of the specific subcontractor, the more difficult it becomes to control costs, and the more necessary it becomes to depend on specific producers; all of these factors make it less likely that new technological skills or ideas will be adopted."*

In this paper we examine subcontractor selection strategies following the adoption of an innovation or organizational change in a project network. We examine how a forward-looking strategy, which hereafter we refer to as the *network learning strategy*, might lead to better outcomes compared to the case where the contractor bases the selection decision only on current conditions of the subcontractor (hereinafter referred to as the *minimum total cost strategy*). In doing so we intend to show that a more forward-looking strategy should play an important role in subcontractor selection in the post-innovation period. We simulate a market with two subcontractors and one contractor where there are multiple successive projects for which the subcontractors compete. The purpose of the paper is to examine the hold-up problem to which a myopic, minimum total cost seeking strategy may lead. Before explaining the model we discuss why this problem is particularly interesting in the architecture, engineering and construction (A/E/C) industry.

Innovation and Learning in Project Networks

A process innovation changes the way a company operates with a cost associated. The cost can be an increase in the duration or the actual cost of a task which a party would be willing to pay only with the expectation of expected future benefits. The feasibility of an innovation depends in part on the amount of time between adoption and the time after-which the network improves upon its pre-innovation productivity. Taylor and Levitt (2007) identify that relational stability is one of the important

factors that affect the duration which project network reaches the baseline productivity level following the adoption of a systemic innovation. Systemic innovations are those that impact more than one firm in the project network (Taylor and Levitt 2004). The more relationally stable the project network is –that is, for example, the fewer subcontractors from which a contractor selects– the faster the systemic innovation benefits propagate through the network. This is justified by the fact that the post-innovation learning occurs not just within the individual firms but at the boundaries between firms in the network. Therefore the strategy of the contractor to work with fewer firms can be seen as an attempt to maximize the benefits of learning within their partner firms and at these network boundaries.

This might not be the case for all project networks. Following an innovation, the tendency of a contractor to stick with the same subcontractor would be stronger than that of a buyer sticking with the same supplier in a manufacturing industry supply chain. What distinguishes A/E/C project networks from manufacturing supply chains is the degree of task interdependence between organizations in the project or supply network. The term reciprocal interdependence, defined by Thompson (1967) as the highest degree of interdependence, affects A/E/C project networks. In this type of interdependence partners, exchange information and resources simultaneously as opposed to the sequential interdependence of manufacturing supply chains where the output of one partner is the input of the other. In a reciprocally interdependent project network, the benefit from inter-organizational learning at the level of the network is more significant when partners work together consecutively as compared to the benefits of inter-organizational learning in a sequentially interdependent supply network. We incorporate this factor in our model and introduce task interdependence as a parameter. This will be explained in more detail in the following sections.

While understanding learning is essential to project network strategy formulation, it is not sufficient to develop a project network strategy following the introduction of a systemic innovation. Taylor and Levitt's (2007) model suggests that it will be more profitable for a contractor to work with a single subcontractor in successive projects. This might be valid if we ignore the potential for subcontractors to behave opportunistically in future projects and attempt to increase his or her share from the gained benefit. This might lead to what economists describe as the hold-up problem in the transaction cost economics literature (Williamson 1975). The increasing benefits of working with a subcontractor will also increase the switching cost of the contractor to use another subcontractor and might therefore lead to dependence between parties as described in the earlier reference to Tserng (2002). This switching cost is the incentive for the first subcontractor to expect more from the gained benefit.

If opportunistic subcontractors cannot increase their price more than the switching cost of the contractor (since that would force the contractor to switch), why would the contractor be put in the disadvantageous position of investing in only one subcontractor? In this paper we develop a model of a market with one contractor and two subcontractors to understand the outcome and modality of a minimum total cost post-innovation strategy that favors the subcontractor with the lowest total cost. We first examine whether or not the *minimum total cost strategy* can be outperformed with a slightly adjusted *network learning strategy* (we do not claim that this is an

optimal strategy, simply an alternative). Then we examine the factor or factors that produce the performance differences between the two strategies.

The Hold-up Problem in Project Networks

Hold-up problem

Transaction cost economics is a common theoretical framework used in the analysis of organizational networks and strategic alliances (Williamson 1975). Managerial decisions regarding the governance structure can be explained by rational behaviors that aim to minimize transaction costs and risk. In market or hybrid forms of governance structures one of the risks inherent in transactions is relational risk. Williamson (1975) suggests that the risk is caused by the fact that the contracts cannot foresee and regulate all possible future contingencies. Williamson also argues that each partner will stick to the contract as long as the conditions do not change. However one of the partners can take the advantage of the loopholes in the contract if there is dependence between partners caused by an asset-specific investment and the needs are changed along the way. Williamson defines this opportunistic behavior as 'self-interest seeking with guile' (Williamson 1975, p. 9). This may lead to the hold-up problem which gives one of the parties a bargaining power over the other.

But it is not obvious that the opportunistic behavior in our case is a version of hold-up problem. Rogerson (1992: p.777) summarizes the required conditions that lead to the hold-up problem as; (1) existence of a non-contractible specific investment by one of the parties for a future transaction and (2) the uncertainty about the specifications of the transaction. In the repeated project environment the second condition inherently exists. In most cases the specification of the next projects are unknown. The first condition, however, emerges during post-innovation when a contractor makes a relation-specific investment by working with a subcontractor. By considering the previous partner selections as an investment, this study changes the standard view that the successful selection depends only on current conditions.

The risk that an asset specific investment creates is trivial from a managerial standpoint. Chang and colleagues (2007), in their case study of the Chunnel Project, examined the hold-up problem that occurred due to process specific investment. They show that the lump-sum contracts can give the client some bargaining power over the contractor. In this paper we examine the hold-up problem that is caused by increasing learning benefits in a repetitive project environment following the introduction of a systemic innovation. The unique property of this case is that there are several decision points until the hold-up problem is faced and managers can avoid it by following a forward-looking strategy.

Switching cost

The effects of switching cost on markets was examined by Klemperer (1987) where he defined the learning cost as one of the three types of switching costs. A typical example that he mentions is the case when a person buys specific cake mix brand X and improves the quality of a cake over time. In this case what seems to be the benefit of learning can also be seen as the switching cost to another brand Y because if he or she switches to Y they will have to start to learn baking with brand Y.

The switching cost may also affect the markets at a macroeconomic level. For

the past two decades researchers have studied the effects of switching costs on market characteristics. However, the majority of research in the business literature on this topic has concentrated on buyer-supplier relations (Beggs and Klemperer 1992; Nilssen 1992). The same problem is specifically interesting for the A/E/C industry and requires attention.

A/E/C industry projects are usually customized and the price mechanism does not work as well as it does for the consumer products. We know that the buyers are at the short side of the market which forces the sellers to approach marginal costs, but when the number of sellers is limited due to the specifications of the work, the switching cost can give a seller some degree of monopoly power over the buyer. If we return to the cake mix example, the buyer does not have to spend too much effort to get information about the price of similar brands since in a supermarket it would be sufficient to simply check the next shelf. This gives the buyer a better sense of evaluation during comparison. However, if a construction project is a customized one, a contractor can compare only the bids they receive since there is no similar product outside of that context.

Integrating Agent-based Simulation and Game Theoretic Models

Simulation has been used widely as a research tool in social sciences. Axelrod (1997) describes the use of simulation as an alternative methodology to induction and deduction. In this study we use a specific type of simulation, agent-based simulation, which is the most appropriate approach for our set of research questions. In agent-based simulation the agents of the system interact with each other by following a set of assigned algorithms. Axelrod argues that, in contrast to the other types of simulation, agent-based modeling does not necessarily represent an empirical application. Instead it helps us gain insight into and understand the fundamentals of a process and reach conclusions which might not be possible by intuition. He also adds that simplicity is a very crucial feature of agent-based simulation. The developer should keep the underlying assumptions simple although he or she has flexibility to arrive at complex solutions or simulated results. This is another important point that distinguishes agent-based simulation from other simulation research that may aim to serve immediate practical applications (e.g., flight simulations). Validation is a much larger concern than accuracy in social simulations where the dynamics of the system and interactions between the components of the system are less known.

Our agent-based simulation model is developed to simulate a multi-period scenario with one contractor and two subcontractors. In each period (each period represents a discrete project in the simulation) subcontractors submit sealed bids simultaneously based on the information they have and the contractor awards the contract to the best bid. The best bid criterion depends on the strategy that the contractor employs. We compare two different strategies, *minimum total cost strategy* and an alternative *network learning strategy*, and show that the *minimum total cost strategy* may lead to the hold-up problem.

In general, for any project i, the total cost of working with the subcontractor j, $TC_{i,j}$, is the sum of the cost of the interdependent work which hereafter we refer as "boundary cost", $BC_{i,j}$, and the bidding price of the subcontractor, $p_{i,j}$. The boundary cost (BC) is not a real cost but the monetary value that represents the difficulty of

working with a subcontractor. *BC* can be understood as a type of transaction cost.

$$TC_{i,j} = BC_{i,j} + p_{i,j}$$

As mentioned previously, the model assumes that the learning also occurs at the boundaries between firms which implies that the *BC* decreases over time. This creates a switching cost between subcontractors since the *BC* of the subcontractor that the contractor has more experience with is lower compared to *BC* of the other subcontractor. We employ the widely accepted form of the learning curve which was introduced by Wright (1936). In the post-innovation stage, the *BC* is assumed to decrease according to the following rule:

$$BC_{i,j} = BC_0 \times (n_{i,j})^{L_j}$$

where;

BC_0: boundary cost of working with any firm for the first time

n_j: number of projects that contractor worked with subcontractor *j*

$L_j = \log_2 \lambda_j$: characteristic learning index for subcontractor *j*

λ_j: learning rate

We also use *BC* to vary the level of task interdependence. Task interdependence is indicated as a percentage which refers to the amount of work that is reciprocally interdependent between the firms. This is where learning at the level of the project network takes place (Taylor, Levitt and Villarroel 2006). In the terminology of the model this corresponds to the *BC* which is the cost of the work that is beyond the responsibility of the subcontractor and, therefore, is not included in the price. The remaining part represents the average cost of the subcontractor. The upper and lower limits of the cost are determined by taking $\pm$ 20% of this average cost. For example if the task interdependence is 50%, the cost of the subcontractor will be between 40% and 60% of the total cost.

We model the price as a first-price sealed-bid auction. We find the Nash Equilibrium (Nash 1951) to determine the bids that subcontractors will submit in each period. The structure of the bidding game is as follows. Each subcontractor *i* has a uniform cost distribution between a and b. This is the cost of the contract to the subcontractor. In each project the subcontractors have information of their type –the cost value– but do not have information about the type of the other subcontractor. Since the types are independent, knowing their own types does not change the belief about the type of the others. For example, the subcontractor 1 knows the cost value before bidding, but has a belief about the cost of subcontractor 2 which is uniformly distributed between a and b.

Vickrey (1961) shows the Nash Equilibrium of this symmetric problem. However in our model the *BC*s of both subcontractors are public information since in practice, subcontractors should be aware of the advantage or disadvantage they have relative to their opponent. This will force the subcontractor who has less experience with the contractor to bid more aggressively. The different *BC*s of the subcontractors may give the advantage to one subcontractor. This asymmetry between the subcontractors limits the extent to which the currently available literature can suggest solutions to the problem. Lebrun (1999) solves a special case of asymmetric bidding

problem with N bidders, but the asymmetry here originates from the difference between the cost distributions not the range as in our case. Griesmer and colleagues (1967) show that, in an asymmetric bidding problem where the costs are drawn from different uniform distributions, there exists a Nash Equilibrium. The initial cost distributions are shifted by the amount of the BCs to determine the Nash Equilibrium of the asymmetric case. Therefore subcontractor *i* sets their price based on the new cost distributions on intervals $[a_1, b_1]$ and $[a_2, b_2]$. Where $a_i = a + BC_i$ and $b_i = b + BC_i$. Griesmer and colleagues (1967) provide the following differential equation for the inverse of the price function[3]:

$$c_i'(p) = \frac{(b_i - c_i(p))(p - c_i(p))}{(p - \overline{p})(p + \overline{p} - b_1 - b_2)}$$

where;

$c_i(p)$ = Inverse of the price –strategy- function
p= Price
$\overline{p}$= Parameter that defines the upper bound on bids of both players[4]

The solution of these differential equations is beyond the scope of this paper, so we omit the derivation and present the solution as briefly as possible.

$$c_i(p) = p + \frac{Kaxe^{a/x} - Kx^2e^{a/x} - x^2}{Kxe^{a/x} + a + x}$$

where; $x = p - (b_1 + b_2)/2$ and $a = (b_1 - b_2)/2$

Using the boundary condition we can solve for K :

$$K = \frac{da + dx - x^2}{xe^{a/x}(x - d - a)}$$

where; $d = \underline{p} - a_1$ and $\underline{p} = \frac{\left(\frac{b_1}{2} + \frac{b_2}{2}\right)^2 - a_1 a_2}{b_1 + b_2 - a_1 - a_2}$

Although the inverse of the price function has a closed form solution, it is not invertible. So we used numerical approximation for the price function. Linear estimation provides enough accuracy for the purposes of this model.

Simulation Experiments and Findings

After specifying the model we ran the simulation comparing the two aforementioned strategies (*minimum total cost strategy* and *network learning strategy*). In the first strategy the contractor selects the subcontractor with the lowest total cost. In the second strategy the contractor is forced to switch partners in the first three projects.

---

[1]Griesmer states that this is the Nash Equilibrium if and only if $b_1 + b_2 > 2 \times a_2$ which is always the case in our simulation.

[4] This is the single parameter that needs to be determined by the user. Griesmer provides the limits for that parameter as: $\leq \bar{p} \leq (b_1 + b_2)/2$. We assume that $(b_1 + b_2)/2$

We also tried switching partners for a longer period but the results are not significantly different from the case where the contractor is forced to choose a different subcontractor for only the first three projects.

Table 1 contains the parameters of the different scenarios we ran. The overall purpose was to compare the two different strategies but we also ran the simulation for varying levels of task interdependence to ascertain whether in some cases there is no risk of hold-up due to learning. Six different levels of task interdependence are examined and 100,000 simulations are run for each task interdependent case.

Table 1 - Range of Strategy Scenarios Simulated

Strategy	Task Interdependence	Learning Rate	# of Projects	Number of Simulations
Minimum Total Cost	0%	0.8	15	100,000
	10%			
	20%			
	30%			
	40%			
	50%			
Network Learning	0%			
	10%			
	20%			
	30%			
	40%			
	50%			

Figure 1 shows the comparison of the averages of 100,000 simulations for 50% task interdependence. The *network learning strategy* is initially more expensive than the minimum total cost strategy, but very quickly by the third project begins to outperform the *minimum total cost strategy* in terms of total cost. We present the cumulative difference between strategies at varying task interdependence in Figure 2.

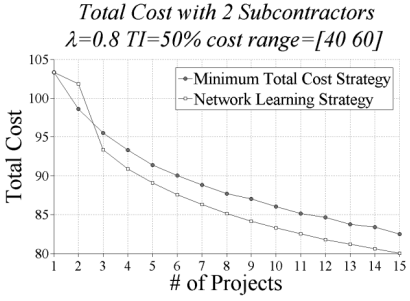


Figure 1 - Impact of Strategies on Total Cost with 50% Task Interdependence

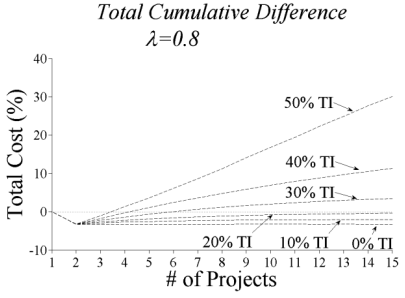


Figure 2 - Total Cumulative Difference between Strategy Total Costs for varying Levels of Task Interdependence

The loss caused by employing the myopic *minimum total cost strategy* is not significant in a single project but reaches significant levels as more and more projects are completed. These two figures together imply that, as expected, there is an opportunity cost of employing the *minimum total cost strategy*, especially in industries where the task interdependence is relatively high which is the case in A/E/C industry. However, Figure 2 also demonstrates that the amount of task interdependence present in a project network moderates the magnitude of the hold-up problem. In the absence of task interdependence there is no benefit to the *network learning strategy* over the *minimum total cost strategy*.

The results suggest when innovations are introduced into reciprocally task interdependent project networks that a short-term managerial perspective focused on achieving a minimum total cost when selecting subcontractors is not optimal. If a firm considers the learning that must occur in a network adapting to an innovation or organizational change, a *network learning* strategy will outperform the *minimum total cost* subcontractor selection strategy. Therefore a subcontractor selection strategy should include the future contingencies and not focus only on current conditions which may result in dependence on a subcontractor, hence potential loss of profit.

Discussion and Conclusions

The concept of the hold-up problem caused by increasing switching cost is not new. However, the cause of the hold-up problem is typically described in the literature as the dependency of either a supplier or buyer on their counterpart as a result of the potential cost if the relation is to be broken. This paper contributes a perspective on hold-up that shows how hold-up can also occur when the switching cost is not too high and there is more than one supplier with which to transact. The dependency does not have to be a consequence of increased switching cost but it can be inherent in the reciprocally task interdependent nature of the industry.

Furthermore, we find that an asset specific investment is not necessary for hold-up to occur. The opportunistic behavior can still cause hazard when there is no physical investment. The benefits of learning in a repetitive project environment can cause hazard not because the buyer will be worse off compared to the first project but because there exists a *network learning strategy* that leads to higher benefits. In the simulation we showed that even though the contractor works with both subcontractors the contractor might be worse off if they follow a *minimum total cost strategy*.

In conclusion, this paper develops an integrated agent-based simulation and game theoretic model which demonstrates that a *minimum total cost strategy* can be outperformed by a forward-looking *network learning strategy*. Therefore the minimum total cost strategy is a suboptimal subcontractor selection strategy in the period following the introduction of an innovation or organizational change across a project network. In doing so we contribute a new perspective on the hold-up problem from transaction cost economics that considers how relationship-specific investments in learning at the task interdependent boundaries between firms in a network can lead to opportunistic behavior by subcontractors in a repetitive project environment. The results also contribute a new understanding of the role of reciprocal task interdependence on hold-up. We find task interdependence to moderate the risk of

hold-up in project networks. These findings have significant practical implications for firms developing subcontractor selection strategies in the period following the introduction of an innovation or organizational change.

References

Axelrod, R. (1997). "Advancing the Art of Simulation in the Social Sciences." In Simulating Social Phenomena, (Eds) Hegselmann, R., Terna, P., pp. 21-40.

Beggs, A. and P. Klemperer (1992). "Multi-Period Competition with Switching Costs." Econometrica **60**(3): 651-66.

Chang, C.-Y. and G. Ive (2007). "The hold-up problem in the management of construction projects: A case study of the Channel Tunnel." International Journal of Project Management **25**(4): 394-404.

Elazouni, A. M. and F. G. Metwally (2000). "D-SUB: Decision Support System for Subcontracting Construction Works." Journal of Construction Engineering and Management **126**(3): 191-200.

Griesmer, J. M., R. E. Levitan, and M. Shubik (1967). "Toward a Study of Bidding Processes, Part Four: Games with Unknown Costs." Naval Research Qtly **14**: 415-33.

Holt, G. D. (1998). "Which contractor selection methodology?" International Journal of Project Management **16**(3): 153-164.

Klemperer, P. (1987). "The competitiveness of markets with switching costs." Rand Journal of Economics **18**(1): 138-150.

Kumaraswamy, M. M. and Matthews J. D. (2000). "Improved Subcontractor Selection Employing Partnering Principles." Journal of Mgmt in Engineering **16**(3): 47-57.

Lebrun, B. (1999). "First Price Auctions in the Asymmetric N Bidder Case." International Economic Review **40**(1): 125-42.

Nash, J. (1951). "Non-Cooperative Games." The Annals of Mathematics **54**(2): 286-295.

Nilssen, T. (1992). "Two Kinds of Consumer Switching Costs." RAND Journal of Economics **23**(4): 579-589.

Russell, J. S., M. J. Skibniewski, and D. R. Cozier (1990). "Qualifier-2: Knowledge-Based System for Contractor Prequalification." Journal of Construction Engineering and Management **116**(1): 157-171.

Taylor, J. and R. Levitt (2004). "Understanding and Managing Systemic Innovation in Project-based Industries." In Innovations: Project Management Research, (Eds) Slevin, D., Cleland, D. and Pinto, J. Project Management Institute, Newton Square Pennsylvania, pp. 83-99.

Taylor, J. and R. Levitt. (2007). "Innovation Alignment and Project Network Dynamics: An Integrative Model for Change," Project Management Journal **38**(3): 22-35.

Taylor, J., R. Levitt, and A. Villarroel (2006). "Simulating Learning in Interorganizational Networks," North American Assoc. for Computational Social and Organizational Sciences Annual Conference, Notre Dame, Indiana.

Thompson, J. D. (1967). Organizations In Action. New York, McGraw Hill.

Topcu, Y. I. (2004). "A decision model proposal for construction contractor selection in Turkey." Building and Environment **39**(4): 469-481.

Tserng, H. P. and P. H. Lin (2002). "An accelerated subcontracting and procuring model for construction projects." Automation in Construction **11**: 105-125.

Vickrey, W. (1961). "Counterspeculation, Auctions, and Competitive Sealed Tenders." The Journal of Finance **16**(1): 8-37.

Williamson, O. (1975). Markets and Hierarchies. New York, MacMillan.

MODELING ARCHITECTURE FOR HYBRID SYSTEM DYNAMICS AND DISCRETE EVENT SIMULATION

A. Alvanchi[1], S. Lee[2], S.M. AbouRizk[3]

[1]PhD. Student, Hole School of Construction, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada Email: alvanchi@ualberta.ca
[2]Assistant Professor, Hole School of Construction, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada Email: sanghyun@ualberta.ca
[3]Professor, Hole School of Construction, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada Email: abourizk@ualberta.ca

Abstract
Construction systems and projects comprise complex combinations of subsystems, processes, operations, and activities. Discrete Event Simulation (DES) has been used extensively for modeling construction systems, addressing system complexity, and analyzing system behavior. However, while DES is a powerful tool for capturing operations as they occur in reality, DES does have difficulty modeling context and its mutual effects on the operational components of a system. System Dynamics (SD), on the other hand, captures feedback loops that are derived from the context level of a system and that can anticipate system behavior; nevertheless, SD cannot effectively model the operational parts of a system. Hybrid SD and DES modeling provide a set of tools that use the capabilities, while improving upon the disadvantages, of these two approaches. Although initial efforts to develop hybrid SD-DES modeling dates back to the late 1990s, in the construction industry, there are relatively few studies in this area, and there is still no robust architecture for hybrid system developers. This paper addresses these issues by proposing a comprehensive hybrid simulation architecture based on the High Level Architecture (HLA) infrastructure, which can be used by hybrid simulation developers in the construction industry. A typical steel fabrication shop has been modeled based on the proposed architecture, and it has been compared with the ideally developed hybrid simulation architecture.

1. Introduction

System Dynamics (SD) and Discrete Event Simulation (DES) are two major simulation-based decision support tools used for analyzing complex systems. While SD works well for capturing the effects of context level parameters in feedback

systems, DES is useful for modeling the effects of operation level parameters in sequential systems. Although most real world systems are combinations of feedback and sequential processes, context level and operation level parameters, and continuous and discrete changing variables, most simulation-based analyses are still facilitated by the use of either SD or DES, with modelers' selection based on which tool can capture more aspects of the problem. This conventional type of analysis may force system analysts to make simplifying assumptions and to accept a lower level of accuracy.

In terms of conceiving a more accurate modeling tool, recent efforts have been made to develop a hybrid architecture for SD and DES modeling (Martin and Raffo 2001, Borshchev et al. 2002, Venkateswaran et al. 2004, Rabelo et al. 2005, Choi et al. 2006). Although most of the studies conducted have come out of the software and manufacturing industries, there are a few SD-DES hybrid studies that have been conducted from within the construction industry (Lee et al. 2007, Pena-Mora et al. 2008).

Most construction-related systems have a combined structure of context and operation level parameters (Lee et al. 2007), and sequential and feedback processes. For example, in a typical construction system, operation parameters such as equipment capacity, and number of workers and labor hours, are combined with context level parameters such as worker skill level, incentives, fatigue, or system throughput, which are the result of sequential operations like cutting, welding, and painting. These have a mutual effect on the hiring/ firing policies of an organization and form a feedback loop. However, there is still no robust architecture that can be utilized for the hybrid modeling of construction-related systems.

In an effort to address this issue, this paper aims at developing an SD-DES hybrid modeling architecture with the capacity to model a wide range of actual construction-based projects. This research has four main stages. In the first stage, recognition, each SD and DES model is examined separately. In the second, comparison stage, different aspects of the SD and DES models are compared, and previous studies conducted on hybrid modeling are analyzed. Then, at the third stage, a hybrid modeling architecture is proposed, based on a distributed simulation using High Level Architecture (HLA). While hybrid modeling is meant to serve mega-construction projects with a high level of complexity, the interactions among different components of the simulation model will be better handled by basing the model's development on the HLA infrastructure. At the fourth and final stage, a sample case is modeled based on the proposed architecture, and the model's performance is examined.

2. SD versus DES

2.1. System Dynamics (SD)

SD is a method for studying the complex systems which are changing over time. It models internal feedback loops which play a major role to form the entire system behavior. "Feedback," which refers to the phenomenon in which the change in the value of one attribute in a system has a mutual effect on the other attributes of that system, is fundamental to using SD as a modeling tool. Usually, these mutual effects work through long interwoven chains of causes and effects; thus, it is difficult to

predict how the system will behave over time without using computer simulation-based techniques.

SD applications can be used in a diverse range of areas, such as studies related to the dynamics of population, social systems, ecological systems, and economic systems. Consequently, SD is an appropriate tool for modeling interactions at the context level of a system. When SD is chosen for analyzing a system, usually a developed SD model is run to simulate feedback system behaviors that have occurred during that system's life cycle. However, although the system is usually mapped into long and complicated chains of causes and effects in the causal loop diagram method, this method does not reflect the physical specifications of the system. Instead, the system specifications are briefed into the embedded formulas recognized for every single interaction.

2.2. Discrete Event Simulation (DES)

DES attempts to model system behavior as it evolves over time by following system events, which are recognized as the change initiators in the system. DES techniques deal with the list of events; this list is filled once every future event is scheduled and is depleted by firing elapsed events. Furthermore, using entity and resource concepts, DES modeling tries to mimic the real system's behavior and its physical specifications. As a result, DES requires a comprehensive phase of recognition in which all corresponding data in the system are collected. System analysts use the output of a simulation run as a set of estimators of stochastic variables (Pooch and Wall 1993), so that the developed DES model is run to simulate system behaviors over a long period of time, until the system attains reasonable stability.

2.3. SD and DES Comparison

While the continuous simulation-based techniques keep track of changes in system status over even steps of time (in SD-based problems), DES adopts a future event list concept to follow the changes in system status over time. Fig. 1 shows the main steps of the SD and DES problem solving methods in continuous and discrete event simulations, respectively.

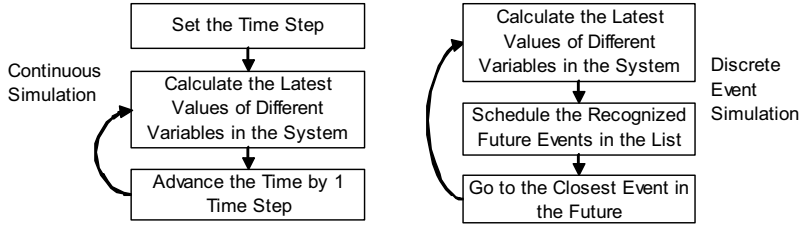


Fig. 1. Main steps in continuous and discrete event simulation calculation methods

The main difference between the calculation steps in the continuous and discrete event simulations is the way that they advance time. While continuous simulation is forced to set an exact value (or range) as one time step is strictly followed by another, the discrete event simulation schedules its future steps according to the latest values of the system variables.

In the continuous simulation, the value of the selected time step should be small enough to capture every significant change in the system. As a result, this time step is based on the most variable periods of the system's life cycle regardless of the level of variation for the rest of the time. This (almost) even time step quality, which continues during the entire time of simulation, results in more cycles of calculation frequently achieving the same level of accuracy using the continuous techniques than in discrete event simulation. Therefore, continuous calculation techniques are considered to be less flexible and adaptable than the discrete calculation techniques.

3. Hybrid Simulation Research

The first attempts to develop and use a hybrid SD-DES system originate from the software industry in the late 1990s. At that time, a booming market in the software industry and fears of widespread Y2K software crashes led developers to seek ways to improve the software development process and gain knowledge on how to design and develop more powerful hybrid simulation tools.

Rus et al. (1999) have tried to incorporate feedback loops into discrete-based activities in the software development process, and this work was built upon by Zeigler et al. (2000), Martin and Raffo (2001), and Choi et al. (2006). This research focused on optimizing the software developing process by providing more accurate evaluation strategies required for important decision-making (e.g. staff hiring, training, and firing polices). Most of these efforts produced simulation software applications that can support hybrid simulation models such as ExtendSim, SimuLog and AnyLogic.

The above software industry based research is predominantly founded on the hybrid software process simulation using discrete event system specification formalism proposed by Zeigler et al. (2000). This hybrid formalism consists of two types of models: atomic and coupling. The coupling model is designed to map complex systems onto related hierarchical modules, and the atomic model works as the syntax used by modules to communicate with each other. One issue addressed by this methodology is that all communication among modules is handled through pre-determined input and output ports; each module will communicate to a limited number of modules. An example of this type of system is a sequential ordered system, in which the main processors are fired successively so that each processor has to talk only to its predecessor and successor.

Meanwhile, scholars from other disciplines, such as manufacturing (Venkateswaran et al. 2004, Rabelo et al. 2005), and also researchers in the construction industry (Lee et al. 2007, Pena-Mora et al. 2008), have become involved in hybrid simulation research. These works focus on enhancing modeling capabilities for the real cases to which they are applied.

Ongoing research on hybrid simulation can be divided into two main categories. The first category consists of those contributions to the development of hybrid simulation software architecture and involves all aspects of both discrete event simulation and system dynamics in their proposed architectures. In the second category, researchers attempt to capture previously neglected interactions between the context levels and operation levels of systems, using a hybrid model of SD and DES to increase the accuracy of system modeling. Software experts are the pioneers of the

first category of research; however, scholars in all other involved disciplines are active in the second category.

4. Hybrid Modeling Challenges

The previously proposed architectures (Zeigler et al. 2000, Martin and Raffo 2001, Choi et al. 2006.) were based on each other and customized for modeling software development projects. However, there are big differences between construction-related works and software-related works. While the software industry is considered to be a labor-consuming industry, the construction industry combines industrial equipment and labor. Furthermore, environmental, safety, material, and equipment issues are some of the most significant factors involved in construction-related jobs (and effectiveness) that do not have a comparable level of importance in the software industry.

Therefore, in construction, more interactions between context level and operation level components should be expected. The first challenge to developing modeling architecture centers on data communication among different parts of the model. Current data communications, which are based on the architectures suggested by the software industry researchers, are handled by specified output and input ports that can communicate to the specified output and input ports in other parts of the model. Although this approach to communication might work for software development projects because of their sequential nature and limited interaction between context and operations, this architecture creates an increasingly complicated communication method when approaching larger scale and more interrelated systems. This challenging issue becomes more clear if we notice that the maximum number of required communication ports in a fully interrelated hybrid simulation model, consisting of n different simulation modules, will be $n*(n-1)$; however, the minimum number of required ports in a sequential system with n different parts will only be $(n-1)$. For example, the number of required ports in a system divided into 10 different sub-systems can vary from 9 to 90.

The other challenge posed by hybrid modeling is time advancement. While the fundamental idea behind using hybrid models is to reflect the effects of the latest changes in the context parts of the system to the operation parts and vice versa, this causes successive changes in the prescheduled events of the future event list in the DES parts with every value update in the SD components of the model (Lee et al. 2007). This results in a massive amount of simulation process time being used for updating and rescheduling the future event lists of the DES parts. This issue will be even more critical when we want to apply hybrid modeling to mega construction projects with numerous context and operation components.

We found two different approaches for reducing the negative effects of this issue: specifying a reasonable time step for data interchange between different parts of the system (Venkateswaran et al. 2004), and considering some adapting criteria for SD time steps to adapt time step duration according to the chronological rates of the changes using methods like fourth-order Runge-Kutta (Fehlberg 1970).

In the first approach, each of the SD and DES parts of the model work separately based on their regular solving methods. A reasonable time step is set for the data interchange between different parts where the data transfer between different parts occurs and the related variables and parameters are updated. This approach to

the time step challenge is limited to hybrid systems in which we can find a time step that is big enough not to interrupt the DES part of the model, but small enough to monitor all significant changes.

The second approach defines an interval for the SD time step and tries to find the proper time step duration based on the changing rate of the system. While the adjusted time step in this approach is based on the explored trend of the system according to the previous records of changes, any unexpected or radical change in the system might be neglected. This approach also forces the solving method to stick to the limited and predefined interval of time for the time step; thus, this approach is still not flexible enough to adapt to all possible system changes.

5. Proposed Hybrid Architecture

The proposed architecture attempts to introduce a comprehensive modeling approach for developing hybrid simulation, while addressing the already discussed challenges to a construction-related context. The architecture consists of three main components: schematic modeling, data communication, and time advancement. Further explanation of each component follows below.

5.1. Schematic Modeling

The first step in developing a hybrid model of a system is to prepare a schematic model that works as a conceptual design of the system and is used as the guideline for model development during the implementation phase. While the interactions between different SD-DES sub-models are usually expanded in different levels of system hierarchy, a hierarchical approach is followed by drawing different schematic models of the system at different levels. As a result, each level of the schematic model consists of a combination of SD and DES models which are related to each other and to the upper and lower levels. The graphical elements used for each SD model and DES model are the usual graphical elements that are used in each discipline (i.e. SD or DES).

5.2. Communication Approach

In the 1990s, High Level Architecture (HLA) was developed as a framework for distributed simulation modeling by the United States Department of Defense (DoD) for military systems simulation modeling (Kuhl et al. 1999). An HLA-based simulation consists of three main elements, namely federates, runtime infrastructure (RTI), and object model template (OMT). The combination of these three elements creates a federation. A federate is an independently implemented and run simulation program which represents some part of the system; however, the federate might share some data or use some shared data in the federation. RTI provides and controls the lines of data communication between different federates, and OMT defines the structure and formation of the data for communication.

HLA is the adopted communication approach in the proposed hybrid architecture and the developed schematic model is the main input for it. Every recognized SD and DES sub-model in the schematic model, regardless of the level of hierarchy where it is situated, represents a federate in our HLA-based hybrid simulation (Fig. 2). All required data to be transferred among different parts of the

hybrid model are reflected in the OMT, in which the sender federates of any part of the data register as the data publisher, and the receivers register as the subscribers.

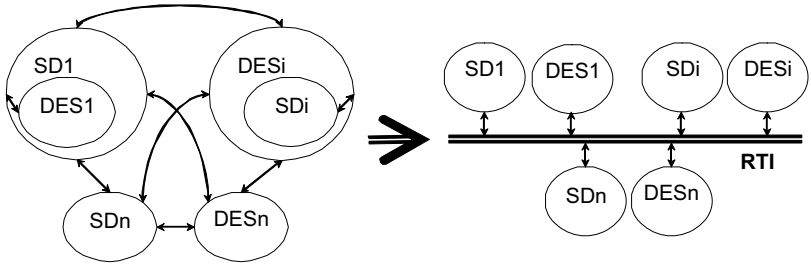


Fig. 2. Determining required federates

This approach to hybrid modeling communication eliminates the need for dedicated data import-export channels, while the RTI handles all required communication afterwards. No matter how interrelated the hybrid simulation is, all communication will be addressed by easily determining the subscribing-publishing structure of the shared data.

5.3. Event Based Advance

The proposed architecture addresses the time progress issue inherent in hybrid modeling by changing the SD-related interactions to the event-based format instead of preset time steps. In this approach, the hybrid model's SD parts borrow some concepts from DES modeling.

Applying the entity concept to SD modeling, we can assume that the stock level is the queue of the entities, and that the flow rate is the arrival-departure rate of the entities to and from the queue. In this approach to SD modeling, we can also assume that the entity concept is the minimum change in the stock level, or entity level, which is still meaningful and important to the system stakeholders; therefore, the hybrid model's SD components are not supposed to report every insignificant change in the stocks until the change in the stock level exceeds the defined entity level, which indicates that an arrival or departure event of an entity (or entities) is taking place.

The schematic models and federation OMT are the main inputs for this part; however, model developers might require a more elaborate design for every single federate than the current schematic conceptual design. All SD sub-models are implemented and run the same, as in the usual SD modeling approaches (i.e. with equal time step, excepting that the changes are reported based on the stock entities' arrival or departure; i.e. when a meaningful change is occurring in the stock level).

6. Experimental Model

Using the proposed architecture, an experimental model of a typical steel fabrication shop has been developed. The fabrication shop consists of five main activities to fabricate steel modules and prepare them to be constructed in the field: cutting, fitting, welding, inspecting, and fixing missed parts (rework) at the operations level.

The context level of the system is the labor hiring/firing process. While some parameters, with values controlled by the context of labor hiring/ firing in the system—such as activities' progress rates, the volume of rework, and the number of interruptions—have an effect on the operational component of the system, the main driver of the labor employment process remains the production rate, which is derived directly from operation. Fig. 3 illustrates the schematic hybrid model of the fabrication shop where SD and DES work in parallel (5.1).

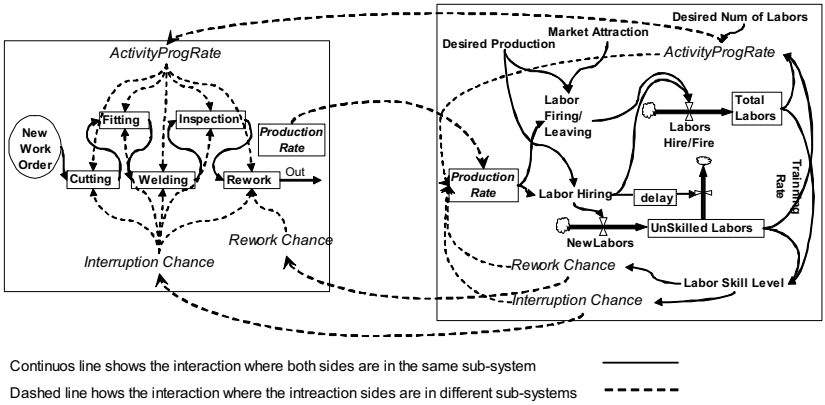


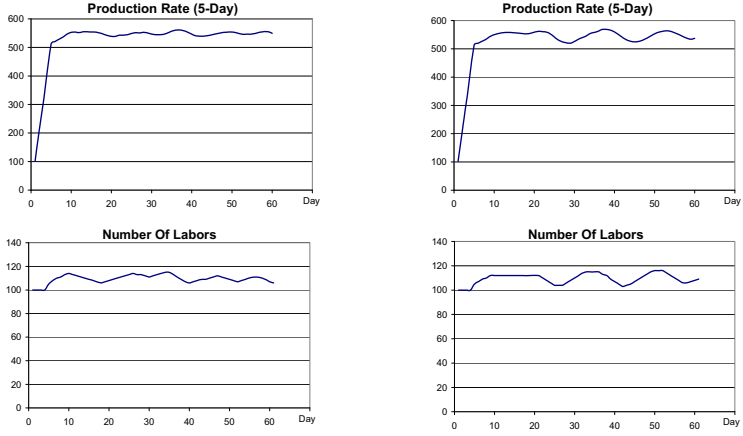
Fig. 3. Schematic hybrid model of the steel fabrication shop

The model was developed for testing the proposed architecture's capabilities. Two main federates were considered for the model: a shop floor DES federate and an SD federate of the labor employment process (see Fig. 3). All four communication lines were modeled as a single OMT object class having four attributes to be shared through the RTI. The COSYE (AbouRizk and Robinson 2006; AbouRizk et. al 2006) framework provided the distributed simulation related services, and Visual Studio.NET was used for building the program interfaces.

The two developed federates are totally independent from each other, and they can even be run from different computers. They simply must communicate with the RTI, which is a mediator between them and looks after all the required interactions. Each federate announces the attributes that it will publish to the federation, and the ones that it wants to subscribe to for updating new published values. This arrangement reduces the complexity of communication, even when increasing the number of federates and communication lines. For example, in our case, the DES federate publishes the Production Rate and subscribes to the Rework Chance, Interruption Chance, and Activity Progress Rate, and the SD federate publishes the Rework Chance, Interruption Chance, and Activity Progress Rate, and subscribes to the Production Rate.

Changes in the production rate and in the amount of labor over 60 days of production were tracked in the simulation. The meaningful level of changes in the shared attributes was determined as the prevalent value for the industry. For comparing the achieved results with the optimal situation, where every change is

instantly reported to the RTI, another hybrid model based on the ideal situation has been developed. Fig. 4 shows the results from both cases. While the DES model is a stochastic model, it is not expected that two different results from one model will be exactly the same; however, as it is shown in Fig. 6, both models follow the same formation for both production rate and number of labor hours. The simulation time was 5 minutes for the proposed architecture and 6 minutes for the ideal situation, which shows a 17% savings in computer processing time. However, in more complex problems with more communication lines and federates, a greater savings of processing time is expected.



Ideal Situation Proposed Architecture

Fig. 4. Achieved results from hybrid simulation models

7. Conclusions

While simulation modeling techniques, such as DES and SD, have difficulty capturing reality when they are used singularly, and when the complexity of a system is increased, hybrid simulation methods are appropriate tools for system modeling and support more accurate analyses of system behavior. Most construction-related systems are made up of a combination of significant operational and context level factors that impact each other (e.g., equipment capacity versus operator skill; number of resources versus resource performance). Because it can deal with these complexities, hybrid modeling can enhance the decision-making processes of construction organizations.

Although research focused on SD-DES hybrid modeling dates back to the late 1990s, most of these efforts have originated from disciplines other than construction, and are, therefore, tailored to problems existing in these disciplines. To address this issue, the current research proposes a customized architecture for construction-related systems. By using HLA as its communication framework, this architecture attempts to improve on the communication methods in hybrid modeling, while offering an accuracy control mechanism that can be used by model developers to strike a balance between time and accuracy in modeling. However, the capabilities of the proposed architecture should be verified by applying it in a real construction project.

References

AbouRizk, S. M., Al-Hussein. M., Mohamed, Y. (2006). "Development of synthetic environments for select construction applications." Collaborative Research and Development Grant, Feb. 2006.

AbouRizk, S.M., and Robinson Fayek, A. (2006). "Synthetic environments for construction planning and control." NSERC Industrial Research Chair Research Program, Feb. 2006.

Borshchev, A., Karpov, Y., and Kharitonov, V. (2002). "Distributed simulation of hybrid systems with AnyLogic and HLA." Future Generation Computer Systems, 18, 829-839.

Choi, K., Bae, D., and Kim, T. (2006). "An approach to a hybrid software process simulation using the DEVS formalism." Software Process: Improvement and Practice, 11, 373-383.

Fahrland, D. A. (1970). "Combined discrete-event/continuous-systems simulation." Simulation, 14(2), 61-72.

Fehlberg, E. (1970). "New high-order Runge-Kutta formulas with an arbitrary small truncation error." Computing, 6, 61-71.

Kuhl F., Weatherly, R., and Dahmann, J. (1999). "Creating computer simulation systems: An introduction to the high level architecture." Prentice Hall PTR, Upper Saddle River, NJ 07458, 5-6.

Golden, D. G., and Schoeffler J. D. (1973). "GSL - a combined continuous and discrete simulation language." Simulation, 20(1), 1-8.

Hollocks B. W. (2006). "Forty years of discrete-event simulation—a personal reflection." Journal of the Operational Research Society, 57, 1383–1399

Lee, S., Han, S., and Peña-Mora, F. (2007). "Hybrid system dynamics and discrete event simulation for construction management." ASCE International Workshop on Computing in Civil Engineering, Pittsburgh, PA.

Martin, R., and Raffo, D. (2001). "Application of a hybrid process simulation model to a software development project." The journal of systems and software, 59, 237-246.

Pena-Mora, F., Han S., Lee, S., and Park, M. (2008). "Strategic-operational construction management: hybrid system dynamics and discrete event approach." Journal of Construction Engineering and Management, ASCE, Sep. 2008.

Pooch, U. W., and Wall, J. A. (1993). "Discrete event simulation a practical approach." CRC Press. Inc., Florida, 184.

Pritsker, A., and Hurst, N. R. (1973). "GASP IV: A combined continuous - discrete Fortran-based simulation language." Simulation, 21(3), 65-70.

Rabelo, L., Helal, M., Jones, A., and Min, H. (2005). "Enterprise simulation: A hybrid system approach." International Journal of Computer Integrated Manufacturing, 18(6), 498-508.

Venkateswaran, J., Son, Y., and Jones, A. (2004). "Hierarchical production planning using a hybrid system dynamic-discrete event simulation architecture." Proceedings of the 2004 Winter Simulation Conference, 1094-1102.

PLANNING TEMPORARY HOISTS FOR BUILDING CONSTRUCTION

Seokyon Hwang[1]

[1]Assistant Professor, Department of Civil Engineering, Lamar University, P.O. Box 10024, Beaumont, TX 77710. PH (409) 880-7557; FAX (409) 880-8121; e-mail: seokyon.hwang@lamar.edu

Abstract

An effective plan of temporary hoists is important in building construction that demands much vertical transportation of resources during the construction phase. Almost every trade of building project relies on hoists to move personnel, materials, and equipment in vertical direction. Thus, the availability of such equipment inevitably influences performance of each trade. Despite its significant roles and functions in building construction, it is challenging to develop an effective plan for the procurement, install, and operation of the equipment. One needs to deal with many decision variables and information associated with decision-making with regard to the selection, erection, operation, and maintenance of hoists. Understanding such significance and difficulties, the present research initiative intends to develop a method that can support decision-making process of planning hoists for building construction. This paper reports the results of the first phase of the present research.

Key Words: Hoisting; Temporary hoists; Building construction; Logistics; Simulation

Introduction

Building construction requires effective planning and operations of temporary hoists. Hoists, together with the cranes, are essential equipment for building construction. Hoists serve as a main means of vertical transportation of resources, including personnel, materials, and equipment. Thus, inappropriate arrangement of temporary hoists can result in significant impact on overall project performance. Too few hoists can create constraints to the job, such as lack of hoisting capacity. Failing to hoist manpower and materials in a timely manner due to lacks of hoists is likely to result in productivity loss. On the contrary, too many hoists can cause hoists be idling for considerable time so as to incur unnecessary expense.

Planning hoists demands extensive collection and analysis of information to make decisions regarding the procurement and operation of hoists, such as number of hoists, capacity of a hoist, the best locations of hoists, and the schedule of erection of

multiple hoists (Daewoo E&C 2002). Although various arrangements of hoists are considered based on available information, it is difficult to evaluate each arrangement and finally choose the best one. The process becomes more difficult when more hoists need to run more floors. Nevertheless, the investigation of current practices revealed that most practitioners rely on personal experience and knowledge obtained from previous projects. Literature review identified that such a significant problem has been hardly studied, while there was much research on planning cranes for building construction (Tantisevi and Akinci 2008).

The goal of the present research endeavor is to develop a method for planning temporary hoists for building construction. This research particularly is concerned with large scale projects such as high-rise building construction that uses hoists heavily. In this paper, the results of the first phase of this endeavor are presented. The objectives of this paper are to present: the results of survey of existing practices, the proposed new approach; and a plan for validation of the proposed approach.

Temporary Hoists

Temporary Hoist

A temporary hoist, also known as a temporary elevator, construction elevator, or construction lift, is commonly used in building construction projects. Being situated at a fixed location, it provides services for transporting resources in a vertical direction to working areas. In building construction projects, hoists normally are leased or rented by general contractors. Leasing companies provide services to erect, dismantle, and maintain the hoists. A hoist system consists of a few components—mast, tie, and car (cage) (Figure 1). Mast sections are erected to build a tower and tied to the structure for stability and one or two cars travel vertically along the mast tower. For the operations of hoists, additional components are required—landing platform (landing, gate, and fence) on each floor, access road, and loading/unloading station.



(a) Double cars and mast tower



(b) Landing, gate, fence, and tie

Figure 1. Temporary Hoist System Components

Notable Differences: Temporary Hoists vs. Permanent Elevators

Concerning the components and operations of a system, a temporary hoist system is very similar to the permanent elevator systems. There are, however, a few notable differences one should pay attention to when planning hoists, which are described in the following, focusing particularly on operations and services. Permanent elevators are operated automatically within a fixed zone, according to an algorithm which is a set of rules determining the motion of elevators, by which elevators are controlled. For example, assuming of a single elevator (Ioannou and Martinez 1992), an elevator going up or down will continue to move in the current direction until it completes its service for passengers in the car and as long as are remaining requests of services in that same direction; it only changes its direction if there are requests in the opposite direction while there are no more remaining requests in the current direction.

Meanwhile, temporary hoists normally are operated manually by operators who are on board. As an operator riding in a car finds people want service, the operator stops the car and let people, materials, or equipment get in the car and continue to move in the current direction. When a hoist runs, it normally does not change direction in the middle of driving before it reaches the last floor in the current direction. Another important point is that the service areas by temporary hoists change as time goes according to progress of a project. In other words, the number of floors it stops on and the spatial interval of travel of a car in a vertical direction change as construction progresses. There are many commercial products for planning permanent elevators. They are, however, not effective to take into considerations the unique aspects of the arrangement and operation of temporary hoists.

Research Methodology

In order to understand the existing approach in practice and collect lessons from practitioners in the industry regarding planning temporary hoists, a questionnaire was designed and distributed to practitioners. The questionnaire is composed of seven questions in three categories. Questions were designed to inquire about practitioners' experiences and knowledge in planning temporary hoists, and also to collect decision variables and input variables that practitioners normally used for the planning. Meanwhile, literature review was not much of help to investigate existing methods.

The first part of the questionnaire includes Question #1, #2, and #3, inquiring about personal experience with temporary hoists on the job site. Question #3 particularly was asked to collect cases and consequences of an inappropriate plan of hoists. The second part that consists of Question #4 and #5 inquires about decision variables need to be determined and input variables required to make decision on each decision variable. The last part, Question #6 and #7, asks about methods (or approach) used by practitioners in real projects.

Summary of Questionnaires: Existing Approach

Characteristics of Respondents

Respondent consists of as follows: project manager/executive (57%); superintendent (14%); project engineer (14%); and estimator (14%). Little more than half of the respondents (57%) have more than 10 years of experience in construction. Approximately 64% of the respondents have been involved in planning temporary hoists, and about 7% of respondents who have less than 10 years of experience were also involved in preparing temporary hoist plans. The threshold of years of experience was set to be 10 years, because the period of time is long enough for construction personnel to work on approximately three to five building projects.

Consequences of an Inappropriate Plan

A significant portion of respondents (almost 60%) reported cases and consequences of an inappropriate plan for Question #3. Nevertheless, it does not mean that the same percentage of the number of projects the respondents have worked on had the issues. A respondent may have observed such a case from one project only while serving on multiple projects in his or her career. The following describes some selected cases.

- Late procurement of hoists and resulting delay of erection on site
- Failure of coordination between structure and hoist erection schedule
- Failing to secure enough clearance between hoists and protruding structure
- Shortage of hoist availability and competition among trades
- Difficult direct unloading due to failure of checking access of truck
- Delayed interior finishing and building occupancy due to hoists
- Violation of code restrictions

Frequently Used Decision Variables and Input Information in Practice

As can be expected, respondents who have been involved in planning process provided more comprehensive and explicit answers to the questions of the second and third part. Figure 2(a) depicts distribution of answers to Question #4—majority of the respondents (about 80%) pointed three variables as the most important decision variables: (a) number of hoists, (d) locations of temporary hoists, (e) locations of hoists, (f) locations of landing platforms, and (g) cost (price per unit and total cost). Meanwhile, (c) rent or purchase was selected by the least number of people, which seems natural where most companies rent hoists on a project basis. Only 14% of respondents addressed other variables such as “single car or double car” and “how many jumps of mast”.

In regard to Question #5, practitioners responded with various input information. Nevertheless, many respondents were confused of input variables and decision variables; for instance, they named locations of hoists, landing floors, capacity of hoists, and jump schedule as input information while those are actually decision variables to be determined in the existing approach. The following summarizes input variables in three categories: project data; erection, operation, and maintenance of hoists; and subjects to serve.

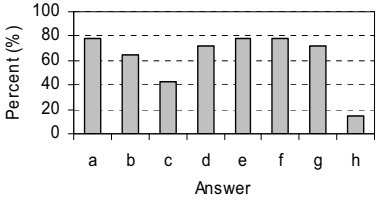
- ***Project data:*** building height, building area, project schedule (structure, enclosing), permanent elevator schedule (installation, tests), areas interrupted

by hoists, site logistics (street access, truck path, loading station access), temporary enclosure (winter protection), enclosing system at hoist location;
- ***Erection, operation, and maintenance of hoists:*** minimum clearance between cars and building, schedule of hoist usage, safety regulations, communication requirements for operation, maintenance requirements, accessibility to hoist and loading/unloading station on the ground floor, travel distance of hoisted materials;
- ***Subjects to serve:*** number of men per day, list of materials and equipment, largest and heaviest material and equipment;

Current Approach Implemented In Practice

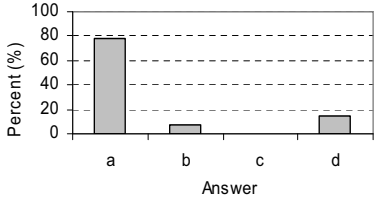
The last part, including Question #6 and #7, inquires about the methods or approach implemented in practice. Figure 2(b) presents distribution of answers to Question #6. Regarding Question #6, experience and knowledge obtained from previous projects was the dominant method in practice—about 80% of respondents have planned temporary hoists relying on experience and knowledge obtained from previous projects. Only a few respondents reported alternative methods, for example, logistic diagrams to study traffic patterns around the hoists. With Question #7, not many respondents have provided the anticipated type of answer. Instead, answers were more relevant to Question #4 and #5, and most of the answers were overlapping with those for the two questions. But a few of them who have much experience provided informative answers, which are summarized below.

- Step 1: Review requirements of the project.
- Step 2: Locate the most convenient, workable, and accessible location.
- Step 3: Decide landing floors.
- Step 4: Determine number of cars and capacity of each car
- Step 5: Erect hoist when schedule requires it to be built.



a. number of temporary hoists
b. capacity of each temporary hoist
c. rent or purchase (?)
d. schedule of placing order, installation, and removal
e. locations of temporary hoists
f. locations of landing platforms
g. cost (price per unit and total cost)
h. others

(a) Question 4



a. experience and knowledge obtained from previous projects
b. mathematical formulas available for planning hoists
c. advanced techniques (e.g., computer simulations)
d. others

(b) Question 6

Figure 2. Survey Results: Question #4 and #6

Proposed Approach

Schematic Model

Figure 3 illustrates a schematic model of decision-making process for planning hoists. The process begins with the preparation of input data: project data, resource schedule, and constraints. Details about these data are discussed in the following subsections. Given the information, a planner creates multiple numbers of arrangements of hoists by using the so-called engineering judgment applying experiences and knowledge learned from previous projects. Resulting sets of arrangements are first outcome of the process. In the next step, each arrangement is simulated to obtain important statistics, such as, waiting time of personnel, cycle time of hoist trip, and idling time of hoists. The statistics are then used to measure the efficiency of the arrangement. Efficiency is measured on the basis of the degree of satisfaction of policies pre-determined as the requirements of hoisting capability for the project. Simulation continues until all available arrangements are simulated and evaluated. With the completion of simulation, all efficiency measurement will be compared and ranked to finalize the decision-making process. At the end, the model produces a report of the arrangements with their ranks in efficiency, recommending the best arrangement.

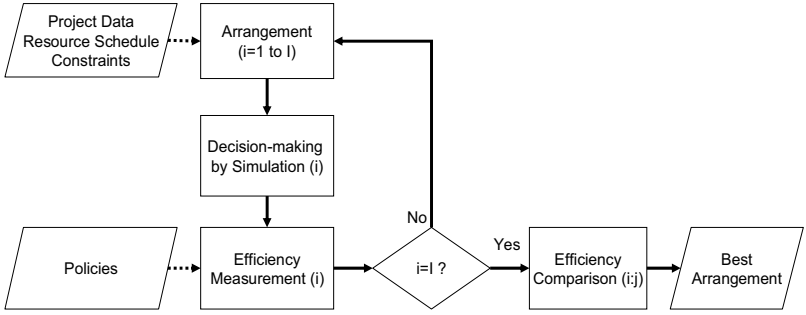


Figure 3. Simplified Schematic Model

Planned Simulation Model

As mentioned earlier, various arrangements can be and should be made using input variables and policies and each arrangement needs to be examined prior to its implementation. Therefore, the decision-making process is essentially the evaluation of what-if situations to find the best solution. Simulation serves well to solve such an evaluation problem. Naturally, simulation is widely accepted and applied to the study of elevator planning (Ioannou and Martinez 1996). A model to be developed in this research can be defined as a stochastic and discrete model. For the development of a simulation model, the present research adopts components of a model from Liu and Ioannou (1992): resources, queues, activities (events), routers, consolidations, links, and network logic. Finally, in order to account for changing service areas over time, simulations need to be conducted phase-wise according to the project schedule, most probably based on the milestone schedule.

Input Variables

In the proposed approach, information or data that are needed for planning hoists in building construction are categorized into five groups. Three groups, project data, resource schedule, and constraints, represent conditions given by a project. These groups are used to generate possible arrangements of hoisting plans. Arrangements are both decision variables and input variables in the proposed method. Arrangements are made by using the above three groups of input variables, then the decisions are provided to simulation stage as input variables, as illustrated in Figure 3. Meanwhile, policies are to be determined prior to simulations by a decision maker in order to meet certain requirements of hoisting. The below lists details of input variables in each category including those provided by practitioners and additional items (*italicized*) identified by the author.

- ***Project data:*** basic informative data of a project (height, area, construction schedule, permanent elevator, winter protection, structure and enclosing system), areas interrupted by hoists, site logistics (access, station), distance traveled of hoisted materials, schedule of hoist usage, *available hoist models and specifications, trades interrupted by existence of hoists (list, amount of work), water-tight (location, installation, schedule), distance between storage yard and hoist, direct loading from the trucks, available area of loading station, forklift turns*;
- ***Resource schedule:*** number of men per day, largest and heaviest material and equipment, *list of materials and equipment, amount of resources to be hoisted to each floor;*
- ***Constraints:*** minimum clearance between cars and building, erection time, safety regulations, maintenance requirements, *shape of building (setback, protruding areas), behavior of people (arriving, waiting, staying, moving) and corresponding probability;*
- ***Policies:*** *thresholds of statistics related to behaviors of personnel, selected list of materials and equipment to use hoists, general conditions of operationss;*
- ***Arrangement:*** number of elevators landing floors, number of hoists, locations of hoists, landing floors, capacity of hoists, and jump schedule, *schedule of placing order, delivery, erection, and dismantling of hoists;*

Ongoing and Future Research

As the survey results show, planning temporary hoists is mostly done intuitively and informally in practice, which is more or less the same situation as planning cranes (Shapira and Glascock 1996). Using formal guidelines and quantitative simulation, the proposed approach should be able to produce more objective and quantifiable analysis for hoisting resources in building construction. In the continued endeavor, it is envisioned to develop a simulation model. The present research currently focuses on the development of the framework of data preparation for simulation. Another ongoing task is the development of a preliminary simulation model based on discrete event simulation technique. Activities include defining the relationships among entities and the development of mathematical equations and logic. Data collection

regarding personnel behaviors is planned. One of major challenges remaining is to automate the generation of the arrangements of hoists. Theoretically, unlimited numbers of arrangements can be made. It is, however, important to reduce the numbers so as to generate a reasonable numbers of arrangements.

Plan for Validation

An ideal validation would be testing the proposed approach in many real projects. The effectiveness of a recommended solution needs to be implemented and its results should be compared with the results of other arrangements. This requires implementation of different arrangements in the same project, which is clearly infeasible and impractical, if not impossible, in real world. Alternatively, a practical and more feasible plan is to focus on the examination of the following: (1) how much informative and thorough the approach is and (2) how sensitive the simulation model is. Its thoroughness will be measured on the identified input and decision variables, classification of information, and guidelines for the generation of arrangement.

Discussions and Conclusions

The present study showed the challenges relevant to planning temporary hoists for building construction. Various consequences of inappropriate hoisting plans well illustrate the importance of an effective plan for temporary hoists. The complexity of hoist planning was well pronounced by the variety of input information and variables that should be taken care of to produce effective plans. Although experience and knowledge may work well some times, the problem of planning hoists is too complex to be solved by intuitive decision-making process. With formal guidelines, the process of decision-making can be more effective and the resulting decisions can be more accurate. It is envisioned that combining knowledge and formal method can enhance the quality of planning temporary hoists.

References

Daewoo E&C (2002). "Telekom Malaysia Project." Technical Report, Daewoo Engineering & Construction, CD version.

Ioannou, P.G., and Martinez, J.C. (1996). "Scalable Simulation Models for Construction Operations." Proc., 28th Conference on Winter Simulation, IEEE Comp. Soc., December 8-11, 1996, Coronado, CA, 1329 – 1336.

Liu, L.Y., and Ioannou, P.G. (1992). "Graphical Object-Oriented Discrete-Event Simulation System." Proc., 24th Conference on Winter Simulation, December 13 - 16, 1992, Arlington, Virginia, ACM, 1285 – 1291.

Shapira, A., and Glascock, J.D. (1996). "Culture of using mobile cranes for building construction." J. Constr. Engr. and Mgmt., ASCE, 122(4), 298-307.

Tantisevi, K., and Akinci, B. (2008). "Simulation-Based Identification of Possible Locations for Mobile Cranes on Construction Sites." J. of Comp. in Civil Engr., ASCE, 22(1), 21-30.

ALLIANCE TEAM SELECTION FOR INFRASTRUCTURE PROJECTS USING MONTE CARLO SIMULATIONS

Mounir El Asmar[1], Awad S. Hanna[2], Chul-Ki Chang[3], Jeffrey S. Russell[4]

Abstract: Similar to the design-build delivery system, the alliance delivery system is used here to denote a special form of partnership between the owner and the design-build team, demonstrated through the substantial involvement of the owner. Design-Build/Alliance delivery systems have been implemented successfully for private projects. However, their use in public work has been hindered by many issues including the presence of qualitative selection criteria and the absence of a scientific evaluation process to select the winning team. This paper lays out a framework which facilitates selecting the best alliance team for a project. Monte Carlo simulations were used to vary all the factors relevant to the decision problem and to uncover biases present in the evaluation. These may arise due to any unfairness of the model represented by the weights of the criteria or any possible discrimination from the evaluators. Use of this tool would complement the high performance of design-build/alliance project delivery systems and further enhance it by ensuring that the selected team is the best one for the job, thus lowering project risks. A case study dealing with a large utility project illustrates the developed framework.

Introduction

The success of a project is very much dictated by the competency of the team designing and building it. Accordingly, selecting the most qualified designer-contractor team for a design-build project can be one of the most important

[1] Research Assistant, Department of Civil and Environmental Engineering, University of Wisconsin–Madison**,** 2256 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706, E-mail: elasmar@wisc.edu.
[2] Professor and Chair, Construction Engineering and Management Program, Department of Civil and Environmental Engineering, University of Wisconsin–Madison**,** 2314 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706, E-mail: hanna@engr.wisc.edu.
[3] Research Fellow, Construction & Economy Research Institute of Korea, 71-2 Nonhyundong Kangnamgu, Seoul, Korea, 135-701, E-mail: ckchang@cerik.re.kr.
[4] Professor and Chair, Department of Civil and Environmental Engineering, University of Wisconsin–Madison**,** 2205 Engineering Hall, 1415 Engineering Drive, Madison, WI 53706, E-mail: russell@engr.wisc.edu.

factors for project success. The owner and associated representatives making the selection decision must understand the critical nature of this time in the project and take the necessary steps toward making the correct evaluation of each team. The task of developing the selection criteria ultimately falls upon the owner of the project and needs to occur before the competitors submit proposals. There are a multitude of criteria to consider, all of which need to be prioritized. Choosing these criteria can be a daunting task; and analyzing evaluations of each criterion to make the finest selection decision can be an overwhelming one. Fortunately, methods exist to make this process easier. The Monte Carlo simulation is one such method that is very efficient when dealing with several inputs. It minimizes the subjectivity involved in decision making under uncertainty.

The Alliance Delivery System

Due to the limitations of the traditional design-bid-build (DBB) project delivery system, especially with respect to project overrun and litigation caused in partly from the late involvement of the contractor in the project, other project delivery methods such as the design-build (DB) method are increasingly used. They are replacing DBB systems, particularly on certain types of innovative projects, because of improved performance (Touran and Lopez 2006). For this type of delivery system to be efficient, the contractor and the designer form what is commonly called a design-build team. The owner has to deal with only one entity, which provides a single point of responsibility. Moreover, the contract type is usually Guaranteed Maximum Price and the owner does not share cost overruns. The term *alliance* is used in this paper to characterize a partnership among the major parties involved in a project, namely the design professional, the general contractor, and the owner. The owner is substantially involved in the project; his/her role extends to five different areas, which constitute the major disparities between DB and alliance:

- The owner specifies certain products, prequalifies certain suppliers, and orders long-term procurement items before the alliance selection has occurred.
- The owner may choose to buy equipment/materials. This is particularly important for equipment that requires long-term lead time.
- The owner conducts a cost-estimating procedure to specify target costs for individual components. The schedule of the project is also fixed.
- The owner has access to actual cost information, has the right to audit overhead costs, and sets a fixed percentage of profit.
- The owner is a partner in risk and reward. Target pricing is established in advance. If the team performs better, the owner and design-builder share the profits; if the cost is higher than the target price, the overrun is also shared.

Literature Review

Previous research shows that design-build project delivery systems can perform better than traditional systems on certain types of projects with respect to cost, schedule, and quality performance; this has been studied for both privately and publicly financed projects (Konchar and Sanvido 1998). Molenaar and Johnson (2003) and Palaneeswaran et al. (2003) showed that optimum contractor selection can be done through comparison of the "best value," which is a measure of cost,

time, and quality, where quality can account for many factors such as environmental, aesthetic and safety factors. Palaneeswaran and Kumaraswamy (2000) studied the best practices and formulated a structured approach to design-build contractor selection. Abi-Karam (2005) and El Wardani et al. (2006) also illustrated different DB selection methods. Although many authors have investigated the various methods for selecting a design-builder, no methods are available that account for any biases that may enter into these design-build evaluations. A Monte Carlo simulation can be used to minimize bias. The Monte Carlo method has already been utilized in decision making and has proven to be efficient when it comes to considering the effect of numerous factors on a specific output. In the past, Monte Carlo simulations have primarily been used in the construction engineering industry to determine the risk associated with change orders. Back and Bell (1995) demonstrated that the Monte Carlo simulation is an excellent tool for analyzing the potential impact of modifications proposed for a complex process. Touran and Lopez (2006) also used Monte Carlo simulations to model cost escalation in large infrastructure projects.

Problem Statement and Purpose

The process is similar for both DB and alliance team selection. Previous studies on DB/alliance team selection do not account for evaluation bias. The weights model, serving merely as an illustration of the problem, can heavily impact selection. Another form of bias could result from the inclination of an evaluator, whether it was deliberate or just because assessing qualitative criteria is a tough task. This leads to our development of a comprehensive selection framework that quantifies qualitative evaluations and, through the use of Monte Carlo simulations, builds upon previous methods by reducing biases in the assessment. Use of this tool would complement the high performance of DB/alliance delivery systems by ensuring that the selected alliance is the best for the job. The methodology is discussed in the next section and is illustrated by a supporting case study in the third section of this paper.

The Alliance Selection Methodology

The process of selecting a designer-contractor alliance consists of four successive steps. These steps can be summarized as follows.

The Alliance Selection Criteria and Their Respective Weights

After the needs of the project are identified, a set of selection criteria is developed. A level of importance (weight) must also be assigned to each criterion. Consequently, a rating system is created for evaluating the alliances.

- Selecting the Criteria

The first step in the process of selecting an alliance team to design, procure, manage, and build a project is to establish a set of criteria or categories that are most important for the owner. The cost and schedule are quantitative entries and are taken into account early in the selection process, since the owner has specified target costs and has fixed the time frame in advance. In contrast to these two quantitative factors, the remaining criteria are mostly qualitative. For this step we are looking at those qualitative criteria that are deemed important for project

success. The following is a sample list of criteria used in selecting an alliance: previous experience with partner and/or owner, employee training programs, workforce stability, safety record, references from other owners, performance guarantees, team/departmental integration approach, experience with type and size of project, approaches to unique aspects of the project, experience and authority of key individuals, innovation of quality management plan, measures to evaluate performance, approach to involve stakeholders, geometric and structural enhancements, aesthetics, maintainability, and public involvement. This is only a sample list of criteria, which can vary depending on the owner's needs for the specific project. The listed criteria are qualitative. The process, however, requires a quantitative evaluation. A simple way to deal with this issue is to rate the bidders based on a numeric scale. A rating system ranging anywhere from one to five points is typically used to assess the owner's satisfaction with an alliance team's adherence to the criteria. The example presented here used a four-point scale. For each criterion, a 1 meant that the alliance team did not meet expectations at all. A 2 meant that the alliance team was below expectations. A 3 meant that the alliance team met expectations. Finally, a 4 meant that the alliance team exceeded expectations represented by the specific criterion.

- Assigning Levels of Importance

In addition to deciding on the criteria for selection, it is necessary to assign an importance level to each criterion; these are shown in column (2) of Table 1. The weight percentages assigned for the selection criteria are determined by the owner prior to the completion of the evaluations and are based on the factors which the owner deems most important. This allows the model to weight each of the ratings given by the evaluators based on the criteria that are more or less critical to the success of the project. After a level of importance has been assigned to each criterion, the sum of the percentages should equal 100%.

Table 1: Importance Factors with Minimum and Maximum Values of Iteration

(1)	(2)	(3)	(4)	(5)
Criteria	**Original Weight**	**Triangular Distribution**		
		Lower Limit	**Mode**	**Upper Limit**
Experience with Owner	10%	5%	10%	15%
Experience with Alliance Projects	15%	5%	15%	25%
Alliance Team Capabilities	20%	10%	20%	30%
Alliance Methodology Approach	25%	15%	25%	35%
Alliance Team Business History	10%	5%	10%	15%
Cultural Fit	10%	5%	10%	15%
Efficiency & Effectiveness	10%	5%	10%	15%

Alliance Solicitation, Presentations, and Evaluation

Once the criteria and their respective weights are decided on, the owner can proceed to the next step which consists of inviting alliance teams to a presentation of the project. Competition is always healthy as it ensures that the owner gets the best available product. But competition between a large number of alliance teams

is not realistic, since time is a significant issue and because the evaluation process is very costly and requires substantial effort on the part of the owner as well as the teams. A limited number of pre-qualified bidders shortens the process time while still allowing for competition. It allows the owner to perform a thorough evaluation, hence minimizing any risks involved in selecting an alliance. The owner's belief in the alliance teams' qualifications to apply for the job and knowledge of their performance capabilities are influential in this pre-selection. These pre-selected potential alliances capable of performing on the project are solicited for work, and the selection criteria are sent to them to be used as guidelines for developing their designs. It is at these presentations that owner representatives evaluate prospective alliances based on the criteria identified. Owner representatives should be given evaluation sheets with the list of criteria and directions on how to rate each alliance. Once the evaluations are completed, they can serve as inputs for the Monte Carlo simulation.

Monte Carlo Simulation

Subjective evaluations are rarely quantified precisely because bias is always a potential issue, be it deliberate or unintentional. A way to deal with bias is to build a model describing the ongoing process then run simulations that will reproduce the procedure and that vary by eliminating evaluators or changing the weights of criteria to account for any biases. Replicating or modeling real systems to predict a certain behavior and investigating thousands of different scenarios for the same case reveal a system's sensitivity to random variation of inputs, lack of knowledge, or input error, thus helping one in making decisions. The method transforms a deterministic model, in which the equation gives one output based on the original input parameters, into a stochastic model where the input variables are randomly generated from probability distributions that sample a certain population and in which the output is different for every run of the model. Let the score for factor 1 = S1, the weight for factor 1 = W1, and so on for the remaining factors. The total score will be a weighted average of all these qualitative criteria. In the deterministic case, the weights are fixed: W1 = 10%, and so on. To reduce the bias from the model that specifies the respective weights, we use a stochastic model. In the stochastic case, W1 equals a random percentage taken from the triangular distribution shown in Table 1, with a mode of 10%, a minimum of 5%, and a maximum of 15%. All the other weight factors, W2 to W7, will have their own distributions too. In other words, the off-the-shelf software simulates the model many times, taking a different point for each iteration from the specified probability distribution for every input. The calculated output will also be different for every run, and its distribution will be calculated. This assures the owner that the importance factors were not the only aspect of the analysis driving the results.

Performing a Monte Carlo simulation is a major stage in the alliance selection process and encompasses three steps: The parametric model is developed, which is in our case the equation computing the weighted score of an alliance. The evaluation data are then inputted, and the weight probability distribution is identified to generate random inputs. Finally, several iterations are performed to evaluate the model. One of the major benefits of the Monte Carlo

method is that, in contrast to deterministic models, it can generate random variables in order to look at a decision problem from many angles. In the case of an alliance team selection, it can change the weights of one or more criteria and observe how this affects the results. Additionally, it can recalculate the scores after one or more evaluators have been eliminated from the analysis to minimize any sort of team bias, which refers here to any unfairness on the part of an evaluator in rating a particular alliance. The program is also coded to report the winning alliance in all situations.

Analysis of Results

The results of the simulation are given in two forms. The first uses only the raw data and yields an average of all evaluators' scores, both weighted and unweighted. A sample page of one alliance team's ratings is shown in Table 2, where the letters from A to H represent the eight evaluators. The closer the unweighted average scores are to the weighted average, the greater the reliability of the model, because this would signify that the criteria are scored in a way where the weights used did not influence the selection results significantly, only in this exact case. For example, this can be the case when the teams' individual scores are very similar for all the different criteria. The second method uses sensitivity analysis to examine the data, which involves varying or removing some of the inputs to the simulation and observing the effect. A sample portion of a sensitivity analysis can be seen in Table 3. This sample makes changes to the simulation by seeking out those evaluators who may have had the largest impact on the results. It is important to note that this sample is only one aspect of the sensitivity analysis. Another aspect is dealing with the bias attributable to the model itself by varying the weights of the input factors.

Table 2: Alliance Team 1 Presentation Summary Scorecard (Raw Data)

Criteria	**Weight**	**Alliance Team 1**							
		Evaluator							
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Experience with Owner	10%	2	2	2	4	3	3	3	3
Experience with Alliance Projects	15%	3	4	3	3	4	4	3	3
Alliance Team Capabilities	20%	3	4	2	3	4	3	3	2
Methodology Approach	25%	2	4	4	3	4	3	3	3
Alliance Business History	10%	3	4	3	2	3	3	2	3
Cultural Fit	10%	2	4	3	2	3	3	2	4
Efficiency & Effectiveness	10%	1	4	3	3	4	3	2	3
Average / Evaluator		2.3	3.7	2.9	2.9	3.6	3.1	2.6	3.0
Weighted Average / Evaluator		2.4	3.8	3.0	2.9	3.7	3.2	2.7	2.9
Average Score					3.00				
Weighted Average					**3.06**				

Table 3: Evaluator Change with Winner Shaded in Gray

Evaluator Change	T1	T2	T3	T4
Original weighted score	3.06	2.52	2.5	**3.09**
After deleting the highest score in each team	2.95	2.41	2.43	**3.03**
After deleting the lowest score in each team	3.16	2.61	2.59	**3.17**
After deleting both the highest and lowest	3.05	2.51	2.52	**3.10**
Without the Ev. whose score had big range (B)	2.95	2.53	2.59	**3.17**
Without the Ev. whose score had second big range (H)	**3.08**	2.61	2.54	3.06
Without both B and H	2.96	2.64	2.64	**3.14**
Without the Ev. who scored team 2 highest (C)	3.07	2.44	2.49	**3.15**
Without the Ev.who scored team 3 highest and scored team 1 lowest (A)	**3.16**	2.48	2.43	3.11
Without both C and A	**3.19**	2.38	2.41	3.18

Alliance Selection Illustrative Case Study

In order to fully reveal the use of the Monte Carlo simulation in selecting an alliance, this paper includes an example of the previously discussed methodology. This case study involves a large company and project, demonstrating the critical nature of the methodology and increasing the impact of the decision.

Project Scope and Delivery System

The nature of the utility project presented in this case study was such that it required an extremely large budget that would be spent over a period of five years. Additionally, it involved construction in 30 different locations spread over approximately 50,000 square miles of land. The project was funded by a big company whose need for on-time completion was rapidly increasing. These facts combined to encourage the owner to use an accelerated type of project delivery system, namely design-build, whereby the contract would be awarded to the "best value" competitor. Moreover, because of the special involvement of the owner, we can differentiate this special type of design-build as being an alliance delivery system. The demands on the alliance partnership chosen for the project were substantial. Consequently, it became imperative that an accurate analysis of each team be performed in order to minimize the risk of financial loss and maximize the benefits. The delivery system included the engineering, procurement, and construction of all thirty facilities. A number of challenges exist with this type of contract. The selected alliance team needs sufficient construction labor, systems to support construction needs, sufficient design support to meet deadlines, proper leveling of resources by the contractor, careful budgeting and forecasting, and sufficient lines of communication, among others.

Alliance Selection Criteria

The first step in the process was to choose the appropriate selection criteria. The company decided on the criteria shown in Table 1 and expanded upon below. The alliance methodology approach, team capabilities, and experience with alliance projects were deemed the most important criteria, with all others being equal.

- *Experience with the owner*: Has either of the partners participated in previous projects with this owner, and were the projects successful?

- *Experience with alliance projects*: Are there other alliance projects that each partner has separately participated in?
- *Alliance team capabilities*: Does the alliance have the ability to complete a project of this magnitude both physically and financially?
- *Alliance methodology approach*: Has the alliance presented a competent plan for the project with a probability of success?
- *Alliance team business history*: Has this alliance worked together before, and if so, what was the result?
- *Cultural fit*: Does the alliance promote a working environment consistent with that of the owner and the surrounding community?
- *Efficiency and effectiveness*: Does the alliance have an efficient and effective plan for and attitude toward the completion of the project?

Solicitation, Presentation, and Evaluation

Four alliance teams were pre-selected for this project. All were asked to submit a proposal package and give presentations describing their qualifications, methodology, and project plan. Eight evaluators represented the owner during these presentations and judged the alliance teams based on the outlined criteria. It should be noted that after the owner's initial determination of the evaluators, the selection criteria, and the four alliances, the selection process lasted for about three months. Evaluations were made and the results compiled.

Simulation

A triangular distribution was used to generate stochastic inputs. This requires only three values for the criteria weights: a lower limit, a mode, and an upper limit. For the purpose of the Monte Carlo simulation, these values are usually obtained from historical data or estimated by a professional in the area based on his/her knowledge and experience. Because of its originality, historical data are lacking for this process, and the distribution inputs were estimated by Dr. Awad Hanna. The model was simple, consisting of the average scores for each alliance, with the project to be awarded to the alliance with the highest score. A thousand iterations were performed for each simulation. It should be noted that other types of distributions such as uniform, beta, and normal distributions were also used to evaluate the same model and produced similar results.

Analysis of Results

- The Untreated Results

The results from the untreated average scores of all evaluators in this case are shown in Table 2 for Alliance Team 1 and in Table 4 for Alliance Team 4. Using these results, Alliance Team 4 appeared to be the alliance that the contract would be awarded to. It is important to note, however, that Alliance Team 1's final score was not drastically different from Alliance Team 4's. Also of importance is the fact that all weighted average scores were reasonably close to their non-weighted counterparts, which indicates that the importance levels did not seem to have an effect on the outcome of the analysis in this particular case. It was at this point that the sensitivity analysis became helpful in determining a clear statistical winner of the project.

Table 4: Alliance Team 4 Presentation Summary Scorecard (Raw Data)

Criteria	W	Alliance Team 4 Evaluator							
		A	B	C	D	E	F	G	H
Experience with Owner	10%	3	4	3	3	3	3		4
Experience with Alliance Projects	15%	3	3	3	4	3	3		2
Alliance Team Capabilities	20%	3	2	3	4	4	3		3
Alliance Methodology Approach	25%	3	2	2	4	4	3		4
Alliance Team Business History	10%	3	3	3	2	3	3		3
Cultural Fit	10%	3	3	3	3	3	3		4
Efficiency & Effectiveness	10%	3	3	3	3	3	3		3
Average / Evaluator		*3.0*	*2.9*	*2.9*	*3.3*	*3.3*	*3.0*		*3.3*
Weighted Average / Evaluator		*3.0*	*2.7*	*2.8*	*3.5*	*3.5*	*3.0*		*3.3*
Average Score		3.08							
Weighted Average		**3.09**							

- The Sensitivity Analysis

The raw data analysis may include biases due to the model, or out-of-the-ordinary ratings on the part of one or more of the evaluators. Altering some of the inputs in the analysis and performing a thousand new iterations of the simulation several times should reveal these biases. As a first step, only the number of evaluators contributing to the final score was changed while all importance levels were kept constant. The results shown in Table 3 had Alliance Team 1 winning the contract in three out of nine conditions. This was a change from the original weighted score which showed Alliance Team 4 as the absolute winner. Then the importance levels of the several factors were varied without removal of any of the evaluators. Out of 1000 iterations of changes in the importance levels, the results of this test had Alliance Team 4 winning 96% of the time. Additionally, the importance levels and the evaluators were varied and shifted simultaneously. The importance levels were varied as done previously, but the highest and lowest scores from each criterion were also removed. The results from this test were similar to those seen before in that Alliance Team 4 remained the winner of the contract about 97% of the time. Another test removed Evaluator B from the analysis because of the wide range of scores reported across different alliances. The results of this test also showed that Alliance Team 4 remained the winner. One more test changed the importance levels and removed Evaluator C from the study because of the high rating given to Team 2. The idea here was to reduce a potential team bias toward Alliance Team 2. Alliance Team 4 was once again the winner of the contract in this scenario. At this point the data seemed conclusive enough to award Team 4 the contract. One more test, however, focused on Evaluator A, who gave Alliance Team 3 a score much higher than its average score. The results of removing Evaluator A from the analysis revealed Alliance Team 1 as the winner. This suggests that some of Evaluator B's ratings were erroneous or subject to bias against Team 1 and would be examined further. Evaluator A scored Team 3 much higher than its average score. However, a closer

look at Tables 2 and 4 reveals that Evaluator A was also the one who gave Team 1 a score much lower than its average. This suggests a strong potential for team bias. Possible reasons are that Evaluator A had bad relations with Team 1 on a previous project or heard negative comments from contractors who worked with Team 1, among others. If Evaluator A were removed from the simulation, Alliance Team 1 would have been selected. From the owner's point of view, repeating the entire simulation without Evaluator A was necessary to ensure that this particular assessor skewed all of the results of the simulation. This was actually the case, and the contract was awarded to Team 1.

Conclusions

Employing Monte Carlo simulations to assist in the alliance team selection was extremely useful in this project. The results showed that the developed weight model was fair for all competitors and uncovered a bias from one of the evaluators that skewed the alliance selection results. The Monte Carlo simulation has evolved into an excellent tool for decision problem analysis in the construction industry. What seemed to be a qualitative analysis was turned into reassuring quantitative results. Making decisions under uncertainty and dealing with decisions involving a number of variables are two of the key benefits the Monte Carlo method has to offer. The professional implications for the alliance selection methodology, with respect to increasing confidence in selecting the best project team, support the movement of a project toward financial success.

References

Abi-Karam, T. (2005). "Design/Build Selection Process—Art or Science," Cost Engineering Journal, 47(5), 14-19.

Back, W. E., and Bell, L. C., (1995). "Monte Carlo Simulation as Tool for Process Reengineering," Journal of Management in Engineering,11(5),46-53.

El Wardani, M. A., et al. (2006). "Comparing Procurement Methods for Design-Build Projects," Journal of Construction Engineering and Management, 132(3), 230-238.

Konchar, M., and Sanvido, V. (1998). "Comparison of US Project Delivery Systems," ASCE, Journal of Construction Engineering and Management, 124 (6), 435-444.

Molenaar, K. R., and Johnson, D. E. (2003). "Engineering the Procurement Process to Achieve Best Value," Journal of Leadership and Management in Engineering, 3(3), 137-141.

Palaneeswaran, E., and Kumaraswamy, M. M. (2000). "Contractor Selection for Design/Build Projects," Journal of Construction Engineering and Management, 126(5), 331-339.

Palaneeswaran, E., et al. (2003). "Targeting Optimum Value in Public Sector Projects through 'Best Value'-Focused Contractor Selection," Engineering, Construction and Architectural Management, 10(6), 418-431.

Touran, A., and Lopez, R. (2006). "Modeling Cost Escalation in Large Infrastructure Projects," Journal of Construction Engineering and Management, 132(8), 853-860.

REAL-TIME SIMULATION FOR LOOK-AHEAD SCHEDULING OF HEAVY CONSTRUCTION PROJECTS

Lingguang Song[1], Casey Cooper[2], and Sang-Hoon Lee[3]

ABSTRACT

Heavy construction work is a highly equipment-intensive process, and contractors work under a unique set of conditions that are characterized by various resource constraints and uncertainty. Accurate and timely look-ahead scheduling based on the most recent project data can greatly improve project execution and control. This paper describes a framework of look-ahead scheduling using real-time data collection and simulation techniques. In this framework, real-time dynamic data of an actual construction operation are collected and used to update a process-simulation model for look-ahead scheduling. Compared with the traditional scheduling methods that are static and time-consuming to maintain and update, the capability of real-time simulation to dynamically incorporate new project data and changes in the work environment offers the promise of improving the accuracy of look-ahead scheduling while reducing modeling burdens on end users. To demonstrate the feasibility of the proposed framework, a prototype system was developed for asphalt hauling and paving projects.

BACKGROUND

Heavy construction work is a highly equipment-intensive process, and it usually spreads over miles, which makes project planning and control more difficult and exposes contractors to greater schedule and financial risks (Peurifoy et al. 2006). Successful execution and control of these projects relies on both effective master planning and short-term look-ahead scheduling. A master schedule provides a global view of a project, and it identifies work packages and the overall execution strategy of the project. A look-ahead or short-interval schedule, on the other hand, is a more detailed plan showing work to be done within a relatively short time window. These detailed schedules reflect actual field conditions and provide field personnel with

[1] Assistant Professor, Department of Engineering Technology, University of Houston, 375 T2, Houston, TX 77204; PH (713) 743-4377; FAX (713) 743-4032; e-mail: lsong5@uh.edu
[2] Equipment Control Manager, Gilchrist Construction Company LLC, Alexandria, LA 71302; PH (318) 427-1138; FAX (318) 445-8507; e-mail: casey.cooper@gilchristconst.com
[3] Assistant Professor, Department of Engineering Technology, University of Houston, 389 T2, Houston, TX 77204. PH (713) 743-5808; FAX (713) 743-4032; email: slee15@uh.edu

instructions regarding what tasks have been done and what tasks are yet to be performed (Hinze 2008). A look-ahead schedule should be developed based on the most recent project performance data, and it must be updated in a timely manner so that it accurately reflects the dynamic project environment. This is especially the case for heavy-construction projects because these projects are greatly influenced by numerous factors that involve uncertainty, such as weather and traffic conditions. Due to the inevitable and almost constant changes along the project timeline, schedulers must be able to quickly collect and analyze project data and incorporate them in the scheduling of future work.

Providing accurate and reliable look-ahead scheduling is challenging in at least three respects. First, data regarding the most recent project performance are the basis for predicting future performance, yet the time and cost required to manually collect and analyze these data can be prohibitive. Second, schedulers must consider uncertainty and various productivity-influencing factors and determine how they will affect the project schedule. Quantifying the combined impact of these variables can be difficult, as has been shown by many previous studies (e.g., AbouRizk and Sawhney 1993). Third, the accuracy of a look-ahead schedule is directly affected by the timing of its preparation, which means that this scheduling task is generally done a day or two before the scheduling period (Hinze 2008). While this approach helps to reduce the guesswork required for scheduling, it also means that schedulers must be able to act quickly and devise a reliable schedule in a very short amount of time.

This paper proposes a framework for efficient look-ahead scheduling of heavy construction projects using real-time data collection and simulation techniques. Within this framework, real-time dynamic data from an actual construction operation are captured and used to update a process-simulation model for look-ahead scheduling. Current industry practice and related research on look-ahead scheduling are summarized in the first section, and the conceptual framework of the real-time, simulation-based scheduling system is then described. To demonstrate the feasibility of the proposed framework, a prototype system was developed, and a heavy civil contractor was involved to establish a realistic case study. Benefits as well as limitations of the proposed look-ahead scheduling approach are also summarized and reported in this paper.

LITERATURE REVIEW

After examining the literature on planning and scheduling, Hinze (2008) argued that very little information on look-ahead scheduling had been provided. He studied the industry's practices based on a sample of approximately 30 construction firms, and he found that look-ahead schedules are typically presented as bar charts structured to cover a period of two, three, or four weeks. Many schedules include a look-back of one week to clarify the nature of the tasks to be performed and the rate at which they are to take place. However, in essentially all cases schedulers rely on readily available project information and their own subjective judgments in evaluating uncertainty and forecasting future project performance.

Look-ahead scheduling deals with day-to-day construction operations, and many of these operations are repetitive and subject to the influence of resource constraints and uncertainty that exist in the project environment. This situation has

motivated several researchers to apply discrete-event simulation to the look-ahead scheduling problem. Discrete-event simulation is a mathematical-logical model which represents a real-world system that evolves over time, and it allows users to experiment with the model to analyze and predict system performance. It is a powerful tool that can combine actual progress data and the uncertainty of the operational environment to predict future project performance. For repetitive construction operations, once the construction work has started, actual data can be collected and used to fine-tune simulation models for better prediction precision. Chung, Mohamed, and AbouRizk (2006) collected actual project data on a bi-weekly basis during a tunneling construction project, and these data were used to improve a base simulation model for more accurate performance forecasting. They showed that a proper updating process for simulation input modeling based on actual project data can reduce uncertainty and improve simulation accuracy. Lu, Dai, and Chen (2007) developed a real-time decision-support system for planning concrete plant operations that tracks activity durations in real time, with the collected data being used to update simulation input models.

Both of the above-mentioned studies indicated that a significant amount of data are required for determining the most up-to-date project performance in order to improve scheduling accuracy. With the recent growth of sensing technologies, a broad range of embedded, wide-area, and satellite-based sensors have become available for real-time and automated project data collection and transmission. For example, equipment-intensive heavy construction projects have seen the use of the Global Positioning System (GPS) to track real-time locations of construction equipment such as earth-moving machines (Ackroyd 1998; Navon and Shpatnitsky 2005) and concrete-hauling trucks (Lu, Dai, and Chen 2007). GPS is also used in the prototype system of this research.

The above-mentioned existing studies focused primarily on collecting and using real-time data to improve simulation input modeling, which concerns the determination of statistical distributions of model input parameters such as activity durations. In addition to the input modeling, real-time data also have the potential to enhance the entire simulation-modeling process, including model formulation, updating, and validation. This paper studies not only the collection of real-time equipment data but also the use of these data for updating input models, operation logic, and for validating simulation models. The following section describes the proposed look-ahead scheduling system and explains how real-time data are used to improve the simulation process.

SIMULATION-BASED LOOK-AHEAD SCHEDULING

Simulation for look-ahead scheduling must account for and react to system changes efficiently. It requires that a simulation model can capture system changes and be updated accordingly so that the changes and their impacts can be determined for look-ahead scheduling. To achieve this, the proposed system integrates three subsystem components, which are data collection, construction process knowledge, and a self-adaptive modeling process, as shown in Figure 1. A baseline project schedule and a baseline simulation model must first be defined by a scheduler. Once the project is started, real-time project data will be collected from the field and used

to update the base simulation model in order to more accurately reflect the actual project environment. Experiments with the updated simulation model can then be conducted, and the baseline schedule can be updated based on the simulation output.

Here, this conceptual system design is applied to look-ahead scheduling for an asphalt hauling and paving operation, which is described below, followed by a detailed account of the three system components in the context of asphalt hauling and paving projects.

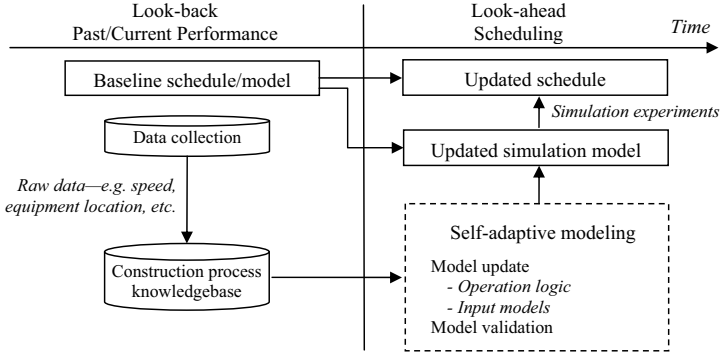


Figure 1. Real-time simulation-based look-ahead scheduling.

Asphalt Hauling and Paving Operation

In a typical asphalt pavement project, hot-mix asphalt is produced at a central asphalt plant and the mix is then hauled by trucks to the job site for paving. This asphalt hauling and paving operation is a cyclical process. The central asphalt plant usually provides asphalt mix for several projects simultaneously. At the paving site, efforts are usually made to balance the performance of the paver and hauling trucks so that the paving operation can be performed continuously. An operation involving an asphalt plant located in central Louisiana is briefly described here.

Major resources utilized in the operation are an asphalt plant, hauling trucks, pavers, and shuttle buggies. The asphalt plant features a double-barrel-drum mix process that blends, heats, and mixes aggregates and asphalt cement and produces a continuous flow of asphalt mix. Fresh asphalt mix is placed in storage silos, from which it can be discharged into dump trucks. The trucks are first prepared by spraying a release agent on their bed, and the asphalt mix is then loaded, with a shipping ticket being issued to each truck when it leaves for the job site. At the job site, the asphalt mix is discharged into a shuttle buggy, which acts as a buffer between the trucks and the paver. As soon as it is not full, the shuttle buggy can receive asphalt mix while simultaneously transferring asphalt to the paver. When a truck is fully unloaded, it returns to the asphalt plant for another hauling cycle.

Real-time Data Collection

The data-collection component collects real-time project performance data and forecasting data on the future operation environment, such as current project progress, activity duration, future resource allocation, and weather. These data can be collected from various sources, including data-collection sensors, project personnel, existing information systems, and other external sources. The hauling and paving operation relies primarily on heavy equipment, and GPS-based location-tracking sensors can be used to monitor the location, speed, and travel pattern of a piece of equipment. Real-time vehicle tracking GPS has become commercially available, and these commercial products can monitor vehicle travel data and transmit them to a remote data server in virtually real time. A GPS package that includes GPS hardware and wireless data transmission service is adopted by the contractor involved in this research (HCSS 2007). Real-time data for this research were collected from seventeen dump trucks and one paver that are equipped with this type of GPS unit.

In addition to real-time equipment data, look-ahead scheduling also requires input data regarding the actual project progress. In this study, a PC-based asphalt plant control system provides truck-loading data, such as job number, job site location, material type, and material weight, which are used to measure project progress and productivity. Look-ahead scheduling also requires a scheduler to estimate future project operation variables that may significantly affect project performance, including such things as the future resource allocation scheme and shift arrangement. Some uncertainty variables, such as weather conditions, can be collected from external data sources. For example, in this study, 10-day weather-forecast data are automatically pulled from a weather forecasting Web service (National Weather Service 2005). The impact of weather on future project performance can be evaluated either subjectively by the scheduler based his or her experience or by statistical models, such as the method described in Wales and AbouRizk (1996).

Construction Process Knowledgebase

Raw data collected from a GPS unit includes equipment travel speed and location, and these data can be collected on a frequency ranging from every few minutes to every few seconds. Useful performance data, such as truck hauling time and the waiting time at the asphalt plant or the job site, need to be extracted from the large set of raw GPS data. An automated interpretation of these time-sequenced data is made possible by associating a piece of equipment's location with construction events and activities based on user-defined construction process knowledge. In the first step, equipment location is associated with construction events (e.g., start of loading) through a concept called "geo-fence." A geo-fence is a virtual area that is defined around a fixed geographic location or a mobile object of interest, such as a paver. Geo-fences must be defined by project personnel for areas such as an asphalt plant and a paver. A comparison of the GPS location of a piece of equipment with the pre-defined geo-fences can reveal meaningful information about the construction operation. For example, when a truck travels across the boundary and into an asphalt-loading geo-fence, a start-loading event is logged, and when it moves out of the geo-fence an end-loading event is recorded. The second step of the raw data interpretation involves extracting construction-activity information from the construction-event data

obtained in the first step. By definition, an activity is initiated by the occurrence of an event and is ended by the occurrence of another event. Therefore, for the previous example, a truck-loading activity and its duration can be defined based on the start- and end-loading events. The knowledge required for this automated data-interpretation procedure is represented in a hierarchical structure of geo-fence locations, events, and activities. Table 1 illustrates the organization of this construction process knowledge.

Table 1. Organization of Construction Process Knowledge

Geo-fence	Action	Event	Activity
Asphalt plant	Enter	Enter plant	Waiting time at asphalt plant
Asphalt silo	Enter	Start loading	Asphalt loading
Asphalt silo	Leave	End loading	
Asphalt plant	Leave	N/A	Truck hauling
Work zone	Enter	Enter	…
…			

Self-adaptive Modeling

For the proposed simulation-based scheduling system, it is important that the initial base simulation model be updated in a timely manner to reflect changes to the project environment. The objective of the self-adaptive modeling component is to streamline the model-updating process by taking advantage of the real-time data gathered by the data-collection component. In response to changes in the project environment, the base simulation model may need to be updated in terms of its input models and operation logic, as described below.

Updates to input models may involve a change of probability distribution types, distribution parameters, and even input-modeling methods. Real-time data can be used to fit to a number of standard distributions, and the best-fitted distribution can be chosen to replace an outdated input model. This input-modeling procedure can be automated, with user involvement being kept to a minimum level, and such a procedure is described in the next section. Another option for input modeling is using external prediction models (AbouRizk and Sawhney 1993). To further improve forecasting accuracy, certain uncertainty variables (e.g., weather and staffing level) and their impacts on project performance can be modeled explicitly using statistical prediction models. However, at this stage of the research, only the standard distribution fitting procedure is implemented.

Updates to the operation logic may include adding or deleting activities and resources and revising precedence relationships. For example, if a truck operates in a job location other than its scheduled location, as evidenced by its GPS records, the modeling system will draw an inference that the truck has been relocated from one job to another. Schedulers will be notified for verification, and if this change is confirmed the simulation model will be updated. Certainly, as with any decision-support technique, this self-adaptive modeling function offers support for model updating, but it cannot completely replace human judgment. User intervention is still required to confirm or disapprove system changes identified by the self-adaptive modeling component. The behavior of this component is further demonstrated in the

case study section, which presents a scenario in which updates to both input models and the operation logic of a simulation model are involved.

Another important feature of self-adaptive modeling concerns automated model validation using real-time data. Because a simulation model is constantly updated to reflect system changes, the updated model must be validated to ensure that it is indeed an accurate representation of the real-world system. When the real-world system already exists, the most objective validation test is to compare the model's output with actual real-world data (Banks 1998). However, it would be inefficient, if not impossible, to perform this validation process manually for the case in which frequent model updating is required. Real-time data provide an opportunity to utilize a computer-aided model-validation process. When real-world data are available, the validation process can be automated by comparing actual performance data with model outputs using classical statistical tests (Law and Kelton 2000). The case study presented later uses a confidence-interval approach and a paired t-test to automate model validation.

In short, real-time data make possible a streamlined process of model updating and validation. When fully implemented, the automated process can help schedulers to refocus on the essentials of scheduling instead of on simulation modeling. They can be freed from time-consuming data-collection and model-maintenance activities and can instead devote their efforts to simulation output analysis and decision making.

The Prototype System

A prototype system was developed for asphalt hauling and paving projects that integrates the GPS tracking technology with simulation for the purpose of look-ahead scheduling. In this system, the base project look-ahead schedule is prepared using a scheduling software tool called The Dispatcher (HCSS 2007), which allows users to schedule and deploy equipment for transportation-intensive operations. Schedules prepared in The Dispatcher are essentially static, which means they must be updated manually by schedulers to reflect constantly changing field conditions. For simulation modeling, the prototype system uses a general-purpose simulation platform—Simphony (Hajjar and AbouRizk 1999)—for model development and experimentation. The base simulation model for asphalt hauling and paving operations is developed using this platform.

In the prototype system, GPS and other scheduling-related data are collected and stored in a Microsoft Access database. To extract meaningful information from raw GPS data, geo-fences must be defined for areas such as asphalt plant loading areas and paver locations. The user interface in Figure 2 shows user-defined geo-fences. Construction process knowledge, illustrated in Table 1 above, is used to extract construction activity information from GPS data, and Simphony's ActiveX library is used to enable automated model updating and validation. The ActiveX library allows a developer to fully control a simulation model using computer codes, and a software module was developed based on this library to automate model updating.

After a change request is made by the self-adaptive modeling component, the software module handles the addition or deletion of activities and changes to input models. To automate the input-modeling process, another software module was

developed based on a distribution-fitting program, BestFit developer's kit (BestFit 2004), which can fit a data set to 28 pre-defined standard probability distributions, with the highest-ranked distribution being selected to be the input model. Optionally, the fitting results can be presented to the end users for confirmation before the final selection, as shown in Figure 3 below.

A CASE STUDY

The sample project involves grading, drainage structures, asphaltic concrete overlay, and related work for widening a 1.66-mile portion of U.S. Route 84 from a two-lane to a four-lane highway. According to the base schedule, the contractor allocated 20 dump trucks and 1 paver to a section of the project, and all vehicles were equipped with GPS units for real-time data collection. A base simulation model for this operation was established based on the master project schedule and historical data prior to the start of this project. The model includes five activities—asphalt loading, hauling, unloading, paving, and truck returning. The model assumes that the resources required include one asphalt plant, 20 trucks of the same size, one shuttle buggy, and one paver with a hopper capacity of one truckload.

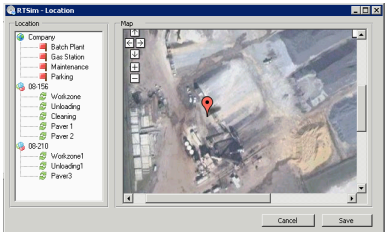


Figure 2. User-defined geo-fences.

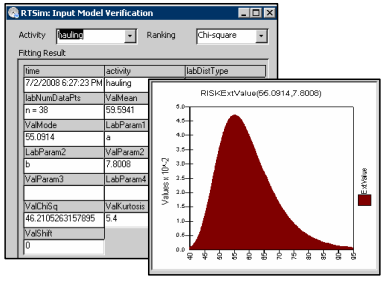


Figure 3. Input-modeling verification.

In this case study, real-time data collected during the first day of the project were used to examine the accuracy of the base model. At the end of the first day of operation, several major discrepancies were captured by the GPS data as listed below. First, three trucks that were allocated to this job did not show up, and so only 17 trucks were actually working on the project. Second, the actual waiting time at the asphalt plant was longer than the queuing time predicted by the base simulation model. Third, because of work-zone traffic and traffic-control delays the actual hauling and returning times were significantly longer than what had been expected. As a result of these discrepancies between the actual conditions and the assumed project conditions, the predicted truck cycle time was more than 20% faster than the actual value measured in the field. This significant error indicates that the base simulation model must be updated in at least three areas—the number of trucks, the waiting time at the asphalt plant, and the waiting time in the work zone. While the change to the allocation of trucks is easy to understand, the changes related to the waiting time are elaborated further below.

In the base model, a truck's waiting time at the asphalt plant and at the job site is determined by its arrival time, the queue length, and the loading or unloading time. Therefore, waiting time is not modeled as an activity but rather as a derived simulation output. However, the actual observed waiting time is much longer than the derived queuing time. This is mainly due to the interruptions caused by external factors that were not considered in the base simulation model. For example, in the case of the asphalt plant, a truck may be kept waiting for a longer time when the plant also serves trucks from other projects and clients. Also, in the case of the job site, the local traffic and the work zone traffic control can significantly increase the time that a truck spends in the work zone. Accurately predicting the influence of these external factors is difficult without information about the actual project conditions, but, fortunately, once the construction work is started, actual data can be collected and analyzed to better model these factors. An immediate solution to the waiting-time problem is to model the waiting time explicitly as an activity using the real-time data. In this case study, the following automated model updating procedure is applied:

1. The number of trucks is changed from 20 to 17.
2. The additional delay at the asphalt plant is modeled as a probability distribution based on the actual waiting time. As a result, a new "waiting at plant" activity is inserted into the base simulation model, and its duration is exponentially distributed with a mean value of 16.3 minutes.
3. Similarly, two delay activities are inserted into the base model to account for the delay in entering and leaving the work zone due to the local traffic and the traffic control. These combined durations are normally distributed with a mean value of 30.6 minutes and a standard deviation of 11.2 minutes.
4. Real-time data are also used to refine other input models for the activity durations of loading, hauling, paving, unloading, and truck returning.

After the changes are identified by the system, they are presented to the scheduler for verification. The purpose of this is to confirm whether the changes identified by the system are in line with the scheduler's perception of the current and future project environment. For example, the user must confirm whether the change from 20 trucks to 17 trucks is permanent or temporary for this project. When the changes are confirmed, simulation experiments with the updated simulation model are conducted to predict future performance, and the accuracy of the updated model is then examined by additional actual data collected from the site. In this case, the actual average truck cycle time is 214 minutes. A paired-t test shows that the 95% confidence interval for the difference between the actual and the simulated average truck cycle time is (-9.9, 10.6), or (-4.6%, 5%), which means that the observed difference is not statistically significant and that the updated model is much more accurate than the base model for look-ahead scheduling.

CONCLUSIONS

Accurate and timely look-ahead scheduling based on the most up-to-date project data can greatly improve project execution and control, and this paper describes a look-ahead scheduling approach based on real-time data collection and simulation techniques that are applied to repetitive asphalt hauling and paving projects. In the study, real-time GPS data from trucks and pavers are collected and

used to automatically update a process-simulation model in order to better reflect actual project conditions. Compared with the traditional scheduling methods that are static and time-consuming to update, the capability of real-time simulation to dynamically incorporate new project data and changes in the work environment offers the promise of improving the accuracy of look-ahead scheduling while reducing modeling burdens on end users.

A critical component of the proposed method is the self-adaptive modeling process. The capability of identifying system changes relies on efficient real-time data collection and accurate data interpretation. First, comprehensive data must be collected to capture the signs of system changes. With the rapid growth of sensor-based technologies, more reliable and comprehensive real-time data will become available for describing the project environment. Second, comprehensive and accurate construction-process knowledge must be defined in order to interpret collected data and identify system changes. To achieve a truly robust self-adaptive modeling process, further research is required in the area of intelligent data analysis and knowledge representation. Finally, the self-adaptive modeling capability streamlines the model updating and validation procedure, but it cannot replace the judgment of a scheduler and user intervention is still required to verify system changes identified by the computer algorithm.

REFERENCES

AbouRizk, S. M., and Sawhney, A. (1993). "Subjective and interactive duration estimation." Canadian Journal of Civil Engineering, 20(3), 457–470.

Ackroyd, N. (1998). "Earthworks scheduling and monitoring using GPS." Proceedings of Trimble Users Conference, San Jose, California, 1–6.

Banks, J. (1998). Handbook of simulation. John Wiley & Sons, NY.

BestFit. (2004) BestFit user manual. Palisade Corporation, NY.

Chung, T. H., Mohamed, Y., and AbouRizk, S. M. (2006). "Bayesian updating application into simulation in the North Edmonton sanitary trunk tunnel project." Journal of Construction Engineering and Management, 132(8), 882–894.

Hajjar, D., and AbouRizk, S. M. (1999). Simphony: "An environment for building special purpose construction simulation tools." Proceedings of the 1999 Winter Simulation Conference, Phoenix, AZ, 998–1006.

HCSS. (2007). The Dispatcher user guide. HCSS Inc., Houston, TX.

Hinze, J. W. (2008). Construction planning and scheduling, 3rd ed. Pearson, NJ.

Law, A. M., and Kelton, W. D. (2000). Simulation modeling & analysis, 3rd ed. McGraw-Hill, NY.

Lu, M., Dai, F., and Chen, W. (2007). "Real-time decision support for planning concrete plant operations enabled by integrating vehicle tracking technology, simulation, and optimization." Canadian J. of Civil Eng. 34(8), 912–922.

Navon, R., and Shpatnitsky, Y. (2005). "A model for automated monitoring of road construction." Construction Management and Economics, 23(9), 941–951.

Peurifoy, R. L., Schexnayder, C. J., and Shapira, A. (2006). Construction Planning and equipment and methods, 7th ed.. McGraw Hill, NY.

Wales, R. J., and AbouRizk, S. M. (1996). "An integrated simulation model for construction." Simulation practice and theory, 1996(3), 401–420.

DEVELOPMENT OF A CONSTRUCTION ENGINEERING LABORATORY COURSE AND FACILITY

David W. Johnston, PhD, PE, F.ASCE[1]

[1] Edward I. Weisiger Distinguished Professor in Construction Engineering and Management, Dept. of Civil, Construction, and Environmental Engineering, North Carolina State University, Raleigh, NC 27695-7908; PH (919)515-7412; FAX (919)515-7908; e-mail: johnston@ncsu.edu.

Abstract

As the construction industry has advanced, an array of field quality control, monitoring, and evaluation devices has become available that the construction engineer often must understand and employ to maintain a safe workplace and to meet the quality requirements of the project in real time, not just hope it passes inspection at the end of the project or at intermediate stages. The education of construction engineers needs to provide an understanding of these methods and devices. Most of the methods and devices are invoked as a part of the construction contract specifications, usually citing standard specifications and test methods published by ASTM and other similar organizations. Understanding these standards and their role in the construction process is also important in the educational process. This paper describes the development and implementation of a construction engineering laboratory course and facility to fulfill these needs.

Introduction

Engineering undergraduate students specializing in construction engineering or in civil engineering with a construction concentration are typically exposed to two types of educational laboratory environments in their major. One is that emphasizing computing and industry utilized software for planning, scheduling, estimating and related tasks. The other type of laboratory environment is represented by the array of traditional civil engineering physical and experimental exposures such as surveying, construction materials, geotechnical engineering, hydraulics, etc. Each of these exposures in a well developed curriculum adds important knowledge and understanding in the preparation of the undergraduate.

The Construction Engineering and Management (CEM) degree program at North Carolina State University has instituted a new one credit hour physical/experimental Construction Engineering Laboratory course with the objective of responding to this industry need. The objective of the paper is to present details of the laboratory learning objectives, the development of the facility, the laboratory exercises, and the equipment involved.

This effort was initiated after a faculty review of the curriculum and reflection on technical changes in the construction process as a part of the continuous assessment process required by ABET Construction Engineering program accreditation and ABET requirements for laboratory experiences [1]. Discussions were held with construction leaders on the department's Advisory Council and with construction engineers from around the country who are participating in the development of the new construction engineering PE exam module. Lists of technologies, activities, and specifications were identified where increased knowledge would be desirable. These were evolved to a list of potential laboratory exercises, a list of equipment needs, and a space plan.

The preliminary list of needed exercises considered the experiences which were already covered in other required labs. The list of added needs included:

- Paint film and other coating thickness measurement;
- High-strength slip-critical structural bolting specifications and wrench calibration;
- Bolt installation by turn-of-nut, tension control, load indicator washers, and calibrated wrenches;
- Calibration of hydraulic systems, load cells, and pressure cells;
- Concrete floor flatness and levelness by F-number methods;
- Rebar and conduit cover, location, and size determination;
- In-place concrete early strength determination for formwork stripping;
- Rigging methods; and
- Post-tensioning process, equipment, and safety.

The purpose of the exercises is only partly to experience actual measurements since this work will often be performed by others under the supervision of the construction engineer. The Student Learning Outcomes are broader indicating that by the end of the course, the student will:

- Gain knowledge of construction technical specifications;
- Gain understanding of specific methods and tests used for evaluation in construction;
- Design and conduct a system of tests to meet a project requirement and analyze and interpret data;
- Improve understanding of construction tolerances;
- Improve reporting skills; and
- Gain understanding of the importance and implications of specification requirements and the safety implications of the evaluation results.

Designing the system of tests involves selection of standard tests accepted for meeting the criteria. Prior student knowledge required for the lab course includes the prerequisite course in construction materials and its associated lab and the co-requisite of either steel design or concrete design.

Laboratory Space

Following construction of a new lab building for structural and geotechnical engineering, the previously existing 3,000 ft^2 (270 m^2) strong floor lab in Mann Hall was reallocated for use by the structural mechanics, pavement materials and construction engineering groups. About 1,000 ft^2 (90 m^2) is used for construction engineering teaching and research lab space (Figure 1). The strong floor anchors and a 5-ton (8.9 N) overhead crane allow assembly of frames used in calibration exercises, connection assembly, and rigging demonstrations. The combination of teaching and research activities justifies allocation of space to construction engineering and allows the faculty to pursue physical research as opportunities are developed without seeking temporary space.



Fig. 1 – Construction engineering laboratory space

Equipment Funding

Funding for purchase, maintenance, and replacement of laboratory equipment is a high priority in engineering programs to allow both state-of-the-art research and education. At NC State, a designated portion of student fees is defined as the Education and Technology Fee (ETF) which is used to:

- "advance the quality of learning experiences and outcomes for students; and

- embrace emerging opportunities that differentiate the learning experience beyond what appropriated funding allows, while remaining accountable to students, the university, and the state, for return on technology investments —examples include but are not limited to equipment, software applications, supplies for educational materials, laboratory expenses, student computing labs and facilities, connectivity infrastructure and services to support student learning, learning spaces, and field trips." [2]

The fees accumulated are distributed to the colleges partly by formula and partly by special application. Departments prepare brief proposals prioritizing uses for the funds which are again distributed by the colleges partly by formula and partly by special application. It is helpful in this process if the proposal includes matching funds from external sources. Fortunately, industry contributions for matching were received and the leverage enhanced ETF funding received. To date, about $75,000 has been expended providing two set-ups for each exercise. A third set-up is planned.

Laboratory Exercises

This section provides a brief description of each exercise. The lab meeting duration is nominally 3 hours long. The emphasis is to provide students with direct hands-on experiences so they will understand the principals and methods involved even though the actual project field measurements and calibrations will be conducted by workers or consultants under their supervision in actual construction. Data collected is recorded on a provided data sheet tailored to each exercise. Certifications of calibration and other material certificates are available for student reference. Issues related the accuracy of each device and the precision of the data collected are factors in each exercise.

Coating Thickness – Coating thickness is specified for several materials in construction such as paint film and epoxy coatings, particularly for protection against corrosion. Two commonly used systems were selected for samples, spray painted steel plate and epoxy coated reinforcing bars. The exercise involves use of three different devices: pen-type magnetic, wheel-type magnetic, and electronic (Figs. 2 and 3). Using each, measurements are made and analyzed following requirements of ASTM A775 [3] for the epoxy coated bars and ASTM D7091 [4] for the painted steel.

Wrench Calibration – High strength bolts (ASTM A325 and A490) used in slip-critical structural steel frame connections must be tightened to specified tension levels based on RCSC criteria [5]. Calibration of electric and pneumatic wrenches must be done on the jobsite daily using the bolts, nuts and washers being used for the project to establish the torque setting for each wrench in use that day to achieve the specified tension. The torque can vary as a result of manufacturing and lubricant differences affecting the friction between the bolt, nut and washer parts. The wrench calibration is performed using a Skidmore-Wilhelm device (Figure 4). Several types of wrenches are used and calibrated by the students for several types of bolts.



Fig. 2 – Pen and wheel type magnetic thickness gages



Fig. 3 – Electronic thickness gage based on eddy currents

Bolt Installation – Using wrenches calibrated in the previous exercise, the subsequent exercise involves bolt installation in connections (Figure 5) to slip-critical tension levels using bolts tightened by the turn of nut method, bolts tightened by the calibrated wrenches, tension control bolts, and ASTM F959 load indicator washers (both plain and with paint squirt indicators).



Fig. 4 – Skidmore-Wilhelm calibrator

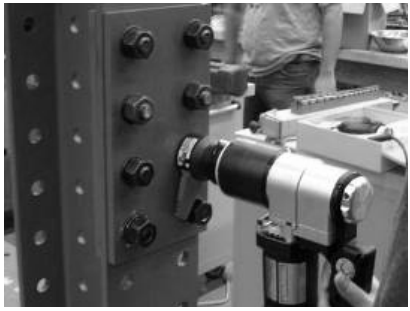


Fig. 5 – Bolt installation to tension criteria

Hydraulic Jacks Calibration – Hydraulic jacks are used in a variety of construction applications. Typically, the load is controlled using hydraulic pressure gages and a calibration chart relating pressure to jack force. For some applications, the calibration must be certified. In other applications, load cells are sometimes used. The equipment used in for this exercise includes a pump, pressure gage, hydraulic cylinder, hoses, load cell, and strain indicator (Figure 6). The array of parts allows the student to become familiar with the operation and calibration of hydraulic systems.

Floor Flatness and Levelness – The flatness and levelness of concrete floors on grade and of elevated floors before stripping is often specified by invoking ASTM E1155 [6] using the F_F and F_L number system. This approach is prevalent in super-flat floor construction. Several electronic devices are commercially available for F-number measurement. A dipstick style D-Meter (Figure 7) was selected for the evaluation exercise. These devices are not used in the lab space, but rather they are used by each group on other slab-on-grade or elevated floor space. The data downloaded is then utilized by students in their reports.



Fig. 6 – Hydraulic system calibration



Fig. 7 – F-number D-Meter

Rebar and Conduit Location – To avoid reinforcing bar and conduit in previously cast concrete when coring, sawing or installing anchors, an electronic rebar locator is often used. These devices (Fig. 8) also have the capability to estimate cover thickness and rebar diameter. The exercise involves learning to use the device and applying its capabilities to map reinforcing in a concrete wall or slab including estimating cover and size of bars located (Fig. 9).



Fig. 8 – Rebar and conduit locating device



Fig. 9 – Student teams mapping reinforcement in existing wall

In-Place Early Concrete Strength – The timing of stripping formwork supporting elevated floors is critical to safety and cost of concrete construction. Since formwork represents about 50% of the cost of concrete construction, there is great desire to strip and reuse the forms as quickly as possible, often within 3 to 7 days. The stripping time is controlled by the strength gain of the concrete and the ability of the elevated floor to support its self weight and other construction loads. The strength gain is significantly influenced by the level of and variations in the concrete temperature. In this exercise, students cast five 6 in. x 6 in. x 21 in. beams and 35 4x8 cylinders and conduct strength tests by several methods on each of the 7 days following casting.

Several indirect test methods are used for field determination of concrete compressive strength. Although they are sometimes used for approximate results with out calibration to the actual project concrete mix design, each should be pre-correlated to tests of cylinders from the actual mix. The rebound hammer (Fig. 10), ASTM C805 [7], has been used for many years to evaluate final strength of concrete; however, it is not recommended by the manufacturer for early strength evaluation and this variability is noted by students. Maturity is a somewhat newer method (Figure 11) which measures the integral of the time-temperature relationship of the concrete following ASTM C1074 [8]. Maturity can be correlated to compressive strength. The Lok-test (Figure 12), ASTM C900 [9], is a device that pulls an embedded disk from the concrete (Figure 13) resulting in a cone failure strength which can be correlated to compressive strength. Cylinders are tested in parallel so that correlation curves can be developed for each method and compared to the approximate curves supplied with the devices. One additional test method, the Windsor Probe based on ASTM C803 [10], is demonstrated rather than used by each student since it involves shooting a projectile into the concrete surface.

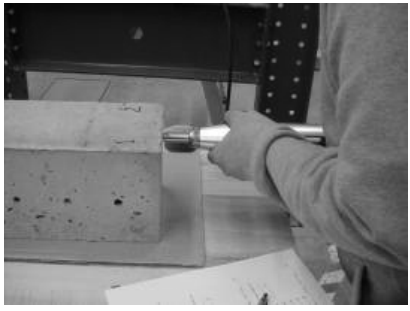


Fig. 10 – Use of rebound hammer



Fig. 11 – Maturity data logger

Rigging Demonstration – The overhead crane (Figure 1) in the lab is used for demonstration of the proper use of rigging hardware. In this process, students become acquainted with types of hardware, interpretation of tagging for load ratings, wear and condition of slings and other components, and rigging configurations.



Fig. 12 – Lok-test pullout device

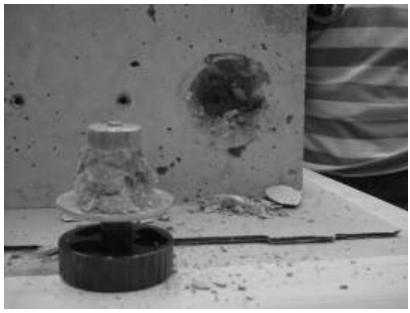


Fig. 13 – Pullout cone failure

Future Additions – Two future exercise additions are desired for the laboratory course. The first is a set-up to demonstrate post-tensioning operations using the hydraulic jacks calibrated in the earlier exercise. The complications of designing this set-up are modeling the force and elongation behavior without utilizing a very long length of prestressing tendon and assuring stressing safety. The second recently identified need is a set-up to physically model the shoring and reshoring process for constructing multi-story concrete buildings. The primary challenge here is scale effects and how to model changing floor slab stiffness.

Laboratory Reports

A laboratory report is required for each exercise. Students work in pairs but the pairing must rotate for each lab meeting and report. As a result of the rotation, students learn from other students, absorb additional ideas for improving the report content and format, and generally overall report quality increases gradually through the semester. Printed instructions indicating minimum requirements for lab reports are provided and discussed at the beginning of the semester. A typical report might include the following sections:

- Laboratory Exercise Objective
- Equipment Description
- Procedure and Specimens
- Data Collected
- Analysis of Data
- Summary and Conclusions
- References
- Appendix (data forms)

However, students are encouraged to innovate where it aids communication and understanding. The instructions also cover standard techniques for citation, format and titling of tables and figures, formatting of specialized figures such as graphs and charts, reference citation, and options for formatting lists of references. Students are encouraged to use digital cameras to collect images that can be used effectively in their reports and learn techniques for image composition in the process.

Lab Safety

Adoption of procedures to create a safe environment for students and instructors in the laboratory is requirement of the University, ABET and OSHA. Labs are required to maintain a safety manual defining procedures to be followed. The safety procedures can vary depending upon the laboratory exercise. A standard for all Construction Engineering Laboratory exercises is the wearing of steel or composite toe safety shoes. Most all construction engineering students have this personal item in the form of a work boot as a result of their work internships. However, many also opt to purchase a casual style version in the form of an athletic sneaker or walking shoe for campus wear. Hard hats, safety glasses, and work gloves are provided in the lab. The use of these items is discussed as a part of instructions for each individual lab meeting. Although use of hard hats and safety glasses may not be technically required for some activities, their use is emphasized to duplicate standard practice on many job sites.

Role of Teaching Assistants

Several required lab experiences are included in the major curriculum including Surveying, Construction Materials, and Geotechnical Materials. An additional required lab elective can be chosen from areas such as Hydraulics and a Structural Behavior Measurements. These lab courses are taught by Teaching Assistants from the respective areas under faculty supervision. At present, the Construction Engineering Lab course is offered as a special option among the elective lab courses available in the department. Multiple sections of the course will be needed when it becomes a requirement in the CEM curriculum and this will provide the opportunity to support additional CEM graduate students as Teaching Assistants.

Future Building Laboratory Plans

In 2008, the North Carolina Legislature funded planning and design of a new building for the Department of Civil, Construction, and Environmental Engineering to replace the 45 year old 80,000 ft^2 (7,500 m^2) existing space in Mann Hall. The planned space is expected to be in excess of 200,000 ft^2 (18,500 m^2). Design is scheduled to be completed in late 2009. Legislative funding for construction will hopefully follow in 2010 with occupancy in about 2012.

The planning process for the Construction Engineering Laboratory includes provision for some space and equipment/instrumentation storage improvements.

Summary and Conclusions

A Construction Engineering Laboratory course is now being offered with an excellent response by the first groups of students. Student evaluations of the course included comments mentioning elements of the desired outcomes, reinforcing that the outcomes were being achieved. Situated for the undergraduate version as a senior

laboratory, the laboratory is also being made available in a graduate credit version for construction engineering graduate students who have not had an opportunity for the exposure in their prior education. The lab course is allowing students to integrate understanding of construction process test methods, safe conduct of tests, interpretation of specifications, analysis and interpretation of test data, reporting of test results, and implications for project safety as one component of their career preparation as construction engineers.

References

1. ABET, *Criteria for Accrediting Engineering Programs*, Accreditation Board for Engineering and Technology, Engineering Accreditation Commission, Baltimore, MD, Nov. 2007, 19 pgs.

2. Education and Technology Fee, http://provost.ncsu.edu/admin-resources/etf.php, North Carolina State University, Sept. 1, 2008.

3. ASTM A775-07b, *Standard Specification for Epoxy-Coated Steel Reinforcing Bars*, ASTM International, West Conshohocken, PA, Dec., 2007, 11 pgs.

4. ASTM D7091-05, *Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic Nonconductive Coatings Applied to Non-Ferrous Metals*, ASTM International, West Conshohocken, PA, Sept., 2005, 7 pgs.

5. RCSC, *Specification for Structural Joints Using ASTM A325 of A490 Bolts*, Research Council on Structural Connections, June 2004, AISC Manual 13th ed., Pgs 16.2-39 – 16.2-57.

6. ASTM E1155-96, *Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers*, ASTM International, West Conshohocken, PA, May 1996 (Reapproved 2001), 8 pgs.

7. ASTM C805-02, *Rebound Number of Hardened Concrete*, ASTM International, West Conshohocken, PA, August 2002, 3 pgs.

8. ASTM C1074-04, *Estimating Concrete Strength by Maturity Method*, ASTM International, West Conshohocken, PA, July 2004, 9 pgs.

9. ASTM C900-06, *Pullout Strength of Hardened Concrete*, ASTM International, West Conshohocken, PA, January 2007, 10 pgs.

10. ASTM C803-03, *Penetration Resistance of Hardened Concrete*, ASTM International, West Conshohocken, PA, April 2003, 5 pgs.

A BALANCED VIEW OF SUSTAINABILITY IN CIVIL ENGINEERING AND CONSTRUCTION

Leidy Klotz[1] and Denise Grant[2]

ABSTRACT

The concept of sustainability is taking a more prominent role in civil engineering and construction curricula all over the world. Sustainability has environmental, economic and social dimensions; however, there is a tendency for the social dimension to receive less focus than the other two. Certainly, with their technical backgrounds and training, the majority of civil engineering and construction students are better prepared to understand and contribute to the environmental and economic dimensions of sustainability. Yet, an understanding of all dimensions is necessary to provide optimal, sustainable solutions to technical problems. The research described in this paper assesses the evolution of students' understanding of sustainability based on the Global Reporting Initiative's Sustainability Reporting Guidelines. Understanding of sustainability is assessed at the beginning and end of a *Sustainable Construction* course. In addition, students in the course perform one of two types of class projects; a case-study learning project, and a project with a service learning component. Comparing the results between students performing each project type will provide insight into each project type's effectiveness in developing students' understanding of sustainability. This research will reveal the understanding of sustainability inherent in a select group of Civil Engineering students. The research will also describe the progression of this understanding during a *Sustainable Construction* course and during problem-based and service-learning type projects.

INTRODUCTION

While specific definitions may vary, sustainability is frequently defined as meeting present-day needs without compromising the ability of future generations to do the same (Brundtland 1987). Sustainability includes three, overlapping, pillars of environment (planet), economy (prosperity), and society (people) (UN 2005; EPA 2008). As evidenced by terms such as "green building," sustainable construction typically has an environmental dimension, seeking to minimize the negative impact

[1] Department of Civil Engineering, Clemson University, 208 Lowry Hall, Clemson, SC, 29634; e-mail: LeidyK@clemson.edu

[2] Department of Civil Engineering, Clemson University, Clemson, SC 29634; e-mail: DGrant38103@yahoo.com

of our facilities on our environment. Economic dimensions of sustainable construction are also emphasized, with substantial discussion of life-cycle operations and employee costs as well as first-cost comparisons between traditional and sustainable buildings (Kats et al. 2003; Mattheisson and Morris 2007). However, the equally-important social dimension of sustainability; which includes considerations such as education, opportunity, community connectivity, and standard of living; must also be considered along with the environmental and economic dimensions.

The Global Reporting Initiative (GRI), which manages the world's most widely used sustainability reporting framework, measures 49 core performance indicators. Over half of these indicators are outside of the economic and environmental dimensions of sustainability, falling into categories including "human rights", "labor practices", "society", or "product responsibility" (GRI 2008). In the United States, the "Context Sensitive Solutions" approach incorporates some aspects of social sustainability in the development of transportation facilities (USDOT 2008). The certification program most associated with efforts towards sustainability in the United States building industry, Leadership in Energy and Environmental Design (LEED), is heavily weighted towards environmental sustainability, placing almost no emphasis on social aspects of sustainability. By definition, LEED is intended as a "Green Building Rating System" (USGBC 2008).

Addressing certain dimensions of sustainability without considering others is risky (Newport et al. 2003). Construction and engineering professionals will create suboptimal, or even damaging, "solutions" if we compromise certain dimensions of sustainability in our efforts to address others. For instance, using certain rapidly renewable materials as building products may reduce material costs (economic) and reduce embodied energy (environmental). What if the widespread use of this material also displaced indigenous populations, resulting in lost cultural resources (social)? The ability to consider the social dimension is a skill that students, researchers and industry professionals in the engineering and construction fields should be developing (Levitt 2007; Allen et al. 2006). This balanced view of sustainability is also essential to the long-term viability of the construction industry, which many of these students will be entering.

RESEARCH APPROACH

This study will assess civil engineering students' understanding of sustainability. The test-bed for this research is a *Sustainable Construction* course offered through Clemson University's Department of Civil Engineering in Fall, 2008. 33 upper-level and graduate students are enrolled in the course, many with an interest in pursuing careers in the construction industry. Understanding of sustainability will be assessed quantitatively through a survey at the beginning and end of the course. Parallel, qualitative questions will be asked of students at the end of the course and may help triangulate the findings of the study. In addition, students in the course perform one of two types of class projects; a case-study project, and a project with a service component. Evaluating the responses from students performing each project type allows comparison of the project types in contributing to students' understanding of sustainability.

This research investigates two questions related to Clemson civil engineering students. First, how do students characterize sustainability before and after a sustainable construction course? Second, does the type of class project performed by students impact this characterization? The research is designed to answer both questions using the following research steps:

1. Students will be informed that data for a study is being collected from the course and given the option to participate in the study. To reduce the chances of subject bias, the students will not be told the research questions or related details on the study.
2. Prior to covering course content, students are required to complete an on-line survey. They are given the scenario: *You have just been hired by a large, international construction company as their "sustainability coordinator." Your first responsibility is to develop a list of indicators to track your company's commitment to sustainability. You hope to make the list as concise as possible without eliminating important information. Rate the likelihood you would include each of the following 45 potential indicators in your company's list.* Student responses are on a Likert Scale ranging from 1 (Definitely will not include) to 4 (Definitely will include). The 45 potential indicators are based on the applicable core performance indicators from GRI's sustainability reporting index (GRI 2008). When necessary, the wording of some indicators is slightly modified to make sense to civil engineering students. Student responses to these questions will form the baseline for both research questions.
3. All students will receive the same course instruction with the only difference being their group project assignment. Project teams will be randomly generated and half of these teams randomly assigned to develop a project with a service learning component, while the other half will be assigned a case-study project. More details about these assignments are provided in greater detail in the following section. An outline of topics covered in the course is as follows:
    a. Global Issues Related to Sustainability
    b. The Ethical Case for Sustainable Building
    c. The Business Case for Sustainable Building
    d. Sustainable Sites
    e. Water Conservation
    f. Materials and Resources
    g. Energy and Atmosphere
    h. Indoor Environmental Quality
    i. Fundamental Sustainability Concepts
    j. The Importance of Process

k. Integrated Project Delivery

l. Drivers for Building Sustainably

m. What You Can Do – Now and Later

4. During the last week of the course, students will be required to complete the same survey. Comparison of scores before and after taking the course will help identify any changes in students' characterization of sustainability. Students will be asked the following qualitative questions during the posttest to compare with the quantitative results: *Has your understanding of sustainability changed as a result of this course? If so, how? Are there specific aspects of this course that changed your understanding of sustainability? Were there any other factors, outside of this course, that may have influenced any changes in your understanding of sustainability this semester?* In this two-group design, students performing the traditional project are the control group, while students performing the assignment that requires integration of a service component are the experimental group (Ary et al. 2006). These project types represent the independent variable and the dependent variable is the students' characterization of the sustainability indicators. The two groups are compared based on their survey responses at the beginning and end of the semester.

The Service Learning Group Assignment

The service learning group assignment will require the students to plan and begin design of a service project, incorporating sustainable construction, which may be implemented in the future by Clemson students. The assignment is based on the application process for the Carter Academic Service Entrepreneur (CASE) grants to support engineering service learning projects. These grants facilitate collaborative preliminary engineering design efforts in community projects (Colledge). A focus on meeting the needs of a particular community is the primary difference between this project and the alternative, case-study project. One anticipated finding of this research will be what impact, if any, this community-focus has on students' characterization of the social aspects of sustainability. Further description of the service learning group assignment is provided as an Appendix.

The Case-Study Assignment

The case-study project is adapted from Amekudzi and Meyer (2004), who describe a project in a Georgia Tech civil engineering course that incorporates sustainability. In the adapted version of the project, students work in project teams to select and examine a civil engineered project including its environmental, economic and social elements. The students are asked to apply the concepts they are learning in class to analyze the project. Project requirements are similar to the service learning assignment minus the explicit connection to a specific community.

RESULTS AND ANALYSIS

The survey results indicate that the students' initial perception of sustainability is most aligned with performance indicators that fall within GRI's "Environmental" category. As shown in Figure 1, indicators in the environmental category were rated

higher (between 30% and 55%) on the Likert Scale than any of the other categories, which are "Human Rights," Labor Practices," "Society," "Product Responsibility," and "Economic."

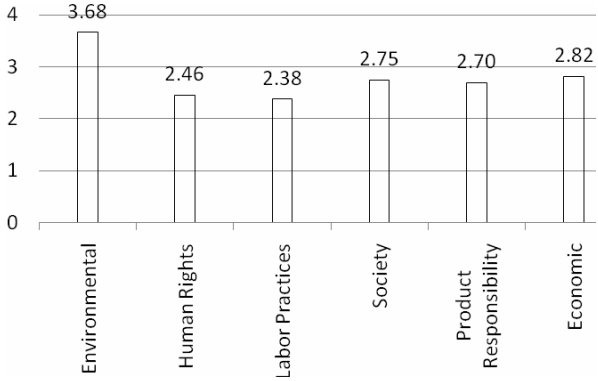


Figure 2: Student Ranking of Sustainability Indicators Grouped by Category

While higher rankings for the environmental indicators were anticipated, the magnitude of the separation between these and other indicator categories is impressive. The 16 GRI environmental indicators included in this study were ranked as the top 16 sustainability indicators by the students (Table 1). Interestingly, the lowest ranked indicators both are from the "diversity and equal opportunity" subcategory of GRI's labor practices category. This does not mean that students do not find diversity and equal opportunity important, but rather that they do not associate these indicators with sustainability.

Table 1: Sustainability Indicators (Adapted from GRI 2008)

Score	Indicator
3.88	Energy consumed by your construction operations.
3.81	Total direct and indirect greenhouse gas emissions by weight.
3.81	Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation.
3.80	NO, SO, and other significant air pollution emissions by type and weight.
3.78	Total water discharge by quality and destination.
3.78	Total weight of waste by type and disposal method.
3.75	Emissions of ozone-depleting substances by weight.
3.75	Percentage of materials that are reused.
3.72	Percentage of materials used that are recycled input materials.
3.63	Energy consumed by your constructed facilities.

3.59	Impacts of activities, products, and services on biodiversity in protected areas and other areas of high biodiversity value.
3.56	Materials used by weight or volume.
3.56	Total water use.
3.56	Total number and volume of significant spills.
3.50	Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with environmental laws and regulations.
3.34	Amount of land owned or used that is in, or adjacent to, protected areas and other areas of high biodiversity value.
3.34	Nature, scope, and effectiveness of any programs and practices that assess and manage the impacts of operations on communities, including entering, operating, and exiting.
3.25	Policy, practices, and proportion of spending on locally-based suppliers at significant locations of operation.
3.16	Financial implications and other risks and opportunities for the organization's activities due to climate change.
3.06	Direct economic value generated and distributed, including revenues, operating costs, employee compensation, donations and other community investments, retained earnings, and payments to capital providers and governments.
2.97	Monetary value of significant fines and total number of non-monetary sanctions for noncompliance with laws and regulations.
2.91	Development and impact of infrastructure investments and services provided primarily for public benefit through commercial, in-kind, or pro bono engagement.
2.78	Education, training, counseling, prevention, and risk-control programs in place to assist workforce members, their families, or community members regarding serious diseases.
2.78	Monetary value of significant fines for noncompliance with laws and regulations concerning the provision and use of products and services.
2.72	Total workforce by employment type, employment contract, and region.
2.72	Significant financial assistance received from government.
2.69	Rates of injury, occupational diseases, lost days, and absenteeism, and number of work related fatalities by region.
2.69	Average hours of training per year per employee by employee category.
2.66	Actions taken in response to incidents of corruption.
2.63	Public policy positions and participation in public policy development and lobbying.

2.63	Programs for adherence to laws, standards, and voluntary codes related to marketing communications, including advertising, promotion, and sponsorship.
2.59	Percentage of significant suppliers and contractors that have undergone screening on human rights and actions taken.
2.59	Company operations identified as having significant risk for incidents of forced or compulsory labor, and measures to contribute to the elimination of forced or compulsory labor.
2.59	Minimum notice period(s) regarding company operational changes, including whether it is specified in collective agreements.
2.47	Percentage and total number of business units analyzed for risks related to corruption.
2.44	Percentage of employees trained in organization's anti-corruption policies and procedures.
2.41	Company operations identified in which the right to exercise freedom of association and collective bargaining may be at significant risk, and actions taken to support these rights.
2.34	Total number of incidents of discrimination and actions taken.
2.34	Company operations identified as having significant risk for incidents of child labor, and measures taken to contribute to the elimination of child labor
2.31	Coverage of the organization's defined benefit plan obligations.
2.31	Procedures for local hiring and proportion of senior management hired from the local community at locations of significant operation.
2.10	Total number and rate of employee turnover by age group, gender, and region.
2.09	Percentage of employees covered by collective bargaining agreements.
2.06	Composition of management group and breakdown of employees per category according to gender, age group, minority group membership, and other indicators of diversity.
1.69	Ratio of basic salary of men to women by employee category.

Data collected at the conclusion of this class were not available in time for publication in the conference proceedings. However, this data will be included in the presentation at the conference.

CONCLUSIONS

Any conclusions based on the results of this study must consider certain limitations. First, the accessible population for this study was civil engineering students enrolled in a *Sustainable Construction* course offered through Clemson University's Department of Civil Engineering in Fall, 2008. The students self-selected to join the course and, therefore, the sample group. The class is likely representative of the Clemson civil engineering student population because the course is a new, elective

course with a broad appeal to attract a representative sample of the department. Presumably, the results from this study will also be applicable to similar civil engineering students in the United States, particularly those at 4-year land-grant institutions. A second limitation is that this study focuses on changes in students' characterization, or attitudes, regarding sustainability. More important changes in knowledge, skills and behaviors are not measured in this study. Separate research is currently underway that will address these limitations (Riley et al. 2008).

Conclusions possible at this time are based on the students' initial perception of sustainability, which is heavily skewed towards environmental indicators. While this recognition is useful, the imbalance in between environmental and other indicators may mean that students do not consider the other aspects of sustainability. Understanding sustainability as including these other aspects will be necessary for students to achieve the best sustainable solutions on their future "real-world" projects. Further, recognition of the different aspects of sustainability in construction and civil engineering could attract a new demographic to these disciplines, which have traditionally attracted students interested in "things," rather than "people" (NSB 2007).

Key anticipated findings of the current research include an analysis of the characterization of sustainability by civil engineering and construction students. Case study and service learning based group projects will be analyzed to discover if either impact students' understanding of sustainability. Regardless of the findings related to the group project types, the research results will have important implications. Understanding how students characterize sustainability prior to the course can help instructors develop their approaches to incorporating sustainability in their teaching. Further, evaluating students' characterization of sustainability at the conclusion of the course will provide lessons-learned for future classes. Progress in these areas could contribute to students achieving more balanced sustainable solutions when they become industry professionals.

Future related research may extend this study to construction industry professionals and policy-makers to both assess understanding of sustainability and measure the impact of any training efforts on this understanding. It is hypothesized that this population will have perceptions of sustainability similar to those of the students prior to the *Sustainable Construction* course. The Construction Industry Cooperative Alliance provides a conduit between Clemson's Civil Engineering Department and the various stakeholders in the construction industry, offering an opportunity to perform this future study (CICA 2008).

REFERENCES

Allen, D, Murphy, C, Allenby, B and Davidson, C. (2006). "Sustainable engineering: a model for engineering education in the twenty-first century?" Clean Technologies and Environmental Policy, 8 (2), pp 70 - 71.

Amekudzi, A., and Meyer, M. (2004). "The Civil Engineering Systems Course at Georgia Institute of Technology." Engineering Systems Symposium. Massachusetts Institute of Technology. Accessed 8/1/08 from http://esd.mit.edu/symposium/pdfs/papers/amekudzi.pdf.

Ary, D., Jacobs, L., Razavieh, A., and Sorensen, C. (2006). *Introduction to Research in Education*. Belmont, CA: Thomson Higher Education.

Brundtland, G. (1987). *Our Common Future*. Oxford University Press.

Carew, A., Mitchell, C. (2008). "Teaching sustainability as a contested concept: capitalizing on variation in engineering educators' conceptions of environmental, social and economic sustainability." Journal of Cleaner Production, 16 (1), 105-115.

Clemson University Construction Industry Cooperative Alliance (CICA) (2008). "Public Service – Construction Industry Cooperative Alliance." Accessed 10/9/08 from http://www.clemson.edu/ce/service/cica.php

Cline, R., Kroth, M (2008). "The Challenges of Using Service Learning in Construction." International Journal for Service Learning in Engineering, 3(1), pp. 1-8.

Colledge, T. (2008). "Collaboration with Jimmy and Rosalynn Carter Partnership Foundation IJSLE-CASE Grants." International Journal for Service Learning in Engineering, 3 (1). Accessed 7/30/08 from: http://www.engr.psu.edu/IJSLE/Vol%203%20No%201%20-%20May%202008/From_the_Editor.pdf.

Global Reporting Initiative (GRI) (2008). "GRI Sustainability Reporting Guidelines – Reference Sheet." Accessed 8/2/08 from: http://www.globalreporting.org/ReportingFramework/G3Guidelines/

Kats, G., et al. (2003). "The Costs and Financial Benefits of Green Buildings." Sustainable Building Task Force.

Levitt, R. (2007). "CEM Research for the Next 50 Years: Maximizing Economic, Environmental, and Societal Value of the Built Environment." ASCE Journal of Construction Engineering and Management, 133(9), pp. 619-628.

Matthiesson, L. and Morris, P. (2007). "The Cost of Green Revisited." Davis Langdon Adamson.

National Science Board (NSB) (2007). "Moving Forward to Improve Engineering Education." Accessed 10/13/08 from: http://www.nsf.gov/pubs/2007/nsb07122/nsb07122.pdf

Newport, D., Chesnes, T., Lindner A. (2003). "The "environmental sustainability" problem: Ensuring that sustainability stands on three legs." International Journal of Sustainability in Higher Education, 4 (4), pp. 357-363(7).

Riley, D., Colbeck, C., Janke, E., and Vacca, K. (2008). "Teaching Sustainability Survey Site." Accessed 8/24/08 from: http://tssurvey.net/

United Nations General Assembly (UN) (2005). "World Summit on Sustainable Development Outcome." Accessed 10/9/08 from: http://www.who.int/hiv/universalaccess2010/worldsummit.pdf

United States Department of Transportation – Federal Highway Administration (USDOT) (2008). "FHWA and Context Sensitive Solutions (CS)." Accessed 10/9/08 from: http://www.fhwa.dot.gov/context/index.cfm

United States Environmental Protection Agency (EPA) (2008). "People, Prosperity and Planet." Accessed 10/9/08 from: http://es.epa.gov/ncer/p3/index.html

United States Green Building Council (USGBC) (2008). "Home – LEED." Accessed 10/9/08 from: http://www.usgbc.org/DisplayPage.aspx?CategoryID=19

APPENDIX

SERVICE PROJECT

The objective of this assignment is for students to plan and begin design of a service project that incorporates sustainable construction. Successful projects may be implemented in the future by Clemson students. Reference Document: "IJSLE-CASE Grant Instructions"

Part 1: Develop a Proposed Project
Complete steps 1-3 of the application process for the IJSLE-CASE grants. Identification of a willing faculty member and community organization will require some planning and persistence. Get started on this right away! Responses should be less than 250 words.

Part 2: Develop a Plan of Action and Budget
Complete steps 4-5 of the application process for the IJSLE-CASE grants. It should be clear how your plan of action incorporates sustainable construction. The budget is $1,000 and is only meant to cover preliminary design. Responses should be 5 pages or less with no more than 750 words of text (pictures, tables, figures etc… are encouraged).

Part 3: Preliminary Design Report
Depending on your project, the preliminary design report may take several different forms (drawings, reports, website, models etc…) You are not expected to have all the information required for a complete preliminary design report at this point. We will work together to develop a fair scope for this part of the assignment.

Part 4: Project Assessment
Based on parts 1-3, complete the project assessment using the IJSLE-CASE Project Assessment Criteria. Since you do not have a completed preliminary design report, parts of the assessment may be based on your anticipated results. Responses should be 5 pages or less with no more than 750 words of text (pictures, tables, figures etc… are encouraged).

Grading Rubric

%	*Content*	*Communication*	*Creativity*
< 75	Project impact not clear for community and/or students	Scope of project is unclear	Project is identical to ongoing service projects
75-85	Project impact is clear, but not related to this course	Clear written description, lacking suitable visual aids	Project is very similar to ongoing service projects
85-95	Project impact is clear and related to this course	Clear writing and visual aids	Project differs from ongoing service projects

ENGAGEMENT OF INDUSTRY IN BEST PRACTICES RESEARCH

G. Edward Gibson, Jr.[1], P.E., F. ASCE and Donald A. Whittington[2], P.E.

ABSTRACT

Construction industry best practices research requires an interaction and feedback mechanism between industry respondents and academia. Typical research methods such as surveys, source document reviews, and structured interviews are typically used, but suffer from barriers which can hamper results. Examples of these barriers include low response rates, asynchronous communication, time commitment of the researchers and respondents, access to project data, and travel costs. Structured workshops (research "charrettes") are a unique and useful method for facilitating data collection between industry respondents and academic researchers. They combine the best tenets of surveys, interviews and focus groups in an accelerated time frame. This paper will explain how these workshops provide a critical avenue for industry interaction. Characteristics leading to successful charrettes will be outlined. The paper will conclude by describing the benefits of these workshops to researchers including lessons learned from successful workshops.

INTRODUCTION

For academic researchers to discover innovative and truly useful findings in regard to construction industry best practices, an effective interaction and feedback mechanism between industry respondents and academia is needed. Typical research methods such as surveys, source document reviews, and structured interviews provide that mechanism, but suffer from barriers such as low response rate, long time for responses, asynchronous communication, time commitment of the researchers and respondents, access to project data, and travel costs which can hamper results. A unique and useful method for facilitating data collection between industry respondents and academic researchers is the use of structured workshops (research "charrettes"), which combine and integrate the best tenets of surveys, interviews and focus groups in an accelerated time frame.

[1] Professor and the Gary Neil Drummond Endowed Chair, Dept. of Civil, Const., and Environ. Engrg., University of Alabama, Box 870205, Tuscaloosa, AL 35487, 205-348-6987, egibson@eng.ua.edu

[2] Graduate Research Assistant, Dept. of Civil, Const. and Environ. Engrg., University of Alabama, Box 870205, Tuscaloosa, AL 35487, 205-348-6550

This paper will discuss how select research charrettes have been applied to research projects over the past 14 years by the authors to investigate best project practices for the Construction Industry Institute (CII) and Texas Department of Transportation (TxDOT) among others. Findings, practices and tools developed as a result of these workshops are widely used in industry today. The paper will explain how these charrettes provide a critical avenue for gaining data and in determining the applicability and usefulness of newly created products or practices intended for industry use. It will illustrate how the interaction among industry professionals and academic researchers provides feedback and open forum discussion concerning critical investigation topics, while providing direction for future research efforts. The paper will also discuss how to conduct these workshops. The paper will address when these types of workshops are best applied, as well as when they may not be as useful. The paper will conclude by describing the benefits of charrettes to researchers including lessons learned from successful workshops.

BACKGROUND OF PLANNING CHARRETTES

A planning charrette is a tool used by designers and facility planners to elicit ideas and leverage industry experience in an intense and targeted workshop format. Based upon the French word for "cart," "charrette" became part of the architectural vocabulary in the early 1900's at the Ecole des Beaux-Arts in Paris (Healey 1991). Nearing the end of a 12 or 24-hour studio project, architectural students would franticly race to finish their work and place it on a collection cart as it was being wheeled along the aisles of drafting tables. It has been said that some students would actually walk along side the cart to make a few last-minute changes before the projects were collected by the instructors.

Currently, planning charrettes are being utilized for a variety of activities including facility programs, master plans, strategic operational plans, primary architectural designs and more (Carter and Burgess 2002; Gibson et al. 2003; Lindsey et al. 2003; Lennertz and Lutzenhiser 2006). Organizations as diverse as the Federal Highway Administration, the U.S. Department of Energy, the U.S. Green Building Council, the U.S. Army Corps of Engineers, and the American Institute of Architects espouse the benefits of these workshops in the planning environment. These charrettes typically last from one to four days and are structured to elicit input and decision making from key project stakeholders.

RESEARCH CHARRETTES

A research charrette is a derivative of the planning charrette, using social data collection methods to elicit ideas and leverage industry experience in an intense and targeted workshop format. Its major advantages are the synergy gained by having a group of industry experts interacting in a structured manner, the ability to use multiple data collection strategies during the session, and the fact that when the workshop is over, the data have been collected and are available for analysis. It also has a secondary benefit of helping to get "buy-in" from industry participants to use or rely on the results of the charrette and to solicit follow-on involvement for validation or testing of any methods, findings, or "best practices tools" developed.

The typical research workshops (or charrettes) would combine several types of data collection methods into a four to six hour session to focus on a single thread of the investigation. The charrette is managed by the researcher or research team, and is singularly organized in its focus. At the end of the workshop, all data necessary to complete a phase of the research investigation has been collected.

The authors have been involved in conducting research charrettes over the past 14 years as outlined in Table 1. A total of 29 charrettes have been conducted with approximately 400 participants, representing over 100 organizations.

Table 1. Sample of Recent Projects Employing Structured Research Charrettes

Research Investigation	Number of Research Charrettes	Number of Participants	Number of Organizations
Project Rating Definition Index for Industrial Projects (Dumont and Gibson 1996)	2	54	31
Alignment During Front End Planning (Griffith and Gibson 1997)	3	38	19
Project Rating Definition Index for Building Projects (Cho et al. 1999)	7	69	35
Expediting Highway Construction While Retaining Quality Tool (Simon et al. 2002)	6	62	6
International Project Risk Assessment (Walewski et al. 2004)	4	44	25
Advance Planning Risk Analysis (APRA) for Transportation Projects (Caldas et al. 2007)	3	62	12
Shutdown Turnaround Alignment Review Tool (Whittington et al. 2008)	4	67	39

TYPES OF RESEARCH INVESTIGATION METHODS

Engagement of industry in "best practices" research requires social data collection and statistical evaluation methods. The data captured is typically a combination of both qualitative and quantitative input by respondents and observations of work practices or interaction of practitioners. Many times, these efforts are exploratory in nature, trying to determine the best methods, processes, and controls needed to gain a successful outcome to a defined problem. For instance, one may want to understand the best methods of planning an industrial project in order to favorably influence the success of the business venture, a subject with limited or conflicted past research studies. This investigation thread would have many independent and dependent variables and is focused on an uncontrolled environment. Typical issues to consider in choosing the investigation methods, along with how the research charrette method integrates into these issues are given below.

Collection Methods

Data collection strategies must be tailored to the research problem statement and are typically a combination of several methods (Gibson and Hamilton 1994).

Typical data collection methods that can be used in a research charrette are given in Table 2. Specifically, the charrette will have one or more surveys (perhaps with the participants bringing a partially completed instrument to the event). Most charrettes include an interactive component that allows the researchers to observe the participants interact with each other in terms of specific problems or research questions, and to relay their observations about the research investigation to date. Finally, if multiple workshops are used with a mixture of demographic respondents, some inferences can be gained from the impact of the research investigation on the attitudes of the participants.

Table 2. Examples of Data Collection Methods Used During or After Research Charrettes

Type of Collection Strategy	Examples
Surveys/questionnaires	Background information about the participants; opinions of relative importance of best practice strategies
Observation	Participant's interaction with peers in the charrette or their opinions about the subject matter
Structured Interviews / Facilitated Discussion	Collective group or small group structured questions and responses
Focus groups	Collective or small charrette group response to research products or findings to date
Informal Interviews	Interaction of the researchers with charrette participants during breaks or lunch
Result Validation	Participants volunteering to test, use or employ research findings subsequent to the charrette

Sample Selection

One of the first steps in designing a research project is to define the population to be studied. The unit of analysis in construction studies can be the project team, a group of individuals, a process step, a project, or a database of existing data. The entire population of construction data in most cases would be too large and diverse to study, producing questionable results. Conclusions reached by a study of such a wide mix of project types would provide overly general information that would not prove useful to any specific subset of the population of project teams. As a result, the sample is generally narrowed to a subset, such as "project teams involved in the planning and execution of industrial capital facility projects," so that the results can be applied specifically to the investigation domain of interest.

Nonprobability sampling is characterized by a selection process that does not result in every member of the population having a chance of being selected. The study population within the construction industry is just such a case. Despite the obvious drawbacks to nonprobability sampling, the study population requires its use for almost all construction "best practices" studies. The research charrette uses the nonprobabilistic sampling method.

Participants in the charrette (some of which may have travelled long distances to attend) are generally invited based on past contacts with the researcher,

recommendations from the research sponsor or oversight team, or are actively involved in an organization such as a department of transportation or a research consortium or trade group and respond to an advertisement. Generally, the charrette will have certain parameters that are applied to screen the participants based on qualifications related to the study. For instance, the number of years experience that a person has been in industry, the types of projects that he or she has been involved with, educational background and so on which allow the researcher to focus in the proper area of assessment for the study. The participants need to be able to focus not only on their own organization's short term goals but also the overarching improvements to the construction industry as a whole. This separation of short term views from long term issues needs to be addressed in the make-up of the data collection instruments. Several charrettes may need to be conducted at different geographic areas to improve participation. This dispersion will typically allow a more robust response set, but geographic differences cannot be inferred based on the locations.

PAST RESEARCH CHARRETTES

As indicated in Table 1, the research charrette method espoused in this paper has been used on several research investigations. A brief discussion of some of these studies is given in this section to illustrate the method's flexibility and its evolution.

The first use of the research charrette method by the authors was during a study funded by CII in 1994. The research problem was to gain insight into planning applications in industrial construction projects. Based on data from a previous research effort (Gibson and Hamilton 1994), and input from a research team composed of 17 industry representatives, a detailed, draft checklist for scope definition called the Project Definition Rating Index was developed. Two research charrettes were used during the effort to refine the checklist and obtain feedback from 54 participants concerning the relative importance of the elements in the checklist. This activity utilized the respondent's experience and insight based on their current projects. The respondents were a volunteer, convenience sample. The developed tool and method, which included relative values of the scope definition elements established in the charrettes, was subsequently tested on 40 projects, with some of the charrette participants providing test cases (Dumont et al. 1997; Dumont and Gibson 1996; CII 1997)

In 1999, the method was applied again on a project sponsored by CII to develop a PDRI for building projects. Seven research charrettes were used in this development effort, employing a very similar methodology to the first study cited above. Again, the tool was refined and developed with input from industry participants, with the charrettes being widely dispersed around the United States. The developed tool and method were subsequently tested on several dozen real projects as another source of data (Cho et al. 1999; Cho and Gibson 2001). This developed tool has been widely adopted by organizations in industry.

In 2001, the research charrette was used for a slightly different purpose. TxDOT was concerned with the speed with which its projects were being delivered. A list of likely strategies were developed by the research team prior to the charrette and then a series of charrettes were held to refine this list, identify whether these

methods were feasible for TxDOT to pursue, and through a series of multi-voting exercises to recommend strategies that could be pursued immediately and others that required additional research. These six charrettes involved 62 practitioners from 6 organizations (and included 24 of the 25 regional construction management districts in Texas), and showed the flexibility of the charrette method (Haas et al. 2003, Simon 2002).

RESEARCH CHARRETTE EXAMPLE

In the fall of 2007 and spring of 2008, the authors used structured workshops in order to prioritize and validate the Shutdown Turnaround Alignment Review (STAR) Tool, a new planning tool for use in shutdowns, turnarounds and outages sponsored by the CII. The researchers used the series of four workshops to obtain industry perspective about the research approach, as well as relative priority of critical elements concerning the tool and method that was in development. The workshops included an overview of the research effort, prioritization of the critical elements in the tool under development and written feedback. Using on-site analysis of the collected data, the researchers were able to present real-time results to workshop participants based on data collected during the workshop as well as a comparison to results from previous workshops.

The structured workshop setting also allowed for facilitated discussions in order to determine strengths and weaknesses of the new tool and planning method, a process that would not have been possible with traditional survey and questionnaire methods of industry feedback.

In total, the workshops allowed the researchers to obtain unique perspectives from 67 respondents representing 39 individual companies concerning the STAR Tool. The participants were able to interact with peers in similar industries and learn other novel approaches to common challenges (Whittington et al. 2008). The research effort is currently nearing completion with several charrette participants actively using and testing the developed tool and method.

RECOMMENDATIONS FOR CONDUCTING RESEARCH CHARRETTES

Research charrettes are an effective method of gaining industry input and insight in studies focused on determining best practices or understanding key parameters affecting project performance. They are particularly effective when the researchers are working with oversight committees from the research sponsor. These committees are important in helping conduct the charrettes and also in developing the background research hypotheses data collection strategies for the charrette. The research charrette is not as effective in situations where a rich dataset is available for review, a national study is required (although it could be used to test the questionnaire), or where observation of methods or field procedures are dictated by the study parameters.

When planning and conducting research charrettes for industry feedback, there are several important considerations to in ensure that the process will obtain the appropriate results. Figure 1 illustrates the process for developing the charrette and the method is discussed briefly below.

Most important in ensuring a successful charrette is the pre-work. The topic, objectives, issues for discussion, a developed and tested data collection strategy, and good background documents need to be in place prior to the workshop. Involving the sponsor and any oversight committee to the research can greatly enhance this preparation.

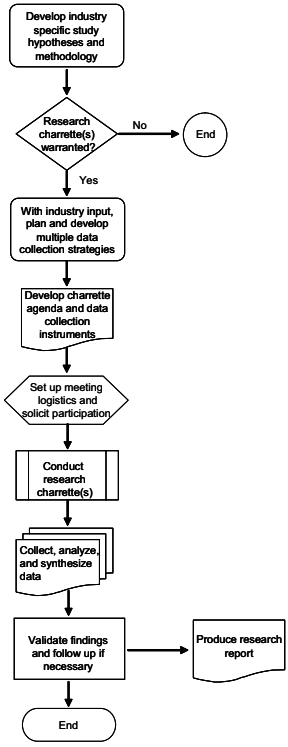


Figure 1. Research Charrette Development Process Map

The researchers need to develop a list of minimum criteria for attendees. Soliciting participants typically requires the assistance of individuals currently practicing in industry, and the researchers must have a working relationship with a team of industry practitioners to facilitate this step. When developing an invitee list for the workshop, overbooking is necessary because, from experience, as many as 40 percent or more of the confirmed attendees will be unable to attend for personal or professional reasons.

The number of participants depends on the intent of the study. In general, involvement of greater than 30 total participants will ensure that sufficient input has been received to elicit consistent viewpoints. This number is considered a large sample in statistical terms, and the authors have observed that the outcome of the data collection effort will only change slightly once this number has been reached and

more data are added. However, the comments and observations in larger total samples can provide a rich source of additional insight if planned correctly. In terms of individual charrette session, from experience, the authors recommend that no more than 25 individuals should participate in order to keep the session members engaged and to manage the effort effectively.

The topic of the research must be interesting and the usefulness of the workshop to help the attendees must be communicated prior to the invitation being issued. The "hook" in place to gain participation is typically the opportunity to interact with other practitioners concerning the subject, and the ability to gain insight into a topic for professional growth. In almost all cases, the authors have provided takeaways (generally partially complete research products and findings to date) during the charrette for attendees and lunch as another enticement.

The meetings must be convenient in timing as well as location for the proposed attendees. Therefore workshops may need to be distributed across a broad geographic area. This also assists in limiting the potential for a geographic bias in the data, although it does not obviate the fact that this is a non probabilistic sample.

The industry practitioners can also assist the researchers as workshop hosts and coordinators including help with creating and communicating the specific workshop logistics such as material and equipment needs, room layouts and seating arrangement, the presence of breakout rooms, food and drink availability, hand outs, nearby hotels, parking and meeting location access/security arrangements for attendees and hosts. Packets of handouts for the attendees must be carefully created with defined takeaways and data collection forms which are given at the beginning of the charrette. A useful method to ensure that the appropriate forms are used and returned is to color-code the handouts.

On the actual day of the meeting, the strategy and agenda for the workshop must be fully formed. The agenda should allow not only for several periods of informal networking among the participants but also periods of structured discussion. The researchers should present a brief background on the history of the research topic as well as expected outcomes of the workshop. Once the overarching data has been collected, one of the primary advantages of the structured workshops can be implemented.

The use of facilitated small group discussions in individual break out rooms allows for a free flow of ideas between the industry practitioners and the research team. These groups should be made up of six to 10 participants. Unlike surveys and questionnaires, this time allows for ideas to be discussed and the researchers to interact with the respondents to clarify thoughts and points. The agenda should allow time for feedback by these small groups to the entire charrette to communicate developed thoughts and ideas to everyone.

Additionally, at least preliminary analysis of the collected data should be presented to the workshop participants so that they get feedback concerning how they responded compared with participants at other workshops held a different times and locations. Appropriate appreciations, long-term follow up, and validation needs to be performed after the workshop has been concluded. Although not done in any of the studies cited in this article, charrette participants could also be conducted after a period of time has elapsed in order to gain additional insight.

LESSONS LEARNED

After conducting a variety of research charrettes, several lessons have become apparent. Among these:

- Performing pre-work and gaining industry input in preparation to hold the charrette is imperative to ensure that the time spent during the charrette is efficient and effective.
- Providing clear and concise logistics information, including pre-meeting information such as location, travel suggestions, agenda, session objectives, and so on will make the session participants better prepared to participate.
- Using a local, active session sponsor who can set up meeting logistics and ensure that several participants can attend helps in getting the appropriate number of participants to the charrette.
- Pretesting all data collection strategies prior to holding the charrette is essential. Again, sponsor representatives can provide a good test set. The first charrette held for the international project risk study used an unworkable comparison and collection strategy (Walewski 2008). This mistake caused the researchers to employ a remediation strategy to collect additional information after the charrette was completed. A pretest would have prevented this rework.
- Developing the list of invitees is not easy. It is difficult to confirm that the participant's backgrounds are appropriate for the particular research topic ahead of time. The participants are a non-random, convenience sample and researchers must state caveats in any data conclusions to account for this issue. In some cases, participants must be removed from the data sample after completing the charrette if they did not meet a screening parameter, such as years of experience.
- Employing the research charrette as part of a multi-prong research effort is best. Case studies, source document review, additional questionnaires, follow-on use of the findings and so on should be used to triangulate or validate the findings.
- Involving industry participants in the charrette gives the researcher access to follow-on data input and also sets the stage for buy-in and usage of the results by industry participants.

CONCLUSIONS

The charrette has been used effectively for planning capital projects for many years. More recently, research charrettes have proven to be an effective method for data collection in industry best practices studies. This approach allows researchers to gather data relatively quickly, collect valuable input from experienced practitioners, make excellent industry contacts, and gain insights with several collection strategies as outlined earlier in this paper. It has some limitations, however, such as non-probabilistic samples and limitations on the type of data that can be collected.

Researchers should consider the charrette as one part of an overall data collection effort for industry best practices studies. Effective pre-work, involvement of sponsors, good logistics preparation, and sound data collection strategies during the charrette provide the basis for its successful application.

REFERENCES

Caldas, C., Le, T., Gibson, G. E., and Thole, M. (2007) "Identifying Right-of-Way Requirements During the Project Development Process," Product 0-5478-1, Center for Transportation Research, The University of Texas at Austin, 224 pp., October.

Carter & Burgess, Inc. (2002). "A common sense approach to design," Water Engineering and Management, 149 (10), 26-28.

Construction Industry Institute (CII) (1997) 'Pre-Project Planning Tools: PDRI and Alignment," Research Summary 113-1, Austin, TX.

Cho, C., Furman, J. C., and Gibson, G. E. (1999) "Development of the Project Definition Rating Index (PDRI) for Building Projects," A report to the Construction Industry Institute, RR 155-11, 296 pp., December.

Cho, C-S, and Gibson, G. E. (2001). "Building Project Scope Definition Using Project Definition Rating Index (PDRI)," *ASCE Journal of Architectural Engineering*, 7(4), pp. 115-125, December.

Dumont, P. R. and Gibson, G. E. (1996) "Project Definition Rating Index (PDRI)," A report to the Construction Industry Institute, The University of Texas at Austin, Austin, TX, Research Report 113-11, 214 pp., June.

Dumont, P. R., Gibson, G. E., and Fish, J. R. (1997). "Scope Management Using the Project Definition Rating Index (PDRI)," *ASCE Journal of Management in Engineering,* 13(5), pp. 54-60, September/October.

Gibson, G. E., and Hamilton, M. R. (1994). "Analysis of Pre-Project Planning Effort and Success Variables for Capital Facility Projects," A report to the Construction Industry Institute, The University of Texas at Austin, Austin, TX, Source Document 105, 239 pp., August.

Gibson, G. E., and Gebken, R. (2003), "Design Quality in Pre-Project Planning: Applications of the Project Definition Rating Index," Journal of Building Research & Information, 31(5), pp. 346-356, Sept.-Oct.

Healey, E. H. (1991). "Planning a library in one week," Am. Libraries, 22 (4), 354-356.

Haas, C., Gibson, G., O'Connor, J., Anderson, C., Somali, B., and Zhang, Z. (2003). "Development and Validation of a Method Selection Tool for Expediting Highway Construction," Research Report Number 4386-1, Center for Transportation Research, 230 pp. October.

Lennertz, B and Lutzenhiser, A. (2006). The Charrette Handbook, National Charrette Institute, American Planning Association Publishing, 188 pages.

Lindsey, G., Todd, J. and Hayter, S. (2003). "A Handbook for Planning and Conducting Charrettes for High-Performance Projects, NREL/BK-710-33425, National Renewable Energy Laboratory.

Simon, E., Gibson, G., Haas, C., O'Connor, J., Somali, B., and Zhang, Z. (2002), "Development of a Tool for Expediting Highway Construction While Retaining Quality," Research Report Number 4386-P1, Center for Transportation Research, October.

Walewski, J., Gibson, G. E., and Dudley, G. (2004). "Development of the International Project Risk Assessment (IPRA) Tool," Research Report 181-11, Construction Industry Institute, The University of Texas at Austin, 366 pp. January.

Whittington, D., Gibson, G., and Cui, Q. (2008). "Analysis Supporting Front End Planning for Renovation and Revamp Projects, Part 2," Research Report 242-12, Construction Industry Institute, Austin, TX.

ASSESSING TRAITS FOR SUCCESS IN INDIVIDUAL AND TEAM PERFORMANCE IN AN ENGINEERING COURSE

Robert M. Leicht[1], Angela Lewis[2], David R. Riley[3], John I. Messner[4], and Brent Darnell[5]

[1] Graduate Researcher, Penn State, rmleicht@engr.psu.edu, 104 Engr Unit A, University Park, PA 16802
[2] Graduate Researcher, Penn State, ama259@psu.edu, 104 Engr Unit A, University Park, PA 16802
[3] PhD, Associate Professor, Penn State, driley@engr.psu.edu, 104 Engr Unit A, Univ. Park, PA, 16802
[4] PhD, Associate Professor, Penn State, jmessner@engr.psu.edu, 104 Engr Unit A, Univ. Park, PA, 16802
[5] Brent Darnell International, brent@brentdarnell.com, 2317 Pembrook Place, NE, Atlanta, GA 30324

With increased emphasis on collaboration, integrated project delivery, and high performance project outcomes, the need for improved team and collaborative skills among engineers has created a push for new competencies to be developed within engineering programs. An exploratory study was completed to identify traits of students which are linked to success in a third year undergraduate construction engineering and management course, most notably team projects. The results of the study will be used to improve professional and collaborative skills in the undergraduate engineering curriculum at Penn State. Ninety-five students in an undergraduate course in the Architectural Engineering Department at Penn State were assessed to identify the individual characteristics which led to success in the course on both an individual and team basis. The students were randomly assigned to teams to complete projects during the spring 2008 semester. Individual exam scores, project scores, and team member evaluations were compared with individual trait assessment, using the Bar-On Emotional Quotient Assessment. The paper provides an introduction to emotional intelligence (EI), the Bar-On Emotional Quotient Inventory, and why EI is important to the Architectural Engineering and Construction Industry (AEC). The methodology and results of the student assessment are then presented. The results identify individual team member traits which suggest success of collaboration through improved performance in team projects. The paper concludes with future efforts in progress to help students to improve individual and team EI competencies.

Keywords: Emotional Intelligence, team performance, engineering education

1. INTRODUCTION

As the Architectural Engineering and Construction (AEC) industry embraces new ideas, such as new technologies, high performance project outcomes and green concepts, there is an increasing need for team and collaboration skills. Unfortunately, collaboration and teamwork skills are often not a focus within an engineering student's curriculum. However, the Architectural Engineering Department at Penn State understands the value of collaboration and teamwork skills. As a result, an exploratory study was recently completed to assess individual and team performance in an engineering course. Emotional intelligence has been selected to assess individual and team performance because it has been successfully used in both the construction industry (Darnell 2004; Butler et al 2006) and other academic settings (Crowley et al 2001). The results of this study, presented in this paper, will serve as the cornerstone for the development of an emotional intelligence module within the department's Professional Development Program for undergraduate students.

2. DEFINING EMOTIONAL INTELLIGENCE

Darnell (2004) and Goleman (1995) state that the success of a person is not limited to either their technical competencies or IQ. Instead, a person's success is greatly dependant on both IQ and emotional intelligence quotient, their EQ. IQ, intelligence quotient, is a numerical value representing intelligence. Emotional intelligence is the capacity to recognize one's feelings and those of others, for motivating ourselves, and managing our own emotions and emotions within our relationships (Goleman 1998). As defined by Goleman (2002), emotional intelligence has five categories, see underlined headings in Table 1.

Table 1: Categories and Subcategories of the Bar-On Emotional Quotient Inventory, modified from Darnell (2004)

Intrapersonal **Self-regard:** "ability to respect and accept oneself as basically good" **Emotional self-awareness:** Ability to recognize one's feelings and share them appropriately **Assertiveness:** Ability to express feelings, beliefs, thoughts and to defend one's rights in a constructive manner **Independence:** Ability to be self directed and free from emotional dependency **Self-actualization:** Ability for one to realize their potential and to be generally satisfied with their life	**Interpersonal** **Empathy:** To be aware of, understand and appreciate the feelings of others **Social responsibility:** To be a cooperative, contributing, and constructive member of a group **Interpersonal Relationships:** "Ability to establish and maintain mutually stratifying relationships"
Adaptability **Reality Testing:** Ability to see the real situation, not being overly optimistic or pessimistic **Flexibility:** Ability to adjust one's emotions, thoughts and behavior as a situation changes **Problem Solving:** Ability to identify and solve problems and implement effective solutions	**Stress Management** **Stress Tolerance:** Ability to not fall apart when adverse and stressful situations occur **Impulse Control:** Ability to resist or delay an impulse, drive or temptation to act **General Mood** **Optimism**: Ability to look on the bright side, maintain a positive attitude, even when faced with adversity **Happiness**: Ability to feel satisfied with life, to enjoy oneself and others, to have fun

To quantify emotional intelligence, Bar-On developed the Bar-On Emotional Quotient Inventory (EQ-i) (Bar-On 1997). The EQ-i is a validated, self-perception instrument that measures five main scales. When an individual takes the assessment, the results are compared against a larger population that has taken the assessment. The results, similar to an IQ test, have a mean of 100, with scores ranging from 90 to 110 considered average emotional functioning. Scores outside the 90 to 110 range indicate atypical emotional functioning. To date, over one million assessments have been performed and have been placed in the Bar-On EQ-i database.

It is important to note that EI is based on an inherited set of traits, but the associated skills can be learned and improved (Goleman 1999). Additionally, scores typically increase with age. Although an individual may have a low score in one or more areas, focused effort can be made to improve weak areas. As a person's ability within a specific competency improves, he or she progresses through four levels of learning. First, the person is not aware of their inability to perform the task or recognize the weakness. When the person realizes their inability, he or she moves to level two. After continued practice, the person can achieve mastery, level three. Level four is achieved when the person is at a point where the task can be performed without thinking about it (Culver 1998).

Emotional intelligence is particularly poignant for engineers and construction managers. First, "the more complex the job, the more emotional intelligence matters" (Goleman 1998). A person in a complex field cannot always understand all of the technical problems they face. EI deficiencies only further hinder the technical expertise or intellect. To design and build nearly any building, a team of individuals must work together. As the level of complexity of the architecture, structure, and building systems increase, the need for coordination and communication between disciplines grows. The categories of emotional intelligence that are typically low for construction managers are emotional self-awareness, and interpersonal skills (which includes empathy, social responsibility, and interpersonal relationship skills). In contrast, construction managers typically have high scores for assertiveness, self-regard and independence.

Furthermore, the way the construction industry historically operated has a significant impact on the emotional intelligence profiles of its constituents. Historically, construction managers did not need to be aware of how other people felt with the competitive low cost award system. Therefore social responsibility was not of high importance. Instead, it was considered almost acceptable to take advantage of others for one's own gain (Butler & Chinowsky, 2006). Additionally, the same practice was true for the selection of subcontractors – the low bid wins. However, today the relationship between the contractor and subcontractor is becoming more important.

As the industry further embraces new technologies and high performance buildings, effective collaboration and communication skills become even more important. Increasing one's EI can help improve these skills (Sunindijo et al. 2007; Butler et al. 2006). Butler et al (2006) show that emotional intelligence and transformational leadership skills are very important for organizations to remain competitive. Sunindijo et al (2007) found that project managers and engineers with higher EI scores tend to have more open communication, proactive leadership styles

and a greater ability to delegate. These traits help to stimulate team performance. If properly used, these behaviors result in positive project and organizational outcomes.

3. EMOTIONAL INTELLIGENCE IN ENGINEERING EDUCATION

Currently, few universities and colleges provide classes to help students learn "soft skills," including emotional intelligence. However, universities who have conducted courses in the area of emotional intelligence are finding that their students are glad they took the course (Crowley et al. 2001). In addition, most of the studies completed and published within the literature of emotional intelligence focus on the EQ-i of individuals, opposed to the composite EQ-i scores of teams. One may assume that a team of individuals with higher individual EQ-i scores will be more successful than a team of individuals with lower individual EQ-i scores. However, by analogy, using good ingredients does not necessarily make a good cake, unless the right proportions of ingredients are used. In addition to incorporating soft skills within undergraduate engineering curricula, this paper explores the relationship between EI competencies and team performance.

4. RESEARCH METHODOLOGY

To study the potential impact of EI competencies, an exploratory study was undertaken. An undergraduate course in architectural engineering, Introduction to the Construction Industry, was chosen to evaluate the current status of EI competencies and to begin exploring the potential impact EI may have on team dynamics. The course utilized both individual exams and team projects to evaluate the students' progress. The course is divided into three main subject areas: Topic #1: Industry Overview and Project Delivery Methods, Topic #2: Construction Estimating, and Topic #3: Construction Scheduling. Each portion of the course had a team project and individual exam. The team projects consisted of randomly assigned three or four member teams that worked together on all three projects throughout the semester. The course was restricted to third year students in architectural engineering, thus the class was made up of over 95% 20 - 21 year old students, 80% male, and over 95% Caucasian. Of the 95 students in the course, 35% had some construction or design related industry experience, typically less than three months.

To assess the current status of the students' EI competencies, the students were asked to take the Bar-On Emotional Quotient Assessment. Of the 95 students in the course, 94 students took the assessment. The assessments were taken within the second month of the course. The overall results and individual scores were provided at the end of the course, shortly before submission of the final team project. In addition to assessing the students EI competencies, the students were surveyed after submission of each of the three projects, prior to receiving their project grade. The survey asked the students to evaluate themselves and their team members on six characteristics related to their contribution to the project, using a 5 point Likert scales, ranging from strongly disagree to strongly agree, for these traits:

- Contributed ideas to the project
- Attended meetings
- Initiated activities to complete assignment
- Accountable to complete tasks
- Asked for group feedback on their work

- Deserves equal credit for group work

To identify the relationships between team collaboration and EI, there were several steps completed to explore the data. First, the class project and exam scores were compiled. For each team the average for each exam was used to correlate the team's performance on an individual basis with their project scores. The three delta points were calculated for each team, as shown in Table 2 and Equation 1, identify the difference between the teams average exam score for each topic and the project score for that topic. Using three projects and exams confirmed that the performance was consistently higher, rather than a single instance.

Table 2: Data points calculated for each team to demonstrate differences in individual and team performance.

Average Exam Score	Team Project Score	(Project Score) – (Exam Score)
Team average – exam 1	Project score – topic 1	Delta 1
Team average – exam 2	Project score – topic 2	Delta 2
Team average – exam 3	Project score – topic 3	Delta 3

(1) $\text{Delta}_i = (\text{Team Project Score})_i - (\text{Team Exam Average})_i$

Using the three delta points, each team was categorized based on consistent performance between average exam and team project scores. After categorizing the teams, they were cross compared with the team performance survey data to understand if the team members worked collaboratively and that all team members contributed to the effort. This combined set of data provides the means to begin identifying individual or team traits which are important for success in collaborative settings.

5. RESULTS AND DISCUSSION

The data collected is presented in three steps. First, the class score data is presented and the teams are sorted based on team performance on projects or exams. Second, team performance is compared with team member evaluations to identify the level of team collaboration. Finally, team EI data is presented highlighting teams with potentially beneficial or detrimental competency levels. It is assumed that the average of an individual's exam scores reflects individual performance and that the average of individual exam scores within a team reflects the composite performance of individuals on a team.

Figure 1 presents the delta points, showing the differences between each team's project score and their average exam score for the three course topics. The differences are highlighted with two boxes of different line types. The solid line boxes highlight teams which scored higher on at least two of the three projects. The dashed line boxes show teams which consistently scored lower on the projects than on exams. The average of all the delta scores for all teams was to score 1.8% better on the exams than on projects. This average does not intend to show a significant relationship but to point out that the grading assessment between the two items may have varied slightly. However, the 1.8% delta and the fact that only one group out of 24 consistently scored higher on their projects, indicates the students were more likely to perform better on an individual basis than in a team setting, showing there is need to develop team skills within these students. The next step was to cross compare the teams with the team member evaluations.

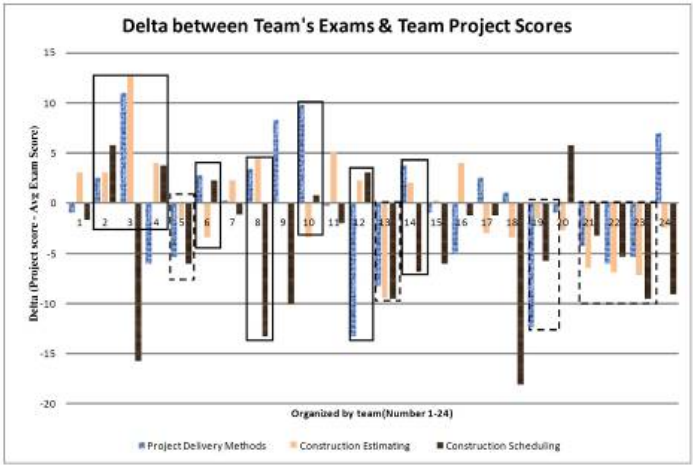


Figure 0: Team numbers (x-axis) versus the difference between a team's project score and team's average individual exam score by topic (y-axis).

While some teams performed better on the projects than individual exams, this did not necessarily mean they worked well as a team. The average team member evaluation for all teams was 4.7 out of 5.0. The lowest average for a whole team was 4.05 and the highest was 4.98. While the average might seem high, it accounts for the overall team score, so teams with lower averages had more members receiving poor evaluations. The average for the entire class was used as a preliminary dividing point to identify teams which collaborated either better or worse than average. In addition to teams not working well together, yet performing well, there were teams that had high team evaluations but performed worse on team projects than on exams. To clearly show this, Figure 2 organizes the teams into four groups, or quadrants.

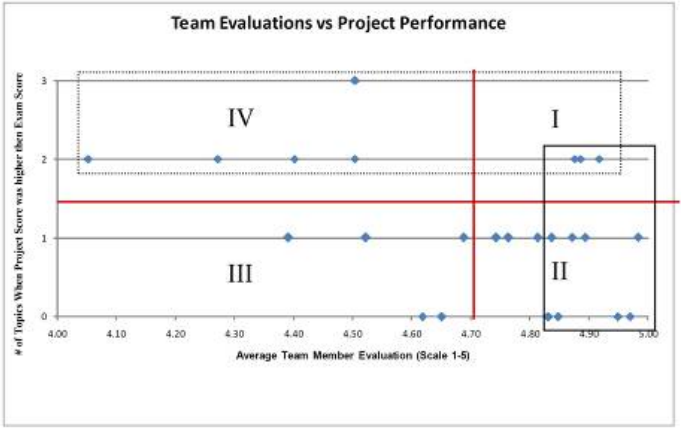


Figure 0: Chart delineating teams into four groups, vertically split with top half performing better on projects than exams. Split on horizontal axis by average team member evaluation score.

In Figure 2 the upper right quadrant (I) shows teams which had above average team evaluation scores and performed better on projects than on exams for at least two of the three topics. The upper left quadrant (IV) is made up of teams which scored better on projects than exams for at least two of the three topics, but scored below the average for team member evaluations. The lower right quadrant (II) indicates teams with team project scores less than exam averages for two or more projects and above average team member evaluations. The lower left quadrant (III) consists of teams which scored better on exams than on projects and had below average team member evaluations. The solid and dotted line boxes indicate the two comparisons which will be made to identify reasons for the differences in performance outcomes.

The comparison between quadrants I and II, considers the differences among the teams with above average team evaluations. Therefore, team surveys (internal assessments), the teams all consistently rated their team members highly on the six factors listed in section 4. Quadrants I and IV, identify teams that consistently performed better on projects than exams. The three teams in quadrant I all had above average team evaluation scores, while the five teams in quadrant IV had below average team evaluations.

Considering first the comparison indicated by the solid line box, quadrants I and II, in Figure 2, the EI competencies of the three groups performing higher on team projects and high team member evaluations (quadrant I) are compared with the EI competencies from the four groups which scored better on all of the exams than on the projects. While there are 11 teams in quadrant II, only the teams which scored higher on all of the exams were used. Figure 3 shows the team average emotional intelligence competencies by category, along with the range of the scores for that competency within the team average. The boxes on Figure 3 indicate areas of differences between teams which scored higher on the projects and teams that scored higher on the exams.

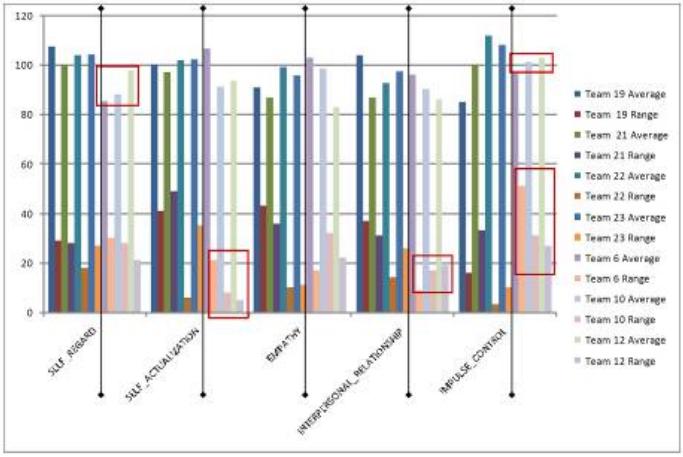


Figure 0: Comparison of EI Competencies amongst teams which scored well on team evaluations. Teams 19, 21, 22, and 23, left of each dividing bar, had higher exam averages than team project scores. Teams 6, 10, and 12, right of each dividing bar, scored higher on at least two of the projects than on the exams.

The teams that scored higher on projects than exam scores tended to have slightly lower self regard averages, suggesting that individual team members were less likely to have big egos. While the self actualization scores were similar for both groups, the range of scores was lower for the teams scoring higher on the projects. This suggests that these teams had a better understanding of their capabilities and skills, likely leading to more effective contribution to the team effort. Similarly, the range for interpersonal relationships was also smaller for the teams performing better on the projects, suggesting a more consistent level of interpersonal communication amongst these teams. The last competency of note is impulse control; teams scoring higher on projects tended to have an average level of impulse control but the ranges were consistently greater. This suggests that the teams need to be balanced, with some team members who are more methodical and others who are more capable of making decisions with less information.

The dotted line box in Figure 2 indicates the comparison of quadrants I and IV, amongst all of the teams which performed well on the projects. In Figure 4, the four boxes are used to highlight differences between the two groups. The far left box highlights slightly lower levels of self regard, suggesting that some meekness among team members allows for teams to better collaborate. The teams with higher team member evaluations also had smaller ranges for the team members' emotional self awareness levels. Showing that having consistent understanding of one's feelings amongst team members will help with conflict resolution or better communication. Teams with higher team member evaluations also had smaller ranges for their self actualization, showing better collaboration when team have a strong understanding of their skills and abilities. Teams with lower ranges for the interpersonal relationship competency also had higher team member evaluation scores. Again the teams which collaborated more effectively typically had a higher range of impulse control, suggesting that balance of this particular competency within a team is important.

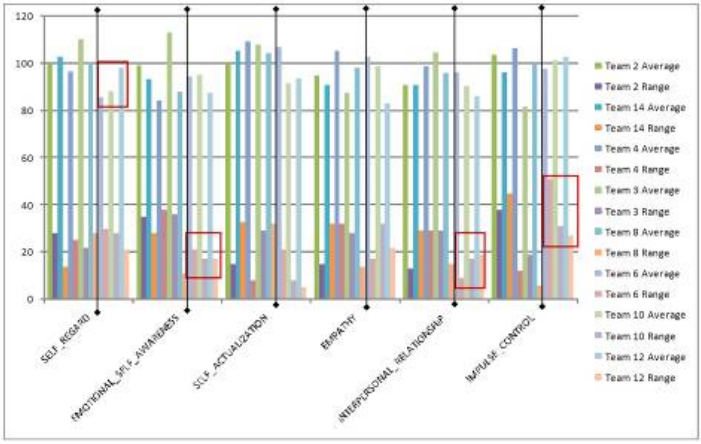


Figure 0: Comparison of EI Competencies amongst teams which scored better on team projects, compared to exams. Teams 2, 14, 4, 3, and 8, left of each dividing bar, had below average team member evaluations. Teams 6, 10, and 12, right of each dividing bar, scored better than average on team member evaluations.

In this exploratory study, similarities and differences amongst team project performance, team member evaluations, and emotional intelligence competencies for a third year architectural engineering course were examined. High performing teams were identified when the team performed better (higher project score and high team member evaluations) than the average of the team's individual exam scores. A high performing team did not result from having a team member with a certain high competency level, but having at least an average level of competency by all team members. Competencies which had the largest impact on how well team members collaborated included:

- Self Regard
- Emotional Self Awareness
- Self Actualization
- Interpersonal Relationships

Competencies which may influence performance outcomes included:

- Self Regard
- Self Actualization
- Interpersonal Relationships
- Impulse Control

The research presented was at the exploratory stage. Some of the limiting factors of this research include:

- the assumption that individual performance and team performance can be compared by averaging a team's exam scores
- team member evaluations are not necessarily objective
- team member evaluations were developed prior to the use of the EI competency study and do not relate to specific EI traits for comparison
- the projects and exams do not correlate for exact matching of content

The results of this exploratory study suggest that a team that properly balances their competencies with their knowledge and skills will be more successful in a collaborative setting. The one competency that stood out was having slightly lower self regard amongst team members. This contrasts the strong assertive leadership image which is often seen in the media and in the AEC Industry. Further and more rigorous analyses should be completed to relate individual competencies and collaborative team performance. A metric could be developed to evaluate the knowledge level of team members, personal preferences of students, how individual versus team tasks are completed and a more detailed team member assessment. In addition, the metric should include an updated survey with quantitative measures that includes questions related to EI competencies.

6. FUTURE WORK

As work in this area continues, a more thorough analysis of the data is being undertaken. Also, a longitudinal study of EI development within engineering undergraduate students is being undertaken to identify if the curriculum impacts these competencies and in what manner. Lastly, a program to allow students to independently work on their own EI competencies is in development and is being incorporated into the Professional Development Program at Penn State.

7. ACKNOWLEDGEMENTS

We would like to thank the student participants for their participation in the study presented in this paper. We would also like to thank the Partnership for Achieving Construction Excellence (PACE), particularly Balfour Beatty, for their support of this work.

8. REFERENCES

Bar-On,R (1997). The Emotional Quotient Inventory (EQ-i): A test of emotional intelligence, Multi-Health Systems, Toronto.

Butler, C.J.; P.S. Chinowsky. (2006). Emotional Intelligence and Leadership Behavior in Construction Executives. Journal of Management In Engineering 22(3):119-125.

Culver, D. 1998. A Review of Emotional Intelligence by Daniel Goldman: Implications for Technical Education. Frontiers in Education Conference, Tempe, AZ Vol 2, Part 2: 855-860.

Crowley, L.; J. Dolle; B. Litchfield; R. Price. (2001). Engineering Emotional Intelligence: Course Development and Implementation. *ASEE Annual Conference Proceedings*, *2001 ASEE Annual Conference and Exposition: Peppers, Papers, Pueblos and Professors*, 2001, Jun 24-27 2001, Albuquerque, NM: 285-4309

Darnell, G.B. (2004). The People-Profit Connection: How Emotional Intelligence Can Maximize People Skills and Maximize Your Profits. Sweet Tea Publishers: Atlanta.

Goleman, D.; R. Boyatzis; A. McKee. (2002). Primal Leadership: Learning to Lad with Emotional Intelligence. Harvard Business School Press: Boston.

Goleman, D. (1999). What Makes a Leader? IEEE Engineering Management Review. 27(1): 4-11.

Goleman, D. (1998). Working with Emotional Intelligence. Bantam Books: New York, New York

Goleman, D. (1995). Emotional Intelligence: Why it Can Matter More than IQ. Bantam Books: New York, New York

Sunindijo, R.Y.; B.H.W. Hadikusumo; S. Ogunlana (2007). Emotional Intelligence and Leadership Styles in Construction Project Management. Journal of Management in Engineering 23(4): 166-170.

ONE APPROACH TO INCORPORATING SUSTAINABLE DESIGN INTO UNDERGRADUATE ENGINEERING PROGRAMS

J. B. Pocock, Ph.D.[1], Z. Mitchell, Ph.D.[2], and A. J. Bates, Ph.D.[3]

Abstract

Schools with undergraduate engineering programs in many disciplines are working to include environmental sustainability and sustainable design into their curricula. This paper describes an example of how these topics are being built into one construction course and will eventually increase within an undergraduate civil engineering program.

For 15 years, the Department of Civil and Environmental Engineering at the United States Air Force Academy has conducted a summer "Civil Engineering Practices – Field Engineering" course. The course is for civil and environmental engineering students between their sophomore and junior years. Over a three-week summer session, the students participate in 21 different activities ranging from surveying to operating heavy equipment. One activity involves building two wood-framed houses. The 900 square feet, two-bedroom houses are built in two pieces each so that they can be transported to the Navajo reservation near Gallup, New Mexico, for needy families. Until 2008, the design and construction of these houses has been conventional to keep the cost down and to meet the educational purposes of inexperienced students. In June 2008, the U. S. Green Building Council – Southern Colorado Chapter (USGBC-SoCo), worked with the Department of Civil and Environmental Engineering (DFCE) to reevaluate the design and materials of the Navajo houses to be more environmentally sustainable and energy efficient. DFCE hosted a "mini-charrette" with USGBC-SoCo members. The participants included

[1] Professor, Department of Civil and Environmental Engineering, United States Air Force Academy, CO, 80840, Phone: 719-333-9119: fax: 719-333-9102, email: james.pocock@usafa.edu

[2] Assistant Professor and Deputy Department Head, Department of Civil and Environmental Engineering, United States Air Force Academy, CO 80840, Phone: 719-333-2054, fax: 719-333-2234, email: zane.mitchell@usafa.edu

[3] Assistant Professor, Department of Civil and Environmental Engineering, United States Air Force Academy, CO, 80840, Phone 719-333-9120, fax: 719-333-2234, email: andrew.bates@usafa.edu

local architects, builders, engineers and designers, some with special expertise in sustainable building design. DFCE faculty members and some students also participated in the mini-charrette. The charrette participants toured the houses under construction, reviewed the drawings and the complete list of construction materials. There were a wide variety of suggested changes to the design and construction materials. The potential improvements in the original design are described and discussed in this paper. More importantly, the opportunities for involving students in the evaluation, design and verification of the improvements is laid out as an example of a problem-oriented approach to incorporating sustainable design into a civil or construction engineering curriculum. While this approach may be unique to the Air Force Academy, the authors hope that it can provide ideas and inspiration for other programs.

Introduction

Schools with undergraduate engineering programs in many disciplines are working to include environmental sustainability and sustainable design into their curricula. The methods for doing so can be subject- or problem-oriented (Lehmann et al 2008), can be based on case studies, or could be part of a capstone experience. Sustainability can also be an opportunity to satisfy the general education component of ABET criteria (Kelly 2008). Civil engineers are already qualified to contribute solutions to sustainable development and green design issues (Bilec, Ries & Matthews 2007). Even so, civil and construction engineering and management are among the disciplines wrestling with how to incorporate sustainability, along with other societal challenges, into their educational formation (Russell et al 2007, Kelly 2008). This paper describes one example of how environmental sustainability is being built into a construction course in an undergraduate civil engineering program. While this approach may be particular to the Air Force Academy, the authors hope that it can provide ideas and inspiration for other programs.

Background

The undergraduate civil and environmental engineering curricula at the U.S. Air Force Academy both include a summer field engineering course between the sophomore and junior year. This course serves as an introduction to the academic major since most of the freshman and sophomore years are taken up with required "core" courses. This is one of several construction courses in the curriculum (Pocock & Kuennen 2007). Over a three-week summer session, the students participate in 21 different activities ranging from surveying to operating heavy equipment. In one of the activities, students, working alongside experienced mentors, build two wood-framed houses. The 900 square feet, two-bedroom houses are built in two pieces each so that they can be transported to the Navajo reservation near Gallup, New Mexico, for needy families. The cost of transporting the house sections is provided by Southwest Indian Foundation (SWIF). Navajo craftsmen place the completed houses on a site and connect them to utilities.

Current Navajo House Design and Materials

Until 2008, the design and construction of these houses has been conventional to keep the cost down and to meet the educational purposes of inexperienced students. The design currently used to construct the houses was originally produced by Air Force Academy students some years ago as a senior design project (see Figure 1). While the house is not a traditional Navajo house, the octagonal shape and some elements of the floor plan (e.g. east-facing door) pay tribute to the historical Navajo Hogan. The design has been adjusted to accommodate requirements from the Navajo Nation, the cost and availability of materials, and the skill level of the students building them.

The one-story houses use conventional wood framing for the floor with two-by-eight joists and oriented-strand-board (OSB) deck. The roof uses two-by-six framed trusses with an OSB deck and asphalt shingles. The octagonal shape of the houses leads to a complicated radial arrangement of the roof trusses. Vinyl siding covers OSB sheathing over two-by-six wood stud exterior walls and interior partitions are two-by-four stud walls with gypsum board.

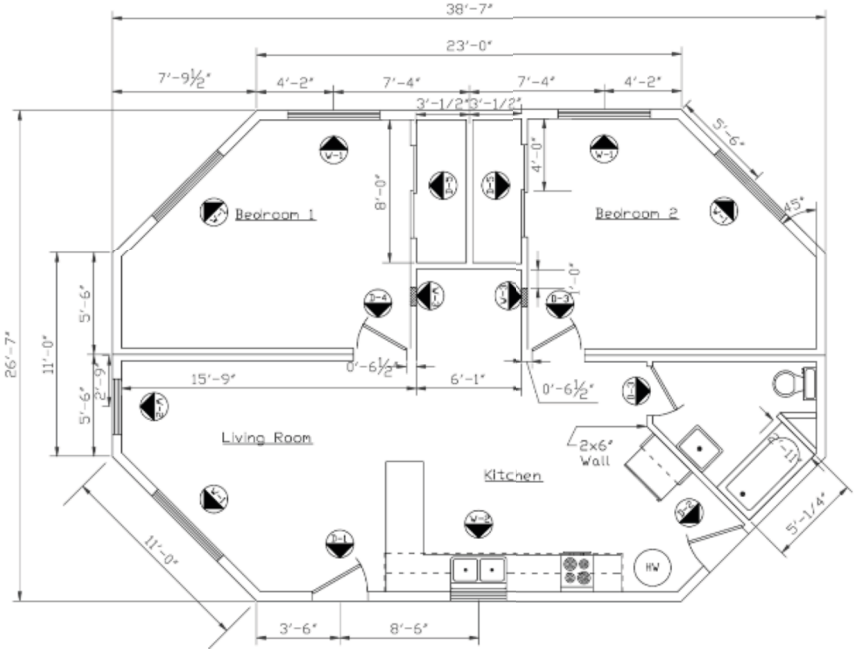


Figure 1. Current Navajo House Floor Plan.

Once on the Navajo reservation, the houses may be sited where few, if any, utilities are available. Electricity is normally available by the time a family moves in. The houses are heated only with a wood-burning stove. Houses include complete plumbing for the kitchen and one bathroom. The water heater and kitchen stove are electric. The finished houses include complete electrical wiring and lighting.



Figure 2. Students and Mentors Building the Currrent House Design.

Comparison to Other Initiatives

The Air Force Academy is not the only institution that has tried to introduce sustainable technologies into its student building projects. The late Samuel Mockbee pioneered this concept through his "Rural Studio" program at Auburn University (Levy, 2000). Started in 1993, the Rural Studio takes students through the design-build process at locations in rural Alabama. The homes and facilities that Auburn students build are designed with affordability and the use of local and recycled materials in mind. A similar program was started in 2000 at Utah State (Bernard, 2008) that focuses on the Navajo reservation in Bluff, Utah. Penn State and the University of Washington have made great strides in sustainable construction on American Indian reservations through the American Indian Housing Initiative (AIHI) (Riley, 2006). Since 1998, these two universities and other partners have focused on the construction of homes and facilities on-site, primarily with straw bales, a readily-available sustainable material that is a waste product of grain production. The use of

straw bale construction has made for durable, energy-efficient buildings that have had positive impacts in the communities in which they are constructed. Faculty and students from Clemson University's Habitat for Humanity chapter recently completed a Habitat for Humanity home that meets the requirements for Leadership in Energy and Environmental Design (LEED) certification (Nixon, 2008). The chapter was named "Campus Chapter of the Year" by Habitat for Humanity International for this effort. Something that makes the Air Force Academy program unique among these initiatives is the fact that the homes constructed by the students are built off-site with materials procured in Colorado instead of on-site with locally available materials.

USGBC Mini-Charrette and Results

In June 2008, the U. S. Green Building Council – Southern Colorado Chapter (USGBC-SoCo), assisted the Department of Civil and Environmental Engineering (DFCE) in reevaluating the design and materials of the Navajo houses to be more environmentally sustainable and energy efficient. DFCE hosted a "mini-charrette" with USGBC-SoCo members. The participants included local architects, builders, engineers and designers, some with special expertise in sustainable building design. DFCE faculty members and some students also participated in the mini-charrette.

The participants began the charrette with a tour of the current houses under construction conducted by faculty mentors who work with students in building them. The participants also received copies of the drawings and a list of materials. After an introduction by members of the faculty, USGBC-SoCo members facilitated the charrette, and divided the participants into three groups to encourage more discussion. Each group was asked to consider how to make the house design and materials more energy efficient and more environmentally sustainable. This was a brainstorming session, intended to generate ideas without evaluating them. Next, each group reported their ideas to all the participants. There was also general discussion to ask questions, clarify, and suggest combinations of ideas. Finally, the ideas were compiled into a single list of 27 suggested improvements. The ideas seek to improve the current house design in a number of ways:

- Reducing energy cost and consumption
- Using materials that are more environmentally sustainable, including recycled materials
- Improving safety and health for the occupants
- Reducing the quantity of materials and improving efficiency of construction
- Revising the floor plan to support the above goals

Below is the complete list of suggested improvements, many of which potentially contribute to more than one type of improvement listed above:

1. Include a "trombe" wall to absorb solar heat during the day and release it at night; possibly made of soapstone or sand-filled interior partitions.

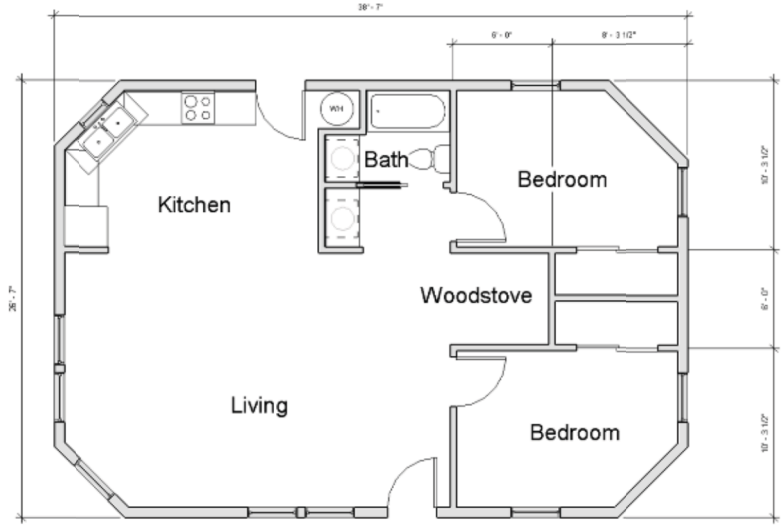
2. Aluminum roofing with simplified framing; increase ceiling height and air flow by matching the shape of the ceiling to the roof form. This would also simplify the roof framing.
3. Install taller double-hung windows for better air circulation; with sill at 30" maximum above the finished floor (ensure windows meet egress requirements). Install windows at stud locations to minimize additional framing.
4. Space wall studs at 24 inches on center rather than 16 inches.
5. Install all low-flow plumbing fixtures and Energy Star appliances.
6. Ensure compliance with "Americans with Disabilities Act" (ADA) for future needs of occupants. This includes:
    a. 3'-0" wide doors
    b. Countertops at 34 inch height, with clear area below for wheel chair access.
    c. Room in bathroom for wheelchair maneuverability (five foot diameter circle)
    d. Install extra blocking in bathroom walls now for future grab bar installation.
7. Provide compact fluorescent light bulbs or LED fixtures.
8. Install a solar water heater
9. Install photovoltaic (PV) panels. Contact local/regional PV provider to discuss training local Navajo workers in the installation process. This could be a valuable resource for the Navajo Nation as well as the PV company.
10. Utilize propane rather than electricity to fuel appliances.
11. Reduce header sizes (appear to be over-engineered, thus wasting materials).
12. Offset studs within the wall to minimize sound transmission.
13. Use only FSC-certified wood.
14. Install occupancy sensors in rooms so that lights turn off if left on when occupant leaves.
15. Use a more renewable alternative to vinyl for siding (e.g. aluminum) and flooring (e.g. ceramic tile).
16. Collect rainwater in a cistern for doing laundry, irrigating garden, etc.
17. Provide a laundry sink in the kitchen, outside the bathroom or adjacent to the back door.
18. Use low VOC paints, caulks and sealants in homes.
19. Provide combustion air for stove and water heater.
20. Increase overall ventilation for health of inhabitants, minimize smoke and fume inhalation from stove
21. Use I-joists for framing rather than two-by-eight floor joists and roof trusses.
22. "Modularize" construction to minimize construction material waste (studs, gypsum board, etc.)
23. Use insulated exterior sheathing rather than Tyvek wrap to reduce thermal bridging.
24. Use steel straps for bracing at corners to help reduce framing.
25. Use tile on all floors in lieu of vinyl flooring
    a. More durable material

b. Sustainable
c. Easy to clean
d. Acts as a heat sink for solar/heat gain in winter

26. Install solatubes for daylight in bathrooms (at minimum)
27. Revise floor plan (see Fig. 2):
    a. Move bedrooms to north side of house.
    b. Provide smaller "chamfers" at corners of building to maximize flexibility of bedrooms.
    c. Provide an additional sink and counter outside of bathroom for other family member use.
    d. Provide "front" and "back" doors for circulation patterns and air flow.
    e. Provide overhangs or exterior shading at south windows to minimize solar heat gain in summer.
    f. Move all plumbing walls to interior walls of home to reduce risk of freezing pipes.

The USGBC Southern Colorado Chapter also volunteered to solicit donations to the Navajo Hogan housing project from vendors and suppliers of sustainable materials and products.

Figure 3. Preliminary Revised Floor Plan Based on Charrette



Student Involvement and Learning

If incorporated, the charrette participants expect these ideas to improve the energy efficiency, environmental sustainability, constructability and occupant health of the redesigned houses. The expected improvements cannot really be validated unless the ideas are incorporated into a completed new design that is built and studied. Each of these tasks provides an opportunity for student involvement and learning.

Besides the students who took part in the charrette, the authors plan to involve students in this project in three ways;

1. Completing the revised design and incorporating the suggested changes
2. Building the new version of the house in future offerings of the field engineering course
3. Validating the improvements in energy efficiency, environmental sustainability, constructability and occupant health.

These three ways will involve students in different tasks and at different levels in their education. This provides the opportunity for different levels of learning according to Bloom's Taxonomy of Cognitive Learning as shown in Table 1 below (Bloom 1956).

Revising the design will include researching each of the ideas for improvement and validating their feasibility (including code compliance), estimating the difference in initial and life-cycle cost and energy use, and researching their impact on the environment. The results of the research and validation will be incorporated into a new set of working drawings and list of materials. This work will be carried out by a small group of seniors beginning in January, 2009 with assistance from faculty and local engineers with special expertise (an update on their work should be available at the 2009 Construction Research Congress).

The goal is for the revised design to be ready in time to build a new version of the home alongside the current design during the summer 2009 field engineering course. This will expose the new class of civil and environmental engineering students (rising juniors) to the differences in the two versions of the houses and make it possible to begin evaluating the performance of the new design. If the improvements are validated, the new version will eventually become the standard design for future offerings of the field engineering course, and Navajo families would enjoy the improvements.

The work to validate the improvements should include:

- Modeling and comparing the energy consumption of each version
- Comparing the actual quantity of materials required
- Verifying the expected reduction in non-renewable materials and increase in recycled content
- Verifying both the initial and life-cycle costs.
- Recommending future improvements or design changes

This effort could be the basis for an interdisciplinary senior capstone course including students from other majors such as mechanical and electrical engineering.

Table 1. Student Tasks and Learning

Student Task	**Student Year**	**Cognitive Learning Categories**	**Examples of Activities**
Completing and Validating Revised Design	Seniors	Analysis, Synthesis, Evaluation	Compare, Design, Revise
Constructing New Version	Juniors	Knowledge, Comprehension, Application	Names, Recognizes, Explains, Constructs
Validating Improvements in New Version	Seniors	Analysis, Synthesis, Evaluation	Evaluate, Discriminate, Justify

Conclusions

This paper provides one example of how to add more sustainability to an undergraduate construction course and engineering curriculum, while involving students beyond just adding new lessons to existing courses. Even though the example in this paper is unique, it has applications to other undergraduate programs. Many undergraduate civil and construction engineering programs include similar student projects, often in conjunction with groups like Habitat for Humanity or Engineers without Borders. The student involvement suggested in this paper could translate well to such programs. Other undergraduate programs that include similar student projects can make use of faculty and industry expertise, such as the local USGBC chapter in this case, to give students a head start on "greening" their projects. The mini-charrette used in this case took a very short time, with almost no cost, and generated twenty-seven ideas for improvement. There are dozens if not hundreds of state and local USGBC chapters across the United States. Most engineering departments also have an outside advisory committee that can also serve as a resource for how to incorporate sustainability into a curriculum.

References

Bernard, M. (2008). "DesignBuildBLUFF: Drawing on two-by-fours." Architectural Record, 196(4), 32.

Bilec, M., Ries, R., Matthews, H. S. (2007). "Sustainable Development and Green Design – Who is Leading the Green Initiative?" J. Prof. Issues in Eng. Ed. & Pract., 133(4), 265-269.

Bloom B. S. (1956). Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain. New York: David McKay Co Inc.

Kelly, W. E. (2008). "General Education for Civil Engineers: Sustainable Development." J. Prof. Issues in Eng. Ed. & Pract., 134(1), 75-83.

Lehmann, M., Christensen, P., Du, X., Thrane, M. (2008). "Problem-oriented and Project-based Learning (POPBL) as an Innovative Learning Strategy for Sustainable Development in Engineering Education." Euro. J. of Eng. Ed., 33(3), 283-295.

Levy, D. S. (2000). "Alabama Modern." Time, 156 (14), 92-93.

Nixon, A. (2008). "Clemson's Habitat for Humanity named Campus Chapter of the Year." Clemson University website: http://www.clemson.edu/newsroom/articles/2008/june/habitat_award.php5.

Pocock, J. B., Kuennen, S. T. (2007). "Construction as the Integrating Element of a Comprehensive Civil Engineering Curriculum." Proc. Annual Conf., ASEE, Honolulu, HI.

Riley, D. R. (2006). "Teaching global citizenship: Reflections on the American Indian Housing Initiative." New Directions for Teaching & Learning, 105, 51-61.

Russell, J. S., Hanna, A., Bank, L. C., Shapira, A. (2007). "Education in Construction Engineering and Management Built on Tradition: Blueprint for Tomorrow." J. Const. Eng. & Mgt., 133(9), 661-668.

CONSTRUCTION EDUCATION IN SECOND LIFE

Kihong Ku, DDes[1], and Yogesh Gaikwat[2]

Abstract

The advancements of digital media and virtual environments have begun to greatly impact typical classroom environments. However, traditional construction education approaches of lectures, seminars, and project group work, have not really taken advantage of the potential of these new tools. Research shows that virtual reality simulation technology offers an effective and complementary teaching method to address the competencies and skills of the construction management process. While there are successful examples of virtual reality applications such as the Building Management Simulation Center in the Netherlands, these facilities limit virtual learning to users who are within the physical boundaries of these buildings.

This paper describes the potential benefits of Second Life – a virtual worlds environment – for simulating role-playing in the construction process and outlines the technical challenges to its adoption for construction education. The core elements of a construction planning scenario for an on-campus building at Virginia Tech is discussed, expanding into an applicable safety training scenario that involves features of construction equipment (e.g., tower crane, forklift) and scaffolding. The authors conclude with future research needs of this new learning environment.

Introduction

Virtual Learning Environments effectively complement traditional education (Koskela et al., 2005; Sawhney and Mund, 1998) extending beyond the physical reach of classrooms over the internet. Building on the advancements of information, communication, and simulation technologies, Virtual Reality (VR) techniques have been extensively utilized for training high-risk occupations such as pilots and nuclear power plant operators. Recently, the mining industry has begun to adopt VR for task-based training (Lucas and Thabet, 2007; Kizil and Joy, 2001). However, VR approaches that utilize role-playing for educational purposes in construction have been limited. While the Building Management Simulation Center in Leeuwarden, Netherlands, and the recently planned Advanced Construction Technologies Simulation Center (ACT) in Coventry, UK, offer innovative experiential learning

[1] Assistant Professor of Building Construction, School of Construction (0156), Virginia Tech, 410A Bishop-Favrao Hall, Blacksburg, VA24061, email: kku@vt.edu
[2] Master of Science in Building Construction graduate, School of Construction (0156), Virginia Tech, Blacksburg, VA24061, email: ygaikwat@vt.edu

through simulated role-playing scenarios that integrate physical jobsite environments (e.g., site huts) and virtual reality models projected onto large parabolic projection screens (Stothers, 2007), these programs are constrained to the physical location of the centers. To benefit a larger audience of construction students who are primarily studying in rather traditional classroom settings, research should investigate the possibilities of virtual reality simulation environments that could be delivered over the internet. The introduction of virtual worlds such as Second Life to construction education has the potential to bridge the gap between learning about a subject and 'learning by doing' (Stothers, 2007). In context of these needs, this paper discusses the possibilities and limitations of the Second Life environment – a virtual world – for construction education, specifically safety training.

Virtual Reality and Virtual Construction Approaches

VR technology has been used in 3D graphics, video games, 3D scientific visualization, architectural design, and medical research and education (Messner and Horman, 2003). Messner and Horman further elaborate on the use of VR for visualization of project designs, visualization of construction plans and schedules, design and analysis of construction equipment, and communication and training of project teams. In addition, they categorize VR technology into desktop VR and Immersive VR. The primary application of VR in construction is to simulate real world properties through 3D visualization and to allow interactive navigation to examine the construction process. Thus, previous VR research in construction has been intimately related to virtual construction research which has concentrated on 3D and 4D CAD modeling that are being applied to construction visualization as a project management tool to assist decision-making of the construction planning process (Kamat and Martinez, 2000; Fischer et al., 2003). These methods link 3D building models with construction activity sequences to visualize activities of a schedule. 4D virtual construction models have also been explored as self-directed tools for web-based open learning (Haque and Shah, 2007). However, a shortcoming of 4D CAD approaches has been the inability to visualize the processes of transportation and installation of construction components, which are instead omitted and simply represented as products within its final position temporarily fading in and out (Rowlinson and Hadikusumo, 2003). To overcome this issue, Huang et al. (2007) have developed a virtual prototyping system which integrates construction processes such as material storage, staging, and erection. Acknowledging the emphasis of research and development on 4D visualization for construction planning, and furthermore, the recent movement towards Building Information Modeling which intends to integrate all relevant information from design to construction, VR for construction education should incorporate and enhance process components and interaction with temporary structures. The value of simulation based construction learning tools is significant (Sawhney and Mund, 1998), and Stothers (2007) describes virtual reality simulator techniques that emulate the complexity of real work environments under work-like pressure to encourage dynamic and critical thinking based on carefully structured scenarios that can be replicated. Therefore, research should examine the potential of VR not only to apply interactive role-playing tools to 4D product models but also to integrate process visualizations of temporary works and construction equipment to enhance real-world context for

deeper learning. A powerful technology that can be used for such process visualization and training is the technology of virtual worlds which will be examined in the next section.

Construction Education in Second Life

Second Life, created by Linden Lab, is a virtual world which is used for serious gaming (i.e., games for simulation of management training, collaborative decision-making, and for education (Nederveen, 2007). This environment is a distributed, virtual space where people are represented as avatars, created and customized by themselves. People can walk, fly, chat, and interact with other people, objects or computer-controlled agents in place-like contexts. Avatars can walk around and build with a building tool-set and the primitive objects – "prims." Unlike video games, Second Life is used by health-care providers, companies, academics, and the military, to learn and work together, and to trade in real world virtual items, or to run medical triage simulation (Economist, 2007).

Some examples of training applications include virtual cancer labs for training doctors by European universities, consortiums of corporate training entities of Wal-Mart stores, American Express, Intel, and more than 200 other companies who are experimenting inside Second Life with alternative ways to foster more collaborative learning environments. As government entities, the Swedish embassy is one of the first organizations that has established a virtual presence in Second Life as an information portal for Sweden.

Nederveen (2007) discusses the possibilities of Second Life for collaborative architectural design focusing on the many virtual complex constructions that have already been collaboratively created within Second Life. In a similar context, Studio Wikitecture's (http://studiowikitecture.wordpress.com/) "Open Architecture" approach demonstrates an interesting collective design experiment for architecture and city planning.

To take advantage of Second Life's functionality for interactive communication and visualization, the authors conducted an investigation of Second Life on incorporating role-playing scenarios for construction process learning and safety training. To understand the applicability of Second Life to construction processes, the lead author established a four step research plan (Figure 1). This paper describes the first and second phase of this research which involved a broad literature review of the Second Life environment for general education, training, and gaming purposes. The second step followed with a preliminary design of the Second Life learning interface for building and construction operations in the format of hypothetical role-playing scenarios. Future research will take these early findings to the next level, implementing a prototype for construction planning and safety training that will be tested with second year building construction undergraduate students, in spring 2009. The prototype will be evaluated afterwards to understand its usability and usefulness to enhance the learning experience. The following section presents the development process and findings of the preliminary design phase.

Overview of Proposed Second Life Environment

A virtual project of a real-life construction project is presented to demonstrate the development process of the building model and the educational scenarios. A virtual model of the Bishop-Favaro Hall, a recently completed Virginia Tech building for the School of Construction (Figure 2) was selected because detailed project documentation (e.g., CAD drawings, shop drawings, etc.) was available and process information (project photos, project schedule, project participant interviews, etc.) of the construction process had been collected during and post construction.

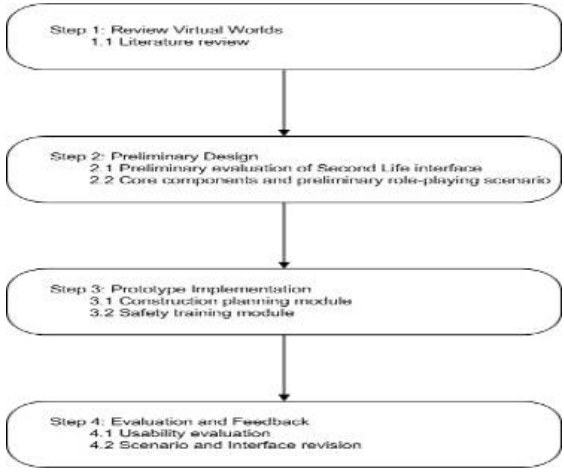


Figure 1. Research plan for the Second Life Construction Learning Environment

The Building model

The first step was to acquire an empty piece of land (island) which is located on the "Panaki Cove" on the Second Life grid to create the virtual model of the existing building (Figure 2). Based on the construction drawings and shop drawings, the building model was broken into steelwork components, concrete floors, architectural precast panels, and windows. Because the modeling process in Second Life is time-consuming in comparison to dedicated modeling software such as Revit or AutoCAD, the authors initially created a Revit model. However, as expected the file import process into Second Life caused difficulties with the Revit CAD file format. Therefore, the authors searched for an alternative modeling tool that was supported by Second Life. The AC3D software interface is similar to standard 3D modeling software, thus allows rather efficient modeling compared to Second Life modeling and produces an acceptable file format to export to Second Life. Third-party plug-in software for CAD software (e.g., AutoCAD, Maya, 3D Max) import is under development by various entities such as the Delft University of Technology. Figure 3 demonstrates the model file conversion process from AC3D to Second Life. The objective of modeling the building was to understand how individual

components could be broken into basic building blocks and components for assembly simulation within Second Life. The modeling exercise illustrated that individual components could be moved, installed and joined, to simulate, material storage, staging, erection, and assembly processes.



Figure 2. Bishop-Favrao Hall photo (top photo by Terry Paiva), model (bottom left) and project site (bottom right)

Temporary works - Scaffold safety training

As temporary works are a critical element of the overall construction planning process (Huang et al., 2007), the case study included an erection scenario of scaffolding. Temporary works can be modeled or also traded within Second Life from other people who have already modeled such structures. Rather than modeling a scaffold from scratch, the case study acquired an existing product within Second Life. Considering the significance of construction falls, involving scaffolding failures, a simple scenario was created for safety training purpose. The first step was to categorize scaffolding hazards into component problems, connection problems, and miscellaneous problems. Component problems are related to single components such as a damaged bracket, a missing plank, or a missing support, to the guardrail, or a missing top rail, or mid-rail. Connection problems are related to connection defects in the scaffold. Miscellaneous problems are concerned with excessive spacing between posts, insufficient overlap between planks or overloading planks with excessive construction load.

The training scenario in Second Life was based on two major tasks, (1) the erection of the scaffolding platform, and (2) the inspection of an existing platform. In the erection scenario (Figure 4), trainees will participate by installing the platform components through a proper installation sequence and making sure that the components are appropriately positioned and connected. Erection instructions are provided within Second Life to trainees before the exercise. In the inspection scenario, the scaffolding components are already assembled and include problems and defects that are strategically planned, to be identified and corrected by the trainee (Figure 5, 6).

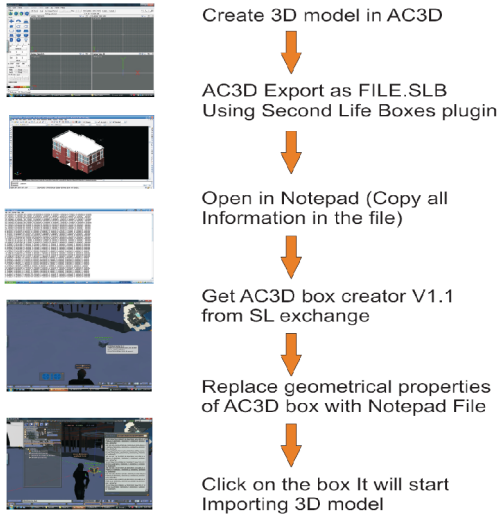


Figure 3. File conversion process

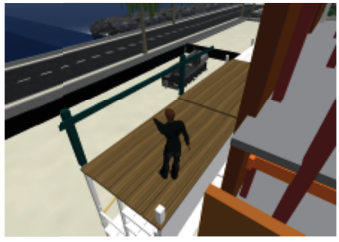




Figure 4. Scaffold training Erecting scaffold

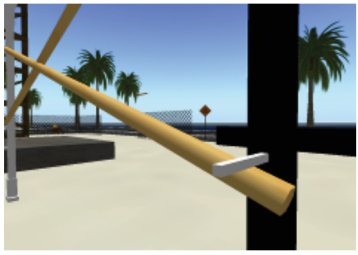




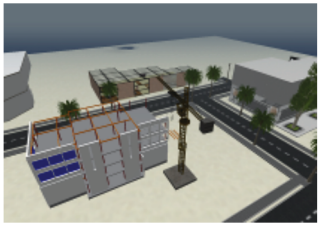
Figure 5. Scaffold training- Dislocated component and missing safety pin (left image)
Figure 6. Scaffold training-Corrective action by trainee (right image)

Construction equipment – Tower Crane operation training

Cranes are a central component of many construction operations and are associated with a large fraction of construction deaths; in fact, estimates suggest that cranes are involved in up to one-third of all construction and maintenance fatalities (Kang and Miranda, 2006). Riggers and signalmen are a critical part of crane operations, and they need to receive training similar to that provided to operators. Second Life simulations can be used for training and studying collision-free and optimal-operational path for erecting structural elements, consequently reducing schedule delays and allowing safe construction. Methods to coordinate multiple cranes in a construction site can also be evaluated.

The creation of construction equipment such as cranes requires additional scripting to be added to the geometric model. For example, scripting is utilized to enable rotational motion of the jib around the base, horizontal movement of the roller along the jib, and vertical movement of the hook by the roller. Scripting is also required to enable the rigger to attach and detach load material from the hook.

For the case study, we acquired an existing crane available within Second Life and studied the possibilities and limitations of crane control (Figure 7, 8). Potential scenarios can address control issues of identifying the geometrical information from given buildings and cranes, searching for the safest and most-efficient paths to erect components.



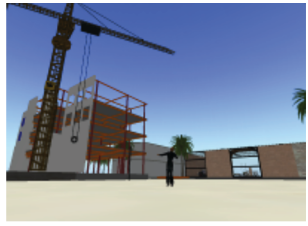


Figure 7. Crane training (left: bird's eye view of crane location on the site; right: ground level view of crane)

Communication is an integral activity for tower crane operation. Voice function in Second Life can emulate radio or other voice communication which is critical for tower cranes or mobile cranes where the operator is unable to see the load

and therefore forced to rely on riggers and signalmen. In addition to voice communication systems, hand signals can be simulated within Second Life training scenarios as well. An illustration of a set of one- and two-handed signals of ANSI/ASME B30.x standards can be easily incorporated into the training scenario.

Training simulation center

A training center was developed nearby the virtual building (Figure 9, 10). This facility was devised to provide safety instructions and the relevant training information for trainees before entering actual role-playing sessions. Displays provided in the facility can be linked to latest information available on the web, as well as training videos of detailed installation procedures (e.g., steel erection). Miniature models are exhibited within this virtual center to assist trainees' understanding of heavy equipment (Figure 9). Instructors can also organize virtual seminars facilitated by chat and voice communication functions that can be used with or between trainees to interact with each other, complementing traditional classroom based lectures learning.

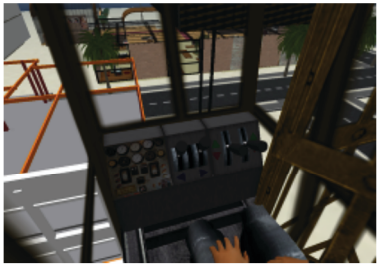


Figure 8. Crane training- operator cabin



Figure 9. Training center- Crane model



Figure 10. Virtual training center in Second Life

Conclusion and Further Studies

This paper presented potential usage of Second Life for educational construction scenarios and the possibilities of process simulation via role-playing. This initial investigation demonstrates new opportunities for simulating construction processes and incorporating experiential learning into traditional classroom environments. Based on our exploration the authors propose that Second Life offers effective means to engage large-size classroom students to interactively study the

construction process of buildings before actually building them. Such scenarios would add value to the understanding of activity sequencing, crew coordination, and interface management which is difficult in traditional educational settings.

In addition to students' participation as trainees within simulation scenarios, the authors also envision students' proactive participation as creators of an open object library of construction equipment and temporary works. Thus, besides utilizing Second Life as a training environment, there is also a need to teach students modeling and scripting skills for designing process components. The pedagogical aspect of involving students in this process is twofold: (1) students will gain a deeper understanding of construction equipment and temporary works by building it themselves, and (2) they will be contributors to an open learning environment that will not only benefit themselves and their peers, but a larger community of construction students.

Despite the above mentioned opportunities a few remarks are necessary. First, importing 3D CAD models is still limited. With the diffusion of Building Information Modeling we expect that software companies will work together to enable direct data translation between Second Life and standard 3D modeling software. The continuing advancements of Building Information Modeling and Virtual Construction technologies mandate research efforts to address successful integration of 4D visualization and intelligent 3D modeling with virtual worlds. Second, virtual worlds incorporate various unrealistic physical properties that conflict with safety training scenarios. For example, Second Life avatars can fly, and earth does not have the physical properties of mass that cause certain soil conditions to cave in. Thus, to utilize Second Life for safety training purposes, advanced scripting and creative solutions will need to be scripted and programmed. Third, from a logistics standpoint, careful role-playing scenarios will have to be developed, to implement pedagogically effective settings that are adequately customized to different size classes and diverse levels of scenario complexities. Fourth, as Second Life is not a goal or end oriented video game, proper feedback systems that assess and guide learners' abilities, need to be integrated into Second Life sessions. This can be facilitated through on-screen dashboards, text messages, automated agents, etc. Fifth, the level of detail of construction activities requires careful coordination when simulating labor or equipment based procedures for construction work. In other words, productivity rates and activity durations are not going to be realistic and thus such factors need to be considered during scenario developments. Sixth, the development of an open equipment and temporary works library would require some common protocol for geometric modeling, feature scripting, and model ownership, file format, equipment size, type, control rules, etc.

This paper presented the early investigations of a four-step research project that has been formulated to understand the educational implications of specific construction role-playing scenarios in Second Life. The follow-up stages are in progress and a pilot study will be conducted in spring 2009 to test the efficacy of this proposed environment. This future research will address the user-friendliness of the interface design and assess the learning effectiveness of the developed role-playing scenarios. Based on the results of the pilot study, the environment will also be tested

in a graduate level course to further investigate the issues and ultimately to apply the concept to a broader audience.

While there are many challenges for implementing a virtual world based construction education environment, broader adoption of this technology for construction education and safety training is anticipated.

References

The Economist, "Getting Serious," December 6th, 2007, https://www.economist.com/search/displaystory.cfm?story_id=10202591

Fischer, M., Haymaker, J., Liston, K., (2003) "Benefits of 3D and 4D models for facility managers and AEC service providers," *4D CAD and Visualization in Construction: Developments and Applications, 2003*, A.A. Balkema Publishers

Haque, M. and Shah, G., (2007) "4D Construction Visualization: Techniques with Examples," *2007 ASEE Annual Conference & Exposition* (ASEE Conferences Excellence in Education)

Kamat V. and Martinez, J. (2000) "3D visualization of simulated construction operations," *Simulation Conference Proceedings, 2000.* Winter, Orlando, FL, USA

Kang, S. and Miranda, E., (2006) "Planning and visualization for automated robotic crane erection processes in construction," *Automation in Construction*, Vol. 15, Issue. 4, July 2006, pg. 398-414

Kizil, MS, and Joy, J.,(2001) "What can Virtual Reality do for Safety?" *The University of Queensland, Minerals Industry Safety and Health Centre.*

Koskela, M., Piia Kiltti, Inka Vilpola and Janne Tervonen, (2005) "Suitability of a Virtual Learning Environment for Higher Education," *Academic Conferences Ltd, http://www.ejel.org*

Lucas, J. and Thabet, W. (2007) "Using virtual reality (VR) to improve conveyor belt safety in surface mining," *24th W78 Conference Maribor 2007 & ITCEDU Workshop & 14th EG-ICE Workshop: Bringing ITC knowledge to work.* Maribor, Slovenia

Messner J. and Horman M., (2003) "Using Advanced Visualization Tools to Improve Construction Education." *Proceedings of CONVR 2003*, Virginia Tech, USA.

Nederveen, S., (2007) "Collaborative design in Second Life," *Second International Conference World of Construction Project Management,* October 24-26, 2007, Delft, The Netherlands

Rowlinson, S. and Hadikusumo, B.H.W., (2003) "Virtually real construction components and processes for design-for-safety-process (DFSP)," *4D CAD and Visualization in Construction: Developments and Applications,* 2003, A.A. Balkema Publishers

Sawhney, A. and Mund, A., (1998) "Simulation based Construction Management Learning Systems." *Proceedings of the 1998 Winter Simulation Conference*

Stothers, N., (2007) "The use of Virtual Reality simulation in the Education and Training of Construction Managers. Are the British going Dutch?" *Second International Conference World of Construction Project Management*, October 24-26, 2007, Delft, The Netherlands

ENHANCING CONSTRUCTION EDUCATION WITH CONTEXTUAL SERVICE LEARNING

Christine M. Fiori[1] and Anthony D. Songer[2]

[1] Assistant Director of Undergraduate Programs, Industry Relations and Outreach, Myers-Lawson School of Construction, Virginia Polytechnic Institute and State University, 330B Bishop-Favrao Hall, Blacksburg, Virginia, cfiori@vt.edu

[2]Associate Professor, Vecellio Construction Engineering and Management Program, Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, 113B Patton Hall, Blacksburg, Virginia, adsonger@vt.edu

Abstract

Recent calls to reform engineering education place emphasis on applied math and science within the broader context of globalization, economics, the environment, and society. To solve these complex problems, interdisciplinary approaches are required and demand additional teamwork skills of new graduates. While this vision for the future is well documented in *The Engineer of 2020* and the ABET engineering accreditation criteria, many engineering faculty are at a loss for how to cultivate and assess these skills in students, particularly when the problem is viewed as adding new content to already packed degree programs. The Center for Leadership in Construction in the Myers-Lawson School of Construction at Virginia Tech provides an educational program that combines classroom learning with authentic field experiences. The program responds to the demands for integrating technical and social domains in a multi-disciplined, globally sensitive paradigm. The course that illustrates the efforts of the program is "Sustainable Construction in the Global Village". The course focuses upon public health infrastructures in resource poor countries and engages students to engineer in context by working in highly complex socio-technical systems that depend on humans for operations and maintenance. Student teams develop iterative design and construction solutions for community identified needs and then build their projects in country. For the course, hygiene and sanitation were the themes for projects. These included a water-storage and distribution system, a hand washing station, secure trash receptacles and school grounds pathways. Design considerations included the use of local materials, ease of use and sustainability, as well as operations and maintenance. The students developed designs and construction plans that detailed the materials required, quantity and cost estimates, a project schedule, a resource utilization plan and a daily safety plan. This paper provides a background on service learning, describes the course development and implementation, highlights the impact this experience had on the students, presents qualitative assessment data from the experience and illustrates how other programs can participate in such learning experiences.

INTRODUCTION

The educational philosophy that embraces the "learning by doing" process is not new. Completing service learning projects is something that various University programs incorporate into their curriculums. Real-world design projects are the highlight of most senior capstone classes. Leadership has been integrated into the core curriculum of many construction programs (Bell and Skipper 2006, Riley et. al. 2004). Most construction programs have an industry advisory board that provides feedback to the administration and engages the students through internships and other mentoring activities. The educational component of the Center for Leadership integrates these often disparate initiatives into a unique blend of student experiences. This is accomplished primarily through a service learning centric model. The model provides a unique integration of multiple pedagogical issues and involves industry, faculty and students. This paper provides background on service learning, describes the course development and implementation, highlights the impact this experience had on the students, presents qualitative assessment data from the experience and illustrates how other programs can participate in such learning experiences.

BACKGROUND

Recent calls to reform STEM (Science, Technology, Engineering, and Math) education, specifically engineering education, place a strong emphasis on applied math and science within the broader context of globalization, economics, the environment, and society. Popular stereotypes portray engineering as a technical, science-based, often de-contextualized activity (Kuhn 1998). The National Academy of Engineering (NAE) report, *The Engineer of 2020,* echoes these concerns and calls for fundamental change in the structure, policies, and practices of engineering education.The report "urges the engineering profession to recognize what engineers can build for the future through a wide range of leadership roles in industry, government, and academia not just through technical jobs" and that "with the appropriate education and training, the engineer of the future will be called upon to become a leader not only in business but also in nonprofit and government sectors (NAE 2004)." This paradigm shift will enable engineers to meet the demands of globalization, which requires a much broader range of skills than technical ability alone. Technology-based concerns must be balanced with more socially-oriented demands (Kuhn 1998). Specifically, elements of good design practice include the ability to define a problem through responsible judgments based on "wide consultation, sensitivity to social, cultural and moral issues, acknowledgement of the political and economic context and critical reflection (Conway 2000)" including consideration of realistic "economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" constraints (ABET 2007-2008 Engineering Accreditation Criteria).

An ideal setting for engineering students to develop these skills is public health infrastructures—water and sanitation infrastructure directly related to public health in resource poor countries. This focus engages students to engineer in context by working in highly complex socio-technical systems that depend on humans for operations and maintenance. This particular problem requires an interdisciplinary, socio-technical solution. Past efforts demonstrate that failures do not often stem from

inappropriate technology application, but rather from a lack of proper operation and maintenance. Specific difficulties arise when human operators are required to operate and maintain technology-driven solutions. Successful operations and maintenance of systems are critical to system sustainability. Designs of such systems must integrate the capacity, limitations and needs of the human operator to foster use and reduce system failure potential (Wilpert 2005). Thus, engineers must investigate context of use and the needs of users (per se operators), being alert to and actively exploring ambiguities found in specific cultures (Kuhn 1998). Part of the paradigm shift described above includes engineers viewing themselves as moral agents balancing technical and social factors, "not just as judges of problems whose definitions are fixed and given (Whitbeck 1995)." A few U.S. engineers in resource-poor countries currently work with government officials, the International Aid System, or with non-governmental organizations making strides in learning the meta-skill design to address social issues with technical solutions. Sadly, engineers are not at the forefront of the most pressing problems requiring socio-technical solutions.

Learning research in STEM settings suggests that public health infrastructure projects will also augment learning of STEM content. Project Kaleidoscope notes that:

1. Strong undergraduate programs promote an environment where learning is experiential and rich in investigation throughout.
2. If the learning process is meaningful to the students causing them to make a connection to other fields of study and is imbedded in the context of their own lives, learning is strengthened.
3. Additionally, practical applications of the knowledge and collaborative settings with peer-to-peer feedback help students to gain confidence that they can succeed. (Project Kaleidoscope 1991)

In addition to confidence, peer-to-peer interactions promote learning. The development of a community of practice in which more experienced members share their knowledge by mentoring new members models the type of learning that occurs in an experimental research lab. In the context of an authentic problem, students quickly learn the requisite methods and language and contribute as full members, in some cases with more novel, creative insights (Newstetter, et.a. 2004). Thus, **the challenge to engineering educators** is to create learning environments around authentic problems that are meaningful to students, and balance technical solutions with social, cultural, environmental, economic, and sustainability concerns, in an environment that features multidisciplinary peer interaction and mentoring. These principles and prior research provide the framework for course development.

CONTEXTUAL SERVICE LEARNING PROGRAM DEVELOPMENT

This section serves to outline the developmental framework utilized for the highlighted project. This includes project organization, project selection and scoping, course design, onsite experience, and assessment.

Project organization

The initial project organization began with an alliance between the Peacework Development Fund and the Center for Leadership. Peacework is a non-profit

organization based in Blacksburg, Va. The group is a comprehensive agency for international development, education, and service in cooperation with a variety of indigenous community partners and international relief programs world-wide. Peacework partners with groups nationwide that have an interest in bridging cultures and alleviating poverty through volunteer service. Representatives from Peacework and the Center worked together during all phases of the project to include a post project review. Additionally, an industry mentor group was formed during the pre-project planning phase to provide insight, resources and guidance.

Project Selection and Scoping

The projects described in this paper are located in Bella Vista, Belize at Our Lady of Bella Vista Primary School. The school enrolls approximately 1000 students in 8 grades. Bella Vista is a small village in the Stann Creek District of southern Belize. Founded around 1993 and composed of mostly immigrant families from Guatemala and Honduras who work the banana farms, Bella Vista has experienced rapid growth over the past fifteen years. This rapid growth has strained its water, electricity and health infrastructure. Peacework has worked with local leaders on several projects addressing some of these challenges.

A site visit to the school was conducted by the authors and a graduate student to discuss short and long term needs with school and community representatives. A Peacework representative coordinated the site visit and accompanied the team. The scope of the visit included identifying projects to meet immediate school needs, viewing the site, taking basic dimensional measurements, and initiating a relationship with the community. Discussions were held with the Principal, 1st Vice Principal and 2nd Vice Principal of Our Lady of Bella Vista Primary School, the Chairman of the Bella Vista Village Council, the chair of the Stann Creek Health Education Ministry, and the Bella Vista Community Nurse Aid. The short term needs and preferences of the school were identified. These requirements defined the projects to be completed by the VT students. The projects included a water re-distribution and rainwater collection system, a hand washing station, trash receptacles and school ground paths.

Water re-distribution and rainwater collection

The goal of the water re-distribution and rainwater collection project was to provide a reliable supply of clean drinking water to the school through a two-pronged approach. The water-redistribution phase replaced the 1 spigot currently supplying water to the school with a distributed system of four, 250 liter tanks located throughout the school grounds. The rain water collection system would provide 250 liters of filtered water during the rainy season as a backup and augmentation to village supplied water.

Hand washing station

The goal of the hand washing station project was to provide a multi-basin hand washing facility constructed adjacent to the school latrine. Students currently washed their hands at the one water spigot or in basins within the classrooms. The station would provide immediate and adequate access to hand washing and help to promote proper hygiene.

Trash Receptacles

The goal of this project was to design and construct trash receptacles at three locations around the school grounds. The school yard was littered by both school

activities and the community. The students collected the litter in trash bags on a daily basis. These bags were placed in a central location for pickup every few days by the village council Chairman who voluntarily removed the trash from the school to a local dump site. While awaiting collection, the trash bags were rummaged through by dogs or other animals requiring the students to repeatedly collect the trash. The construction of secure trash receptacles in locations determined by the Chairmen will improve the appearance and hygiene of the school grounds.

School Ground Paths

The goal of the pathway project was to design and construct walkways that would facilitate clean and dry access to academic and administrative buildings during the rainy season. The school campus consists of 8 buildings, separated by hard-packed, un-graded earth with minimal drainage capability. During the rainy season, teachers and students were forced to walk through mud and water to access the buildings.

Course Design

The classroom components critical in the development of the project included the student selection, course design, course objectives, selection of project teams and classroom activities. The structure of these is highlighted below.

Student selection

Students who were interested in the project were required to complete an application and a statement of intention highlighting the reasons they desired to be involved. The students were interviewed by the project senior leadership to select the final group. Nineteen students, (8 graduate, 11 undergraduate) were selected and enrolled in the class entitled, "Sustainable Construction in Developing Countries." Each of these students was required to sign a commitment agreement that highlighted their responsibilities while partaking in the program. The agreement required each student to make a personal commitment towards contributing to the overall success of the program. The 19 students where from 8 different majors and represented 4 colleges. 15 of the students were construction and engineering majors. The team not only represented a cross-section of academic backgrounds and levels it was diverse in terms of gender and ethnic background.

The Course Design

The class focused on the project management issues associated with sustainable construction in developing countries and was designed for students of all academic backgrounds. The integration of economic, political, and social issues provided a transformative, multi-disciplined, global context to engineering and construction sustainability issues throughout developing countries.

Course Objectives

The course objectives were designed to accommodate students of all academic backgrounds. Upon completion of the course, students should be able to:

1. Describe the strategic issues and social responsibilities involved in developing global projects sustainably.
2. Enumerate the total construction process (life cycle) from the early conceptual phase through final project decommissioning.
3. Articulate the design considerations involved in developing appropriate solutions for sustainable projects.

4. Understand the process of developing quantity takes-offs and construction cost estimates for a relatively simple operation (earthwork/concrete).
5. Construct a simple project schedule using appropriate methodologies and understand how these are used as a basis for short term resource planning.
6. Enumerate issues related to quality management and safety.
7. Understand and experience teaming skills and conflict resolution.

Selection of Project Teams

A team of students was assigned to each of the four projects identified by the school officials. Teams were determined based upon feedback received through an interest survey administered to the class. Two graduate students were assigned to each team, to serve as team leaders throughout the project. The teams developed design solutions for the community identified needs in the classroom.

Classroom Activities

Design considerations included the use of local materials, ease of use and sustainability, as well as operations and maintenance. The students developed designs and construction plans that detailed the materials required, quantity and cost estimates, a project schedule, a resource utilization plan and a daily safety plan. During classroom sessions, students received technical guidance from faculty, cultural and social insight from Peacework, and project planning and safety information from industry mentors. Upon completion of the designs, students presented their solutions to the class for feedback and their designs were forwarded to the industry mentor group who were part of the onsite team.

When the students returned from the trip, each team completed a final presentation and report. The presentation highlighted the experience of the teams, the changes that they made to their original design, the challenges they faced onsite and the lessons that they learned. Additionally, they were responsible for creating as-builts of their projects,as well as operation and maintenance guide for their project. Student journals were also collected for faculty review.

On Site Experience

The onsite plan for student engagement involved not only the 7:30am to 5:00pm work day, but daily debrief and feedback sessions. The students were also required to keep a journal during their time in Belize. They were asked to reflect on their days from four viewpoints: personal, community, team and project. Their entries were to include personal observations, changed perceptions, insights into sustainability, notable moments during the day, changes in their approach and lessons learned.

At the end of each working day, the team leaders gathered with the Peacework representatives and the faculty leadership to discuss the events of the day. During these nightly briefings the teams addressed the challenges that they faced that day, while brainstorming solutions to these problems. Team leaders were responsible for updating the group on the progress of their team, outlining the production goals for the following day and requesting any material, equipment or personnel needs. Each day the leadership of the teams alternated between the two graduate students on the teams. These debriefings served as a handoff to the new leader.

Assessment

A multi-dimensional course assessment was used to determine if the approach was successful in terms of student education and growth, industry participation and community interaction. To assess the learning objectives of the class, several methods were used. These included, participant observation by faculty, daily feedback sessions in the field and student journals.

Observations

Throughout the entire experience the authors observed the behaviors of the students, how they performed as a group, how they reacted to challenges on the jobsite, how they collaborated and how they personally and academically advanced. The one thing that was constant throughout the project was change. Change occurred in schedules, in scope and in design. During the design phase, the water distribution and rainwater collection team realized that their scope was highly ambitious. They completed a design that required the construction of a new water distribution system, four units to house 250 liter water storage tanks and a rainwater collection and filtration system. The team realized while completing their construction schedule that they would not be able to complete the entire project with their team of four. The team leaders met with the faculty to discuss their concern and the decision was made to remove the rainwater collection and filtration system from their scope. This was based upon the needs and desires expressed to the faculty by the staff of Our Lady of Bella Vista.

A notable change that highlighted the willingness of the teams to collaborate occurred a week before the entire group left for Belize. The hand washing station team and the water distribution team realized that the location of the water source for the hand washing station would not provide enough pressure head for operation. The teams worked together to refine their designs and developed a solution that incorporated the hand washing station into the water storage facility. The solution was not only innovative, but truly collaborative.

During the construction phase, changes to designs occurred daily based upon the challenges the teams faced and the requests of the school administration. Fire ants, changing soil conditions, lack of wheel barrows and the intense heat required that the teams alter their schedules and worked together to accomplish their projects. A critical schedule change revolved around the presence of the over 1,000 children on the site. The teams took breaks when the children were in the school yard and delayed their lunches to accommodate recess. This resulted in longer days, but allowed the teams time to interact with children and provided for a safer jobsite.

The greatest challenge faced by the groups was access to water. The town water system only supplied water to the school for two hours in the morning and two hours in the afternoon. The groups had to plan their work around this access to have enough water to mix concrete for foundations and mortar for the masonry walls. The teams worked together to solve this problem by utilizing the unused 250-liter water tanks for temporary storage to supply their concrete and mortar mixing needs.

The school pathway team changed their design to accommodate the needs of the school principal. They watched her walk through the school yard each day and noticed that she consistently walked on a diagonal path from her office to the first academic building. They modified their design to incorporate a diagonal path that connected to the other sections of path they had in their original plan, much to the delight of the principal.

The most noticeable component of the experience was how the teams performed under the changing leadership each day. Each graduate student exhibited different leadership styles and traits. Throughout the week each improved upon their approach, some gained new levels of confidence, while others excelled beyond the expectations of the faculty.

Daily feedback sessions

Each evening during the debriefing sessions, the groups brainstormed about solutions to the challenges that they faced during the workday. While the faculty helped to facilitate the process, the solutions were developed and agrees upon by the students and implemented the next day by the team leaders.

Student Journals

The course provided a real life example of the design and construction process. The students thoroughly planned their projects but during the building process conditions changed and they had to adapt. This was reflected in the student journals. One student wrote, "No matter how much planning, there is always more to be done than originally thought." Another student titled a section in their daily journal, "What we planned, and what really happened."

The integration of industry and faculty outside of the department was vital to the success of the project. A student wrote (referring to the Dean of the College of Architecture and Urban Studies) "Jack was usually the "go-to" man, in the rare case that he was not already there. His willingness to step back and have others do the work in order to give feedback and advice ensured that this trip was a learning experience." Another student noted, "That was the other aspect of the trip that was inspiring – seeing professionals take their personal time and money to help a group of students and a school."

This study abroad program was far greater than just the experience of traveling to another country. Students who participated in previous study abroad trips noted that they felt like a foreigner in other countries – however, in Belize they were part of the community. One student noted, "We were not visitors, we were accepted into the community, we were part of the culture." Another student wrote, "Leaving the Belizean [school] boys behind at the worksite was sadder than I thought it would be. Some of those boys annoyed me all week, but when our bus pulled out of the gravel lot, I was sad to leave them."

Unintended impacts

At the end of the trip, the group realized the impact their actions had on the Bella Vista community and the improvement of the quality of life for all who attend and work at Our Lady of Bella Vista Primary school. The tangible impacts of the projects constructed were not the only contribution the students made to the community. The vice principal, with tears of joy in her eyes thanked the group and stated, "Your efforts have inspired us to begin a program to plant flowers in the bed areas created by the paths." She also took special care to recognize the hard work of the women in the group, "Women in our culture do not do things like manual labor, you have inspired us." These gender roles were noted in the journal of every female student.

Keys to Success

A variety of factors contributed to the success of this project. The critical success items included selecting the appropriate partners, in-depth pre-project planning, procurement, and project execution. The following section provides lessons learned in relation to each item.

Partners

Peacework has worked to improve schools, support literacy and education, and promote access to affordable and quality health care in Belize since 1994. Partnering with Peacework provided a network of individuals who helped to implement our ideas and support our students. This eliminated years of relationship building and enabled the fruits of the course a rapid deployment allowing students to see the impact their efforts had upon the community.

The project incorporated a unique blend of academic and industry leadership. The emphasis on partnering with industry, not only financially, but having them actively engage in the process in the classroom and onsite provided great benefits in terms of mentoring for the students. The industry mentoring team was a vital part of the project. These individuals played the role of teacher, of constructor, of supervisor and of worker. They were invaluable to the experience for the students, contributing to their growth while instilling confidence in their abilities. The project materials and associated support costs were funded by our industry sponsor. Additionally, student travel and costs were supplemented by industry funding, with students paying a nominal amount for the 7-day experience.

Pre-project planning

A pre-project site visit is critical for identifying projects, building relationships with the community and identifying accommodations and material suppliers. A valuable lesson learned included the early involvement of the industry mentors to provide feedback and identify constructability issues prior to arrival onsite. Structural stability issues were identified on the roof assembly for the water distribution storage huts in the field that could have been more easily addressed in the classroom.

Procurement

To ensure that the material required for construction to begin when the entire team arrives, a team member arrived three days early to coordinate with the Peacework staff onsite. This individual ensured that the correct material was procured and transported to the site. Material delivery time is often a large unknown in international settings. For short duration projects, it is best to have all materials delivered prior to or at the beginning of the work. However, if there is an assurance that materials can be delivered in a short period (next day or two), it may be beneficial to begin with a lower than estimated quantity. Additional materials can be procured mid week if necessary. This will allow the group to absorb scope changes or overestimates.

Project Execution

In order to execute the project, proper equipment is essential as well as site planning. Locating the material storage sites for large items such as block, sand and aggregate, is critical so they do not conflict with project locations. Equally important is the identification of an on-site storage location which affords security and allows overnight storage. In addition to material issues, it is important to consider the well-

being of the students. For future trips, we will consider a half day off mid-week to allow students to relax. Many students were becoming exhausted mid week. To ensure the safety of all individuals on the site, coordinate work schedules around school times and around weather (hottest times of the day) as much as possible.

CONCLUSIONS

The project provided an authentic engineering experience in the context of a developing country. The learning that occurred during the project was hands-on, experiential and the mentoring of the students was accomplished through industry guidance and peer-to-peer interaction, creating a community of practice. The classroom work served to prepare the students for the experiences they would have on-site and enabled them to work collaboratively. The implementation of the program, while successful, also brought to light several lessons learned. These include selecting appropriate partners, planning the project, procuring materials and executing the project safely and efficiently. Based upon the success of this project and the lessons learned, the authors feel that with customization that this program can be successfully implemented in other university programs.

REFERENCES

Conway, R. (2000). Ethical judgements in genetic engineering: The implications for technology education. *International Journal of Technology and Design Education, 10*(3), 239-254.

Kuhn, S. (1998). When Worlds Collide: Engineering Students Encounter Social Aspects of Production. *Science and Engineering Ethics, 4*(4), 457-472.

NAE. (2004). *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, D.C.: The National Academies Press.

Newstetter, W. C., Kurz-Milcke, E., &Nersessian, N. J. (2004).*Agentive Learning in Engineering Research Labs.* Paper presented at the ASEE/IEEE Frontiers in Education, Savannah, GA.

Project Kaleidoscope (2002). Recommendations for Action in Support of Undergraduate Science, Technology, Engineering and Mathematics.

Riley, D.R.,Horman, M.J., and Messner, J.I., (2004). "Building Blocks of Leadership: A Professional Development Program in Construction Management Education", *Specialty Conference on Leadership and Management in Construction*, Construction Research Conference, ASCE, Hilton Head, SC, March 25-26.

Bell, LC., and Skipper, C.O., (2006). "Integrating Leadership Development into a Civil Engineering Curriculum", Working Paper, Clemson University.

Whitbeck, C. (1995). Teaching Ethics to Scientists and Engineers: Moral Agents and Moral Problems. *Science and Engineering Ethics, 1*(3), 229-308.

Wilpert, B. (2005). Psycology and Design Processes. *European Psychologist, 10*(3), 229-263.

IMPROVING THE INTERNSHIP EXPERIENCE: CREATING A WIN-WIN FOR STUDENTS, INDUSTRY AND FACULTY.

Christine M. Fiori[1] and Annie R. Pearce[2]

[1] Assistant Director of Undergraduate Programs, Industry Relations and Outreach, Myers-Lawson School of Construction, Virginia Polytechnic Institute and State University, 330B Bishop-Favrao Hall, Blacksburg, Virginia, cfiori@vt.edu
[2]Assistant Professor, Department of Building Construction, Virginia Polytechnic Institute and State University, 330A Bishop-Favrao Hall, Blacksburg, Virginia, apearce@vt.edu

Abstract

Student internship programs in the construction industry are mutually beneficial relationships that foster student growth, enhance academic program relationships with industry partners, and challenge faculty to include current information in their curriculums. In the construction disciplines, real-world experience is essential to the development of well-prepared graduates and provides students with an opportunity to interact with various levels of construction personnel. The internship program is an integral part of the Building Construction Program at Virginia Tech. Although summer internships are not a mandatory graduation requirement, in 2003 students were presented with the option of applying their internship experience as a for-credit elective class. As part of the class students were required to sign a statement of goals with the company of choice outlining their desired objectives for the nine-week experience. During the internship, students kept a daily diary documenting activities and key benchmarks of their goals. Upon returning to campus in the fall they completed a written report and delivered an oral presentation summarizing the experience. Since 2003, 100% of graduates participated in one summer internship experience and over half enrolled in the credit option. During the summer of 2007, the internship for credit program launched a pilot course that increased student responsibilities during their internship program. Throughout the summer, students were tasked with five assignments that required them to research sustainability practices within their companies. This paper highlights the new program development, defines the revised internship objectives, describes the implementation process and presents the lessons learned.

Introduction

Internship programs are an integral part of many engineering and construction programs throughout the country (Blanchard, 2004; Otero, 2000; Tener, 1996; Wiggins, 1999). The link between the classroom and the real world is essential to the

growth of the student (Wiggins, 1999). Internships give students exposure to more than the academic side of an industry and enable a student to apply classroom material more effectively (Tener, 1996). The student benefits of exposure to engineering practice as part of a curriculum are well documented (Otero, 2000). Internships also engage industry and faculty. They serve as a link between academia and industry and encourage the development of mentoring relationships. This partnership develops a well prepared graduate who is ready to accept the roles required to become successful in their chosen career.

Description of Current Program

Virginia Tech's internship program is a meaningful partnership between industry, the Building Construction program and the students. The program provides real world experience each summer as well as successively increased responsibility in a professional industry setting. Students may intern with the same employer over three summers, or choose to experience different employer environments. The sponsoring employer provides a salary based on internship and other work experience. Internship work experiences are progressively offered in three primary areas:

Field Operations – In this capacity, students would be working as a laborer, helper, or technical assistant. They may also experience assisting in surveying, checking material delivery, timekeeping, cost control, submittal processing, filing, drawing controls, schedule checking, and subcontract monitoring.

Office Operations – In this capacity, the students are preparing quantity take-offs, working with vendor and subcontractor contracts, developing estimates, and performing scheduling functions. They may also be tasked with activities such as checking drawings and specifications for completeness and discrepancies, attending bid openings and conferences. They are also involved in handling the paperwork components of managing the construction process.

Project Management – At this level, a student may perform management, field engineering or office functions at the advanced experience level of a mature intern. To work at this level, the student must demonstrate the ability to accept responsibility and put into practice the skills, attitudes, and judgment learned in earlier internship periods.

The majority of the undergraduate Building Construction students choose to participate in summer internships, with many taking a for-credit option earning three credit hours. Historically, the requirements for this course included writing a statement of goals, keeping a daily journal, writing a paper summarizing the experience, presenting a slide show presentation of the internship, and returning an employer evaluation. This nine-week internship experience provides students with opportunities to problem solve, think critically and utilize information learned in the classroom. Often, the internship site becomes the student's future place of employment upon graduation.

The student population of the Department of Building Construction has doubled in the past 5 years with 153 students in 2002 to over 350 students in 2007. As of 2007, 100% of the graduates obtain full-time positions within a year of graduation. 100% of graduates had at least one summer internship experience and 68% enrolled in the internship for credit option for one summer.

Reasons Driving Changes to Existing Program

The impetus for the change in format of the internship program was driven by the department head and the assistant department head upon reviewing the student journals and their oral presentations. The level of work that was completed by the students did not illustrate a degree of academic rigor expected for academic credit. They challenged the faculty and the career and academic advisor to develop a more rigorous structure to the internship for credit program that built upon the existing foundation.

To begin the process of developing a new program, the faculty reviewed the current program to determine the strengths and potential areas for improvement that would impact the growth of students. The original program highlighted three elements that were critical for a successful internship program:

1. A goal-oriented student with a strong work ethic and a desire to advance,
2. A sponsor firm committed to mentoring students**,**
3. Continual care and attention by Virginia Tech Building Construction faculty throughout the internship process.

These three elements were clearly in place in the existing program, so the faculty reviewed the stated program objectives. These included:

1. Familiarize students with the construction industry planning, design, and field operations.
2. Introduce students to the interrelations among the various tasks and participants in the construction process.
3. Expose students to management and communication functions performed within a construction project.
4. Aid students in acquiring specific skill sets which will enhance their value to employers and the industry.

Based upon these four objectives, the faculty decided to focus their efforts upon the fourth objective and set out to develop a new approach that would improve specific skill sets. Based upon informal industry feedback, input from faculty and student surveys, the new internship program concentrated upon the following skill sets:

1. Improve interpersonal skills and leadership
2. Develop students abilities to complete independent research
3. Increase the advancement of meta-cognitive skills
4. Provide for peer-to-peer interactions across companies during the internship period

Methodology

The restructuring of the program to meet the identified goals began with the faculty brainstorming ideas. During these sessions, it was determined that the interns would

help faculty collect data relating to current company practices. At the end of the internships, the collected data would be analyzed by faculty and a report produced and provided to the industry partners. The report would compare company practices and enable individual firms to see how they stack up to their competition. The faculty agreed to focus upon sustainability practices within the organizations for the pilot offering of the program. The goal was to collect background data on the companies for future use by the faculty.

In order to utilize undergraduates to collect this information, the faculty determined that they would need to develop specific, rigorous protocols that could be easily administered. Five protocols were developed for the pilot program, each focusing upon different aspects of the adoption of sustainable construction practices. The protocols were distributed to the students via a Blackboard Site at one to two week increments throughout the summer. The students completed the protocols and submitted them through an online survey mechanism that automatically compiled data.

To prepare the students for the completion of the protocols, an information and instruction session was held prior to the beginning of the internship program. During this session, the faculty briefed the students about the changes in the program and provided an interactive presentation regarding interviewing protocols and practices that would be important as they collected their data. In addition to preparing the students, industry partners were also briefed about the changes in the program, as these changes would require their participation and agreement.

In order to meet the desired objective of improving the defined student skill sets, the protocols were designed to embody each of these elements. During the development phase of the protocols, research was completed regarding learning styles and development of interpersonal skills. The learning styles of Kolb and Blooms taxonomy were reviewed as well as the methods of other researchers to include, Kanungo, Eisenberg and Berkowitz.

The designed protocols required the students to be resourceful in their data collection methods and forced several of them to move beyond their level of comfort when completing interviews of various members of their companies. To help students think about how they personally approach tasks, they completed a managerial resourcefulness survey that was adapted from the research work completed by Kanungo and Menon (2005) prior to beginning their internships. Kanungo and Menon identified that resourcefulness is critical in performing leadership roles that require coping with non-routine, unprogrammable and ill-structured tasks. The work required of the students fell within the realm of these types of tasks. Additionally, their work addressed the fact that managerial resourcefulness is a mediation cognitive and self-regulatory competency that is consistent with the meta-cognitive approach to self-regulation (Kanfer, 1990).

The survey questions for managerial resourcefulness were either descriptive of individual behavior (i.e., When someone interferes with my task, I get angry with him/her) or were indicative of behavioral preferences (i.e., I like people who would say I can do it when faced with difficult tasks). A six-point response format (very characteristic of me to very uncharacteristic of me) was used to rate these items (Kunungo and Menon, 2005). The students completed the survey prior to their internships and again after the completion of the program to determine if their attitudes had changed.

In addition to the completion of the five protocols and the resourcefulness surveys, the students were also required to post comments on a discussion board hosted through the Blackboard site for the course. The students were encouraged to give feedback about the protocols, discuss their experiences with completing the protocols and also to help each other with difficulties they were experiencing completing the assignments. The faculty monitored the discussion board throughout the summer and responded to student questions and suggestions for improvement. The goal of the peer-to-peer interaction was to enable students to learn from others experiences and for them to build their confidence relating to the completion of the protocols. In addition to confidence, the peer-to-peer interactions promoted learning. When a community of practice is developed, in which more experienced members share their knowledge by mentoring new members, the type of learning that occurs models that of an experimental research lab. In the context of an authentic problem, students quickly learn the requisite methods and language and contribute as full members, in some cases with more novel and creative insights (Newstetter et al., 2004).

The Protocols

Protocol # 1 – Internship Information

The first protocol focused upon understanding more about the student, the company they planned to work for, and the job they were undertaking throughout the summer. This protocol was completed prior to the beginning of the internship. This required the students to contact their employers to learn more about the company and their job.

The survey contained questions relating to prior work experience, level of education and concepts and understanding of sustainability and green building. Other questions focused upon the type of construction work in which the company engaged and the environment in which they would be working. Additionally, students were asked to provide the name and contact information of their supervisors so faculty could contact them if needed. The purpose of the first protocol was to establish a snapshot of the students, the companies and the type of work in which they would be engaging.

Protocol #2: Corporate and Leadership Innovativeness Factors

The second protocol was the first implemented on the job. It was designed to guide the student in collecting information about the company's perspectives on innovation. Innovation can be defined as something new or perceived to be new by the person adopting it, e.g., an innovative technology. It also refers to the process of introducing something new. In the context of the internship, the focus was on understanding how

their company fits within the spectrum of innovativeness in general so that a better understanding of how it reacts to a specific type of innovation (sustainability) in later protocols could be assessed. The data collected and reported here helped to establish a baseline for understanding the adoption of sustainability within the firm.

In the protocol, students were asked to collect information directly from the leader of the company, workgroup, or project through an interview, plus additional information that they could obtain from various other sources within their company. The questions focused upon individual and company innovativeness and the metrics by which the company defines success.

Protocol #3: Baseline Sustainability Best Practices
The third protocol was designed to establish a baseline of the best sustainability practices the company utilized. Students were tasked to observe current practice for both general office procedures as well as projects, and to also ask questions of the people in charge of these practices.

The focus of this assignment was to determine what practices the company currently uses at the corporate and project levels that represent sustainability best practices. For each of the practices in the developed checklist, students were asked to either observe directly whether or not it is being used in the company, or ask someone in the company whether it is being used. The project-specific practices in particular required students to work with a company representative to determine if the practices are used on *other* projects.

Protocol #4 – Understanding Adoption of Sustainability Best Practices
The fourth protocol investigated the experiences and reasons behind the best practices the company employed. This protocol was based on the findings from Protocol #3 that established an inventory of sustainability best practices employed by the company.

For this exercise, students were tasked to select three practices identified in the previous survey that their company presently uses or has tried in the past but abandoned. They were instructed to locate one or more people to interview who have had direct experience with the development or implementation of each practice.

Protocol #5 – Recommending New Best Practices
In the final assignment students were asked to investigate three sustainability practices *not* currently used by their company and make recommendations regarding implementing those practices. Students were required to present their recommendations to one or more decision makers in their company, and record their responses to the proposal.

For each of the three chosen practices, they prepared a short brief containing the following information.

1) The practice they are recommending for their company to adopt, along with a short description that practice.
2) The benefits the company would experience from implementing this practice.
3) The changes the company would have to face to implement this practice.
4) Next steps to move forward with implementation.

After they prepared the briefs for their three practices, each student present their recommendations to the company. The preferred format for the brief was an oral presentation. However, if a time could not be scheduled, students were able to provide their recommendations to their supervisors in written form to review. After review by the company leader the students arranged a time to sit down with them and conduct a short interview to receive their reactions. They were responsible for posting their presentations online as well as the reactions from the company leaders.

Results

This class served as a pilot program to improve skill sets of the students, to help faculty in the development of protocols that could be implemented by undergraduate students and to determine if this model could be replicated. To determine if these goals were met, the faculty received feedback from the students, assessed their pre and post-test responses to the Managerial Resourcefulness survey, and reviewed the data collected.

Course Feedback

Upon returning to campus, the students completed a detailed evaluation of the program and attended a debriefing session with the faculty. The evaluation asked the students to rate their overall experiences, address the challenges they faced completing each of the protocols and to identify positive experiences and areas of improvement for each protocol. Additionally, they were asked to estimate the amount of time they dedicated to the completion of the protocols and the value of the online discussion boards.

During the debriefing session, the students were asked similar questions by the faculty in an open discussion format. The initial response from the students was favorable. However, some students felt that the protocols required too much time to implement. Students voiced opinions of the program ranging from “I absolutely hated it,” and “It was way too much work,” to “This was so much better than last year,” and “I learned more about my company and their policies than I would have on my own.”

The debrief session led to three major suggestions for improvement of the program.
1. All of the protocols should be distributed to the students prior to beginning their internships. This would allow the students to view the work they were expected to complete.
2. The protocols should be reviewed for repetitive information and should be more succinct in format, so as not to require such a large amount of a supervisor’s time.

3. The internship should provide a wider range of topics that students could choose from. The protocols related strictly to sustainability and became monotonous for the students.

The session also defined the positive aspects of the program. The verbal comments received from the students were distilled to the following major themes.
1. Students learned more information about their companies than they would have on their own.
2. The comfort level of the students interviewing "higher-ups" in their companies improved throughout the summer.
3. Students enjoyed researching sustainable practices and presenting them to their companies. Some students indicated that their suggestions were currently being implemented within the company.
4. Students expressed that they enjoyed the Blackboard discussion postings because it enabled them to help each other with difficulties they were facing. It also allowed them to see the type of work in which other students were involved.
5. Students felt they knew more people within the company and developed a better relationship with their project managers and team leaders as a result of the interviewing process.

Upon reviewing the detailed surveys that 32 of the 39 students completed, the results proved to be interesting. The major challenges identified by all 32 students was finding the time to complete the protocols and locating the correct person from which to obtain the necessary information. These challenges were indicated throughout the summer on the Blackboard discussion board and the faculty attempted to alter the protocols to help alleviate these challenges. To assess how much time was "too much" the final survey asked students to estimate the amount of time they spent on average each week on the class. The amount of time ranged from a high of 8 hours to a low of 20 minutes. On average the students stated they spent 2.53 hours per week. The faculty determined that the amount of time was not excessive, but will consider time challenges in the future.

Managerial Resourcefulness Survey Results

The results of the pre-and post-test were utilized to determine improvements in student attitudes towards completing tasks. The major improvements identified from the survey centered upon the ability to focus on tasks, details and completing projects on time. These skills are essential to future academic and industry success. A major goal of the program was to have the students improve their abilities to perform independent research. On the post-survey 27 of the 39 students rated the question "Information gathering is part of my initial problem-solving techniques," as "very much like me" as opposed to the 17 students who had the same rating on the pre-test. Additionally improvement was achieved in how students approached problems. While 13 students answered "very much like me" on the pre-test to the question, "I tend to stop doing a job when major difficulties get in the way," only 1 responded that way on the post-survey.

The results of the managerial resourcefulness survey revealed that the students had improved their attitude towards difficult tasks and independent research while improving their focus and attention to detail. The survey also indicated that the students enhanced their abilities to persist in academic pursuits and how they approached intensive tasks.

Implementation Tips

The five protocols presented in this paper provide a structured approach to engage students in the process of becoming reflective practitioners while obtaining useful data about current practice in industry. From a pedagogical standpoint, these protocols can be considered a formalized "scavenger hunt" for information about the company. From a research perspective, the protocols may be considered human subjects research, and should be evaluated as part of a formal application to your university's Institutional Review Board (IRB).

Students participating in the internship experience can benefit from pre-internship training on etiquette, interview methods, and basic communication skills before they go out into the field. They may be required to undertake basic training in human subjects research before the protocol receives IRB approval. Many institutions offer online courses that can be quickly completed by students on their own time, resulting in a certificate of completion that can be required as a prerequisite to the internship experience.

The internship experience can also be facilitated by having the instructors or internship coordinator contact participating companies ahead of time to introduce the requirements being made of the students and to explain the potential benefits to companies of providing support and cooperation to interns attempting to complete the protocols. One potential benefit to companies is to provide them with a summary of findings across all interns, perhaps even with their own data provided as a reference point. With a sufficient pool of companies represented in the internship pool, this data can serve as a valuable benchmark of how well the company performs with respect to its competitors.

Requiring students to complete the first protocol during the semester before the internship will provide contact information for each student's supervisor as well as introducing the students to the data upload requirements if an online data collection mechanism is to be used. It can provide an opportunity to identify and resolve potential problems before students disperse for the summer.

Students should also be engaged in a discussion before they leave about managing priorities when collecting data. Some students in the pilot course had concerns about not being able to both do their internship work AND collect and input the data required for the internship credit. This concern is valid in a construction environment where students are working long hours. However, students should be reminded that they are receiving course credit for their experiences and encouraged to treat the internship just like a regular course in terms of time expectations and requirements.

Finally, instructors who hope to benefit from data collected by summer interns should use caution in qualifying that data and any results that may be derived from it. Ultimately, the primary goal of a student undertaking an internship is to experience industry first hand, not to perform as a researcher. Accordingly, the quality of data received may be less than what might be expected using other data collection methods, and should be acknowledged as such. The most critical issue to discuss with students ahead of time from a research standpoint is how to handle situations when data can *not* be collected.

Although most students in the pilot study were able to successfully obtain all the information requested in the protocols, some students had more difficulty than others due to the nature of their job, the level of cooperation provided by their companies, or the lack of experience or knowledge of their companies with sustainable construction best practices. The aim of the internship is not to penalize students in this situation compared to those fortunate enough to work for cooperative or innovative companies. In fact, some students who had difficulty getting data from their companies actually found themselves playing a teaching role as they introduced their companies to the practices mentioned in the protocols! Instructors should provide an opportunity both to discuss how such situations should be handled *before* the internship as well as *during* the internship as problems arise. The use of discussion boards was particularly helpful in this regard during the pilot offering of the module.

Conclusions

The change in the for-credit internship process met the goals that the faculty outlined by improving student skill sets. This conclusion is based solely upon the feedback we received from the students, the results of the Managerial Resourcefulness survey and the surveys returned from the companies. While more rigid assessment of the program will occur in the future, the faculty are highly encouraged by the results from the pilot offering. Changes suggested by the students will be implemented in the program this upcoming summer. Additionally, the faculty are developing more rigorous assessment surveys for the industry and more quantitative assessment measures for the student learning objectives. One aspect that the faculty did not include in the pilot program was surveying the companies regarding their experiences with the new structure; however, this will be included as part of the next offering. Overall, based only upon the qualitative feedback received, the program improved the communication skills of the students, developed their abilities to conduct independent research, and provided a more rigorous academic product.

Comments: The protocols can be reviewed at the Engineering Pathway Digital Library (http://www.engineeringpathway.com/)

References

Eisenberg, M., and R. Berkowitz. (1990). Information problem solving: The Big Six skills approach to library & information skills instruction. Norwood, N.J.: Ablex.

Kanfer, R. (1990). Motivation theory and industrial and organizational psychology. In M.D. Dunnette & L.M. Hough (eds), Handbook of Industrial and Organizational Psychology (pp 75-170). Palo Alto, CA: Consulting Psychologists.

Kanungo, R.N. & Menon, S.T. (2005). "Managerial Resourcefulness: Measuring a Critical Component of Leadership Effectiveness." *The Journal of Entrepreneurship*, Vol. 14, No. 1, 39-55.

Otero-Keil, Z. & Basantis, M. (1999). "An Industrial Internship Program to Enhance Student Learning and Marketability." Proceedings of the 2000 American Society for Engineering Education Annual Conference & Exposition, *"Engineering Education Beyond the Millennium"* St. Louis, Missouri June 18-21, 2000.

Rowe, J. W. K. (2004). "A Qualitative Study of the Student Internship Experience, Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, *"Engineering Education Reaches New Heights"*, Salt Lake City, Utah, June 20-23, 2004.

Tener, R.K., (1996). "Industry-University Partnerships for Construction Engineering Education." *Journal of Professional Issues in Engineering Education and Practice*, Vol. 122, No. 4, 156-162.

Wiggins, J.A. (1999). "Summer Internships in the Construction Industry; NJIT and NJBCA, Partners in Education." Proceedings of the 1999 American Society for Engineering Education Annual Conference & Exposition, *"Engineering: Education to Serve the World."* Charlotte, North Carolina , June 20-23, 1999.

IMPROVING COURSE COMPREHENSION THROUGH EXPERIENTIAL LEARNING

Kirsten A. Davis, Ph.D., P.E., R.A.[1] and R. Casey Cline, Ph.D.[2]

Abstract

While lectures are the most common way to teach students, they are not necessarily the best way to convey some types of information. Consider the famous quote by Confucius: "I hear and I forget. I see and I remember. I do and I understand."

This paper discusses a hands-on experiential learning laboratory, which complements the lecture in a Construction Management (CM) materials and methods course. Many CM programs avoid hands-on experiences due to the vocational/technical stigma. However, experiential learning transforms construction concepts that are often abstract and out of context for many students in an exclusively lecture course into tangible objects and processes. The hands-on laboratory reinforces and supplements material covered in lecture and improves course comprehension by allowing students to learn through discovery. The laboratory aspect of the course also improves leadership, promotes teamwork, and increases student confidence.

This paper discusses specific laboratory experiences used and their educational value, student feedback regarding the experiential labs, and lessons learned for CM programs interested in adding or expanding their hands-on learning experiences for students.

[1] Assistant Professor, Dept. of Construction Management, Boise State University, 1910 University Drive Boise, ID 83725-2075 USA
Email: kirstendavis@boisestate.edu
[2] Assistant Professor, Dept. of Construction Management, Boise State University, 1910 University Drive Boise, ID 83725-2075 USA Email: ccline@boisestate.edu

Introduction

Construction education programs are charged with providing an education that will foster a student's ability to successfully undertake a leadership role in the management of the construction process. To manage the complex construction process requires substantial knowledge of modern management theory and practices, the ability to lead a diverse group of skilled and non-skilled personnel in daily operations, and expertise in the construction processes for which he or she is responsible (Cline 2008). Traditional transmission type teaching methodologies, requiring the teacher to "stand and deliver" information in a systematic process (Pratt 1998) are conducive for teaching management theory and practice. However, the effective transfer of practical leadership skills and knowledge of construction specific processes is more difficult to achieve.

When developing learning applications, it is important not to confuse education with learning (Merriam and Brockett 1997). Education emphasizes the educator and mainly deals with teaching methods, actions, and/or processes. The concern of education is specific learning outcomes and the process of teaching students the information needed to achieve those outcomes (Thomas 1991). Learning is a focus upon the person to whom the change occurs. Learning is a process of gaining knowledge and/or skills through formal or informal means (Rouda and Kusy 1996) and is the result of the exchange of information from educator to learner. It can be in the form of intentional transfer of information from educator to learner, as well as incidental or unplanned learning (Thomas 1991). Kimble (1961) contends that learning is a relatively permanent change in observable behavior that occurs as a result of reinforced practice. Individuals involved in the learning process are capable of performing afterwards in a way that they could not before being involved in the learning experience. Though it is possible that the change in behavior may not occur immediately following the learning experience, the learning process facilitates the change in behavior that results from reinforced experience or practice. It is this formal process that separates education from learning. Thus, education cannot exist without learning; learning, however, not only can exist outside the context of education, but is often found in other contexts (Thomas 1991).

Experiential Learning

Experiential learning is a philosophy of education based on what Dewey (1938) recognized as a "theory of experience". He contended that forming a theory of experience is needed in order that education may be intelligently conducted. Based upon the work of Dewey and other educational theorists, Kolb and Kolb (2005) developed an experiential leaning theory (ELT) based upon six propositions:

1. Learning is a process where the primary focus should be on engaging students in a process that best enhances their learning;
2. Learning is best facilitated by drawing on the students' prior knowledge so that more refined ideas can be examined, integrated and tested;

3. Conflict, differences, and disagreement drive the learning process. Learning takes place when the learner is required to move back and forth between reflection and action and feeling and thinking;
4. Learning is a holistic process that involves the integration of thinking, feeling, perceiving, and behaving;
5. Learning results from synergetic transactions between the person and the environment, where learning occurs through the assimilation of new experiences and existing concepts; and
6. Learning is the process of creating knowledge, which stands in contrast to the "transmission" model upon which traditional educational methodologies are based.

Terms used to describe different experiential learning methodologies include: active, collaborative, problem-based, and demonstration and simulation. Prince (2004) states that active learning is an experiential form of learning that requires the learner to engage in meaningful learning activities. Collaborative learning adds a component to the active learning process that requires the learner to work in a group towards a common goal. Problem-based learning adds yet another component that requires the learner to work on "real-world" problems that are used to provide a realistic context. Galbraith's (2004) book on adult learning methods contains a chapter written by Gilley that defines demonstration and simulation. Gilley states that demonstration and simulation are used to enhance the learning experience by providing a learning methodology that is more readily understood when demonstrated, or when there is need to show a process in action.

Bolstered by andragogical study on adult learning theory and research literature on experiential learning, the authors have developed experiential learning applications to effectively facilitate a student's mastery of knowledge, skills, and competencies necessary for success in the construction management field. The learning application, consisting of both lecture and lab sections, has evolved over several years through trial and error, employing multiple experiential learning theory processes including collaborative and service learning components.

Laboratory Experiences

The remainder of this paper discusses a hands-on experiential learning laboratory, which complements the lecture in a Construction Management (CM) materials and methods course at Boise State University. Students attend the lab portion of the course three hours per week. A number of different experiences are incorporated into the laboratory including:

- An OSHA 10-hour course;
- Construction jobsite layout;
- CMU wall construction under the supervision of an experienced mason;
- Concrete forming system assembly/construction for a wall, round columns, and square columns;
- Concrete testing including air entrainment, slump, and cylinder tests;

- Erection of a structural steel frame (4 columns, 8 beams, open web steel joists, and metal decking) using an overhead crane and scaffolding; and
- Light gauge steel frame construction (metal studs) for walls that include two door and two window frames.

Laboratory Experience: Structural Steel Frame Erection

Due to space limitations, this paper will only discuss in detail the structural steel frame erection laboratory experience. Detailed information about other laboratory experiences is available from the authors. The steel frame lab experience occurs near the end of the semester in the fall and in the middle of the semester in the spring. The order of labs changes from fall to spring so that indoor labs are done in the colder months and outdoor labs are done in the warmer months. The lecture schedule also changes each semester to reflect the order in lab.

The structural steel frame erection laboratory experience begins with safety aspects. Although the students complete the OSHA 10-hour course at the beginning of the semester, many safety requirements are reintroduced in context, including materials handling safety, crane safety, steel erection regulations, scaffolding requirements, and personal protective equipment (PPE). Throughout the structural steel frame erection (and all other laboratory experiences), students are required to demonstrate their knowledge and understanding of appropriate safety practices through their actions in the laboratory.

Once the safety aspects have been reviewed, students are given framing plans that illustrate the completed steel structure (see Figure 1 for a portion of these plans). They begin by determining the locations of the four columns, based on information on the plans. This is greatly simplified for them because they use anchor bolts that are recessed into the floor under removable cover plates, though they do have to determine the correct recessed anchor bolt locations. Pedestals, which serve as baseplates for the columns, are attached at the anchor bolt locations using a double nut application. While not completely in sync with reality, these beginning aspects are necessary given our facility layout. Students then use the skills they learned in the construction jobsite layout experience to level the pedestals (baseplates) to the correct elevation using survey equipment. At this point they also assemble a rolling scaffold that will be necessary for the remainder of the steel erection.

They next learn how to correctly use chokers, taglines, and shackles to move the steel with an overhead crane, as well as hand signals to direct the crane operator (see Figure 2). The students erect four 17-foot high columns using the overhead crane and the scaffolding. The topics of bolts, driftpins, and spudwrenches are discovered and discussed at this point. With the columns in place, they begin to hang the wide flanges and channels that serve as beams connecting the columns (see Figure 3). The “floor beams” are approximately four feet off the ground and the “roof beams” are approximately twelve feet off the ground. The students must wear PPE as if they were much higher above the ground, simulating a real project, but in a safe learning environment.

Due to facility constraints, the students must determine an appropriate order for hanging the upper and lower beams so that they have access to reach all connections using the rolling scaffolding. They also discover that if their columns are not true, they cannot hang all of the beams. Once all beams are in place, they proceed with the erection of open web steel joists on the lower level, followed by metal decking. Terminology learned in lecture, such as a joist seat, as well as subtleties such as the orientation of the decking, becomes apparent to the students at this point.

Upon completion of the steel frame, the students work with light gauge metal framing to add walls to the structure, complete with windows and doors.

Grading of Laboratory Experiences

The laboratory portion of the class is graded based on attendance, safety, participation, and attitude. It is more important that the students have the opportunity to try things and learn without the fear that doing something wrong will negatively affect their grade. However, the material covered in lab is included on exams the students take in the lecture portion of the course. Exams include pictures of items used in lab for identification by the student (vocabulary building). Safety aspects are emphasized in each exam as well, focusing on the safety practices that relate to the building materials and methods covered in a particular exam.

Educational Value of Laboratory Experiences

The hands-on laboratory reinforces and supplements material covered in lecture and improves course comprehension by allowing students to learn through discovery. The laboratory aspect of the course also improves leadership, promotes teamwork, and increases student confidence.

This course is a freshman-level course and, while many students come in with some construction background (usually wood framing), many others come with absolutely no construction experience. It is particularly important for the students with no background to practice skills in a safe environment, allowing them to build confidence before hitting a jobsite, perhaps on a summer internship.

Pratt's (1998) apprenticeship perspective gives detail of why the experiential side of learning is important for the learner. He states that as we gain experience, those experiences combine with other experiences and knowledge in our mind. When this happens, the learner's personal theories expand and they increase their ability to handle problems and situations with confidence. Work-related experience is needed to educate learners because, as stated by Pratt (1998), often knowledge is hidden from view, but that knowledge is the absolute key to success. Unfortunately, it is often this hidden knowledge that is not taught and yet is essential for learners to succeed. Experiential learning, such as the laboratory experiences discussed here, can bridge this gap in the education process.

A majority of the lab experiences are team projects, requiring the students to work cooperatively and collaboratively to solve problems and complete projects. It is usually very evident which students are natural leaders in the laboratory, regardless of their experience level. Those students are given the opportunity to enhance their leadership abilities. However, the other students are also expected to be in charge at times and begin to develop leadership skills. The lab experiences require the students to think at both a macro and micro perspective, exercise internal motivation, and respect the ideas of others in the group. It is this cooperative and collaborative experience that gives the students a real world understanding that is not possible in a typical lecture-only teaching style.

It is very important to note that these laboratory experiences are not to train students to be laborers or experts in any of the topics covered. Instead, the aim is to provide them with an opportunity to learn about different construction techniques and discover subtleties that are difficult to convey in a conventional lecture setting. The students also become very aware of and begin to appreciate the skill that is required in the many construction trades.

Assessment of Laboratory Experiences

An objective outcomes assessment of the effectiveness of the laboratory experiences is difficult to provide, not unlike assessing the effectiveness of any type of active learning instructional method. "When asking whether active learning 'works,' the broad range of outcomes should be considered such as measures of factual knowledge, relevant skills and student attitudes, and pragmatic items as student retention in academic programs. However, solid data on how an instructional method impacts all of these learning outcomes is often not available, making comprehensive assessment difficult" (Prince 2004, p. 224).

Student feedback to date indicates that the laboratory experiences are valuable and help them relate to abstract or out of context information discussed in the lecture portion of the course. They have the opportunity to touch materials and discover first-hand how they go together. They often report that this is one of their favorite courses in the curriculum. Students also indicate that it improves their leadership skills, promotes teamwork, and increases their confidence.

> "Taking the lead in a group of students you just met is not easy…. Through this class you learn diplomacy as well as assertive behavior required to motivate but not boss your fellow classmates."
>
> The lab "improved my confidence remarkably. I felt I could have an educated conversation about construction activities knowing their applications not just the textbook relevance."

Additional student feedback will be included in the presentation, along with a formal comparison of students with lecture only vs. those with lecture and lab experiences, which is in-progress at this writing.

Lessons Learned

Although the Boise State University (BSU) program discussed here has been largely successful, there are some lessons learned that may be useful for CM programs interested in adding or expanding their hands-on learning experiences for students.

Support for the laboratory experiences is crucial to its success. There must be support from the university/college/department to provide space for the activities to occur. The BSU lab spaces include indoor and outdoor facilities which accommodate both teaching areas and material/equipment storage. Support from industry is needed for material/equipment donations, as well as expertise for demonstration and supervision of some activities. At BSU, a local mason assists in the masonry lab experience and a local concrete testing company assists in the concrete testing lab experience. Faculty knowledge must be high for labs taught without industry support.

There are costs involved in creating and running the laboratory experiences as well. Some costs are one-time and occur only when a new lab experience is introduced. For example, the structural steel erection lab experience at BSU requires an overhead crane, as well as steel columns, beams, joists, decking, bolts, tools, safety harnesses, etc. However, other than replacement of tools and safety equipment every few years due to normal wear and tear, there are virtually no additional costs of this experience. Some costs reoccur every semester however, such as the concrete used in the concrete testing lab experience. These costs must be expected and budgeted. BSU includes a lab fee (currently $25 per student per semester) that covers consumable materials. In many semesters, there is a surplus which allows for the purchase of new one-time items that improve and refine the existing lab experiences.

Faculty time is also necessary for the lab experiences to be successful. There is the obvious preparation time necessary, just as for any course, but there are some other aspects that are perhaps not as obvious. In most of the lab experiences, the students build something. At BSU, these assemblies are not permanent and must often be dismantled by faculty, with volunteer student assistance, after class is over. Sometimes this can be almost as time-consuming as the laboratory itself. The structural steel frame built in a Tuesday afternoon lab must be dismantled before the Thursday afternoon class arrives. This process can take up to two hours, although this is in part due to the slow speed of the overhead crane and the distance between the storage location and the erection location. Coordination between the lab and lecture is another aspect that can take time. At BSU, one faculty member teaches the lab and another teaches the lecture. They must coordinate the course schedule and material coverage so the students have consistent information presented in a logical order without undue duplication. To accomplish this, they must be very aware of what the other is doing during their respective class time. This often requires attending the class time of the other on a regular basis. The awareness of what the other is teaching is particularly important for consistency in evaluating the students. It takes time to establish and refine lab experiences and get them to the point where they require little advanced preparation and coordination, but with the same faculty working together over multiple semesters, over time it does get easier.

Finally, standardization is necessary for success with laboratory experiences. Each experience should be reproducible from one semester to the next so that each group of students has a comparable classroom experience with well-defined learning objectives.

Conclusions

Deviating from traditional educational methodologies used in majority of construction engineering and management curricula is not without risk. Experiential learning methodologies and can be construed as "touchy-feely", a term that Hessler (2000) identifies as a devil term in higher education, stigmatizing work as unintellectual, unsubstantial, and lacking rigorous scholarship. "Skeptical faculty regard active learning as another in a long line of educational fads. For many faculty there remain questions about what active learning is and how it differs from traditional engineering education, since this is already "active" through homework assignments and laboratories" (Prince 2004, p. 223). However, Bonwell and Eison (1991) conclude that experiential or active learning leads to greater knowledge retention, enhances the attitude and motivation of the learner, and improves thinking and writing skills. Based on student feedback at BSU, the experiential learning used in this freshman-level course on materials and methods concurs with Bonwell and Eison's findings. The experiential learning improves course comprehension, improves leadership, promotes teamwork, and increases student confidence.

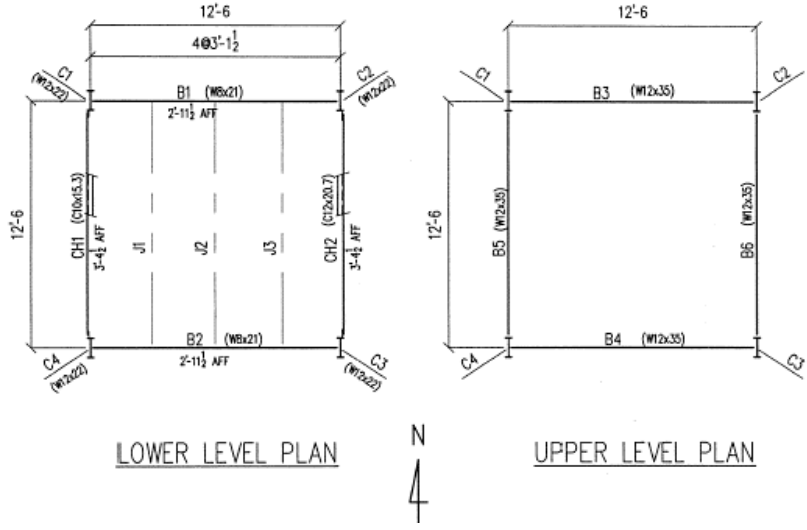


Figure 1: Steel Framing Plans



Figure 2: Students Using the Overhead Crane



Figure 3: Students Hanging Beams at the Upper Level of the Structure

References

Bonwell, C. C., and Eison, J. A. (1991). "Active learning: Creating excitement in the classroom." *ASHEERIC Higher Education Report No. 1*, George Washington University, Washington, DC.

Cline, R. C. (2008). "Teaching key competencies of effective construction project managers to adults in higher education," Ph.D. dissertation, University of Idaho, Moscow, ID.

Dewey, J. (1938). *Education and experience*, Simon and Schuster, New York.

Galbraith, M. W. (Ed.) (2004). *Adult learning methods: a guide for effective instruction,* 3rd ed., Krieger Publishing Company, Malabar, FL.

Hessler, H. B. (2000). "Composing an institutional identity: The terms of community service in higher education." *Language and Learning Across the Disciplines*, 4(3), 27-42.

Kimble, G. (1961). *Hilgard and Marquis' conditioning and learning*, 2nd ed., Prentice-Hall, Englewood Cliffs, N.J.

Kolb, A. Y., and Kolb, D. A. (2005). "Learning styles and learning spaces: Enhancing experiential learning in higher education." *Academy of Management Learning & Education*, 4(2), 193-212.

Merriam, S. B., and Brockett, R. G. (1997). *The profession and practice of adult education: An introduction*, Jossey-Bass Inc. Publishers, San Francisco.

Pratt, D. (1998). *Five perspectives on teaching in adult and higher education*, Krieger Publishing Company, Malabar, FL.

Prince, M. (2004). "Does active learning work? A review of the research." *Journal of Engineering Education*, 93(3), 223-231.

Rouda, R. H., and Kusy, M. E. (1996). "Development of Human Resources Part 6: High performance training." *Tappi Journal*, 79(2), 322-323.

Thomas, A. M. (1991). *Beyond education: A new perspective on society's management of learning*, Jossey-Bass, San Francisco.

VISUALIZATION AND MULTIMEDIA APPLICATIONS IN COST ESTIMATING EDUCATION

By Saeed Karshenas, PhD, PE

Department of Civil and Environmental Engineering, Marquette University, Milwaukee, WI 53233; PH (414)288-3530; FAX (414) 288-7521; e-mail: saeed.karshenas@marquette.edu

Keywords: Visualization, Cost Estimating, Revit, Multimedia, Problem-based Learning.

Abstract

This paper discusses a software system designed as a teaching tool for construction cost estimating education. The software creates 3D models of Revit designs. The 3D models can store multimedia information for each building element for future retrieval. A user while navigating a 3D model of a building can select an element and view estimating information, video segments of similar elements during construction as well as geometry and material information for the element. The 3D model is also able to interface with Microsoft Excel for cost estimating and with Microsoft Project for scheduling and 4D visualization. The paper discusses how the application streamlines access to building construction information and supports implementation of problem-based learning in cost estimating education.

Introduction

Construction cost estimating requires a large amount of knowledge and experience. Historically, cost estimating courses have done a good job in teaching the science of cost estimating which includes the estimating process, how to organize an estimate, sources of labor, equipment and material cost information and quantity takeoff. When it comes to pricing and labor productivity, students are referred to a table or a reference book. The argument is that estimating labor productivity requires experience and experience is acquired after years of practice.

There is no doubt that experience is a crucial ingredient for crew productivity estimating and it takes years of practical experience to acquire the skills necessary for becoming a good estimator. However, this does not mean that observing and analyzing construction operations should not be a major part of the construction cost estimating education. In fact, including construction operation case studies in cost estimating courses enhances student's critical thinking and problem solving abilities.

Including more understanding of construction operations in an estimating course requires a major revision in how estimating knowledge is presented to students. Students must perform less repetitive, mechanical activities and spend more time observing, thinking, discussing, reflecting and solving problems. This requires:

1- Making access to cost estimating information intuitive and fast.
2- Automating extraction of building element geometry and material from CAD models.
3- Exposing students to as many actual construction operations as possible.

Advances in computer software technology have made implementation of the above requirements possible. Computer databases have made it easy to organize a large amount of data and perform fast search and retrieval of the stored data. This study goes a step beyond organizing estimating information in a database and makes inquiry about and access to the information intuitive and fast by providing a virtual building as the interface to the information.

In the cost estimating process, quantity takeoff has always been the most tedious and time-consuming phase. Since paper drawings can only transfer design information visually, transfer of element geometry and material properties from design documents to estimating spreadsheets cannot be automated as long as design documents are in paper form. With the advent of 3D CAD software and its gradual adoption by designers, automated transfer of design information from digital CAD files to estimating spreadsheets is possible (Karshenas, 2005 and 2006).The software discussed in this study interfaces Revit Architecture (2009) for extracting building element geometry and material properties for estimating purposes.

Exposing students to various construction operations requires repeated visits to on-going construction project sites or using technology to bring construction field operations to students. Since repeated access to construction sites in a semester is not an option, recording various construction operations for student use is the next best option. But does exposing a student to videos of various construction operations make him/her a good estimator? The answer is generally no. Therefore, the main question that must be answered is: how should field case studies be used to enhance the

thinking, problem-solving and learning skills of students taking a cost estimating course?

Educational psychologists have been investigating this type of question and ways to improve the learning process for many years. A review of research on how learning occurs provides the best answers to these questions. One elegant answer is provided by Jonassen, et al, (2003), "… the solution is to help students construct their own meaning for the world. This means teacher's roles shift from dispensing knowledge to helping learners construct more viable perceptions of the world." Jonnassen, et al, recommend development of technologies that engage learners in knowledge construction, conversation, articulation, collaboration and reflection.

This paper presents a general description of a software system developed by the author that streamlines access to construction information and knowledge, minimizes a number of tedious and mechanical tasks involved in estimating and, therefore, allows students and instructor to spend more time with what Jonassen, et al (2003), call knowledge construction, conversation, reflection and collaboration.

Since the developed software system uses 3D graphics and multimedia technologies to achieve its objective, the next section reviews literature on visualization and multimedia applications in construction education.

To be effective, any visualization and multimedia learning tool must be based on how human mind works and processes information. The section following the literature review presents the main theories on learning and their recommendations for developing effective learning tools.

Visualization and Multimedia Applications in Construction Education

The most recent application of visualization in construction education is by Lucas, et al (2008) in which they discuss the structure of a virtual reality application for belt conveyor safety training program and the first phase of its implementation. To develop their system, they created a digital model of a conveyor belt system using Autodesk's AutoCAD and 3D Studio Max. The digital model was then imported into Right Hemisphere's Deep Creator. Within Deep Creator animations were added to simulate the belt moving. When completed, the system offers a training program and is capable of testing the knowledge of a belt conveyor user.

Messner, et al (2005) describe Virtual Construction Simulator which is designed to allow students to immerse themselves into a 3D construction project, perform a detail analysis of the design and develop a plan for the construction process. They also discuss the successful implementation of 4D Computer Aided Design modeling in an undergraduate curriculum and provide their vision for an ongoing research into the

application of advance visualization technologies within the construction engineering and management option in the Architectural Engineering Department at Penn State.

Another interesting application of multimedia technology in education is the use of computer-based case histories as classroom supplements for a new course on the role of Wetlands in design and construction (Chinowsky, 1997).

Learning Theories

In order to develop tools and environments that foster learning, it is important to understand what learning is and what factors influence the learning process. For many years, educational psychologists have been debating how learning occurs. A number of theories have been advocated by various learning experts about how people learn. The main learning theories that have greatly influenced education during the 20th century are classified as behavioral, cognitive and constructivist (Allessi and Trollip, 2001).

Behavioral theory is based on Pavlov's research (1927) that was extended by other behavioral psychologists such as Skinner (1974). This theory maintains that learning should be described as changes in the observable behavior of a learner made as a function of events in the environment (Allessi and Trollip, 2001). In other words, learning is the learner's response to a stimulus and instruction is typically target-structured around the presentation of the target stimulus and the provision of opportunities for the learner to practice making the proper response (Ertmer and Newby, 1993). This theory has significantly influenced the classroom instruction approach by putting too much emphasis on the instructor and instructional material.

The Cognitive theory tries to answer the deficiencies of the Behavioral theory in explaining several aspects of human behavior. This theory is based on human cognitive structures and the way in which those structures are organized. Cognitive theory places emphasis on mind, memory, motivation, thinking, reflection and other internal processes. Of the different schools of cognitive learning psychology, perhaps the most dominant is based on an information processing theory. This theory attempts to describe how information in the world enters through our senses, becomes stored in memory, is retained or forgotten and is used (Allessi and Trollip, 2001). Cognitive learning research results have had a great impact on multimedia learning (Mayer, 2005) and software interface design (Te'eni, et al, 2007).

According to Mayer (2005), development of any learning system must be based on three cognitive science principles: (1) the human information processing system includes dual channels for visual/pictorial and auditory/verbal processing, (2) each channel has limited capacity for processing, (3) and humans actively engage in

cognitive processing in order to construct a coherent mental representation of their experiences. These active cognitive processes include paying attention, organizing incoming information and integrating incoming information with prior knowledge.

The constructivist learning theory challenges the cognitive view that there is an objective world that we perceive through our senses and education is the process of helping the learner correctly interpret it. The constructivist view holds that people create a meaning or concept of the world by their experiences and learning is a process of people actively constructing knowledge. Proponents of this learning philosophy maintain that instructional designers should create educational environments that facilitate the construction of knowledge (Allessi and Trollip, 2001). To accomplish this goal, educators should design learning systems that are engaging and allow learners to explore, think, collaborate and explain.

A Constructivist learning model that has become very popular is problem-based learning (PBL) (Ronis, 2008). In PBL, learners work towards the understanding and solving a problem. A PBL process starts by assigning a real-world and open-ended problem to a group of students. The student group conducts its own research, plans its strategy, form its hypothesis and find its solutions. During this process, the instructor is available to students, helps students stay on track but does not offer much information as to lead the inquiry.

Application Architecture

The software system described in this section is designed to serve as a learning tool by construction management students. Currently the software system has the following capabilities:

1- Interface with Revit Architecture for extracting geometry and material information for a building model.
2- Create a 3D visualization of a building using information extracted from its Revit design files.
3- Interface with Microsoft Excel and Project for estimating and 4D visualization, respectively.
4- Provide multimedia information about building elements.

In order to have full access to the graphics engine, full navigational control, and two-way communication with the CAD engine, it was decided to develop the software system from scratch rather than using commercial visualization or 4D software. The software was named virtual building creator (VBC) and was developed using Microsoft DirectX graphics library.

VBC consists of several components as shown in Figure 1. Revit Interface component allows VBC to programmatically interact with Autodesk Revit Architecture for extracting a building model's geometry and material properties and if necessary send commands to Revit to interact with or modify the building CAD model.

Using the information extracted from a Revit design, the Graphics engine creates a 3D model of the design. The mouse and keyboard interface component allows the user to navigate and interact with the 3D model. Currently, navigation in a VBC model includes orbiting or flying over a model using a 3rd person camera as shown in Figure 2, or walking around and inside the model with a 1st person camera as shown in Figure 3. The camera's yaw, pitch and travel are controlled by user for complete real-time navigation of a model.

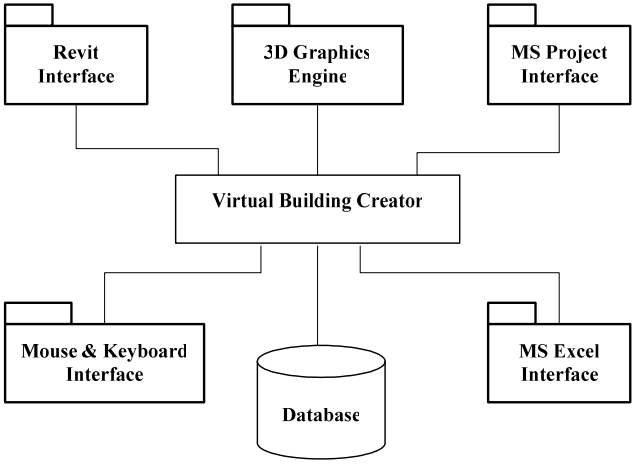


Figure 1- VBC Application Architecture



Figure 2- A Fly-over View

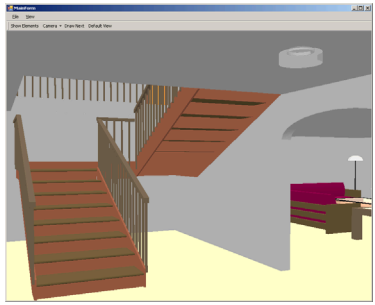


Figure 3- A Walkthrough View

The MS Project Interface component allows two-way interactions with Microsoft Project for transferring building elements to Microsoft Project for scheduling and importing a building schedule from Microsoft Project for simulating its construction process. Figures 4 and 5 show the construction stages after completion of the foundation walls and after the backfill operation, respectively, for the residential building depicted in Figures 2 and 3. Figures 4 and 5 are examples of the advantages of a custom graphics engine for visualization. The site work details shown in the Figures 4 and 5 require full control over the graphics engine.

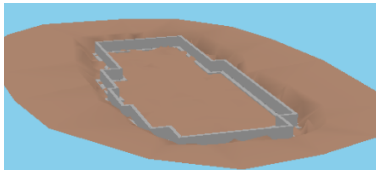


Figure 4- Project Ready for Backfill

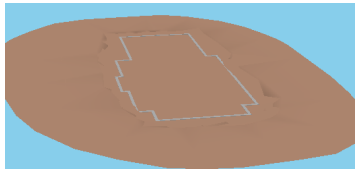


Figure 5- Project after Backfill

The MS Excel Interface component allows exporting project element geometry and material properties to Microsoft Excel for quantity takeoff calculations (Karshenas, 2005 and 2006). The application uses a relational database for storing building information and educational content related to building elements.

Currently the VBC application is a stand-alone workstation application. Efforts to add network access for collaborative learning are underway.

A Natural Interface to Construction Information

Graphical user interfaces normally use symbols, indices or keywords for navigation and access to information stored in a computer. This method of interaction is different from how we interact with the 3D world around us. One way to facilitate learning is

to introduce new material gradually but in a way that the general pattern and organization of information is clear to students. A virtual building is a great interface to the vast amount of construction information that must be stored for a building. Thomas Furness writes "… when we are immersed in a virtual environment, we in effect become part of the message. Then we can interact within the virtual environment using the same natural semantics that we use when interacting with physical world. These factors empower the virtual interface as a medium with an unprecedented efficiency in communicating information, making it ideal for a transportation system for our senses, i.e. an electronically mediated presence. This is the best way to substantially increase bandwidth to the brain."

VBC retrieves geometry and material properties for each element from Revit and also allows the user to attach additional multimedia content to each building element for future access. This capability allows a user to demand construction information about a building element during a walkthrough. A virtual building with multimedia educational content about cost estimating will be referred to as walkthrough knowledgebase for cost estimating (WKCE). A WKCE is built by the author using VBC software and is gradually being loaded with cost estimating information and knowledge for various building elements.

When using WKCE, the user has the option to select a building element and retrieve cost estimating information and knowledge related to the element. For example, by double clicking a steel column a dialog box presents the following options to the user (the actual dialog box is not legible after reduction so the content is listed below):

- Introduction to Steel Cost Estimating
- Quantity Takeoff
- Fabrication
- Erection
- Crew Combination
- Expert Interview
- Element Information

By selecting an item, more detailed information about the item is presented. The additional information is presented using one or more media formats such as text, narration, images or video. For example, Element information option presents the geometry and material information extracted from Revit in a tabular format. On the other hand, the erection option presents video segments of actual steel members being installed. The expert interview option provides video segments of short interviews with experienced estimators or video segments of past course guest lecturers sharing their experiences on steel construction cost estimating.

VBC system provides the infrastructure for creating the next generation of digital visual books in building construction. Content creation for WKCE is a slow process

but is in progress. At this point in time, cost estimating content for steel beams and columns and block masonry construction are in place.

Problem-based Learning Applications

As discussed above, problem-based learning (PBL) is a constructivist approach to promote learner's thinking and problem-solving skills. This section describes an implementation of PBL by the author in a cost estimating course at Marquette University. In the course student groups independently work on a cost estimating project.

A PBL project involves a real-world, open-ended problem that does not have a clear-cut solution. In the estimating course, each student group is assigned a labor productivity estimating problem. For example, if the class project includes steel construction, the PBL project could be, "… recommend a crew for the erection of the steel work in class project and estimate crew productivity. Perform a what-if analysis for the problem." Each group is expected to submit a written report and present its solution orally to class for peer evaluation.

The following are criteria for PBL evaluation (Ronis, 2008). The evaluation criteria are communicated to students at the beginning of the project.

- Research quality
- Strategies used
- Organization of research
- Communication
- Comprehension
- Collaboration.

A good starting point for students to research their PBL assignment is the WKCE Erection and Expert-interview video libraries. Students are also expected to contact local contractors and communicate with professionals who work in the field.

Summary and Conclusions

To be effective, any visualization and multimedia learning tool must be based on how human mind works and processes information. This paper presented a software system designed to promote construction cost estimating learning processes. The latest cognitive learning research results were used for designing the multimedia content of the system and how the content is presented to the user. The video library of the learning tool, when adequately populated, may be used as a resource for implementing a problem-based learning approach. The feedback from a limited number of students who worked with the system was very positive.

References

Alessi, S.M. and Trollip, S.R., (2001), "Multimedia for Learning- Methods and Development," 3rd edition, Allyn and Bacon, Boston.

Revit Architecture (2009), "Autodesk Revit Architecture," http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=11091739 (11/1/2008).

Chinowski, Paul, S., (1997), "Introducing Multimedia Cases into Construction Education," Proceedings of the 4th Congress on Computing in Civil Engineering.

Ertmer, P.A., Newby, T.J., (1993), "Behaviorism, Cognitivism, Constructivism? Comparing critical features from an Instructional Design Perspective," Performance Improvement Quarterly, 6(4), 50-72.

Furness III, Thomas A., (2001), "Toward Tightly Coupled Human Interfaces," Frontiers of Human-Centered Computing, Online Communities and Virtual Environments, Springer, London.

Jonassen, D.H., Howland, J., Moore, J. and Marra, R.M., (2003), "Learning to solve problems with Technology, A Constructivist Perspective," second edition, Merrill Prentice Hall.

Karshenas, Saeed, (2005), "Cost Estimating in the Age of 3D CAD Software and Object Databases," ASCE Construction Research Congress, San Diego, CA.

Karshenas, Saeed, (2007), "A Computerized Approach to Design Cost Estimating," Transactions of the American Association of Cost Engineers International.

Lucas, J., Thabet, W., Worlikar, P., (2008), "A VR-Based Training Program for Conveyor Belt Safety," ITcon Vol. 13, pg. 381-407, http://www.itcon.org/2008/25.

Mayer, R.E., (2005), "The Cambridge Handbook of Multimedia Learning," Cambridge University Press.

Messner, J.I., Riley, D.R., and Horman, M.J., (2005), "An Interactive visualization Environment for Construction Engineering Education," ASCE Construction Research Congress, San-Diego, CA.

Pavlov, I.P., (1927), "Conditioned Reflexes," London, Clarendon Place.

Ronis, D.L., (2008), "Problem-Based Learning for Math and Science- Integrating Inquiry and the Internet." Second Edition, Corwin Press, Thousand Oaks, CA 91320.

Skinner, B.F., (1974), " About Behaviorism," New York, Knoph.

Te'eni, D., Carey, J., Zhang, P., (2007), "Human Computer Interaction- Developing Effective Organizational Information Systems," John Wiley and Sons, Inc.

WORK EXPERIENCE IMPACTS ON CONSTRUCTION MANAGEMENT STUDENTS' COGNITIONS RELATED TO CONSTRUCTION WASTE RECYCLING

MaryEllen C. Nobe[1]

ABSTRACT

Constructors can significantly impact the sustainability of a construction project through the implementation of construction waste recycling programs (CWM). Prior research, however, has identified a lack of implementation of waste recycling programs due to general contractor's unfamiliarity with and commitment to such practices. Educators are responding by incorporating principles of sustainability into undergraduate curricula. The results from this study, however, suggest that early work experiences may be counter to education efforts in this area. Senior construction management students who had two to three time the work experience of junior students were less willing to participate in CWM programs. Additionally, the senior students were more likely to have less favorable cognitions (i.e. value orientations, attitudes and norms) and behavior intentions toward construction waste recycling. These results are significant to an industry that is trying to become more sustainable and the educational institutions that are striving to provide environmentally literate graduates.

INTRODUCTION

Climate change is a long-term problem that can be addressed, in part, in the built environment by changing how buildings are designed, built and operated (Buckley 2006). During the building process, constructors make many choices that impact the sustainability of the building process. One such decision is whether or not to implement a construction waste recycling (CWR) program. Beyond the enormous stress buildings place on the environment for raw materials, they are also significant contributors to landfills as a result of job site management practices. Over one-third of municipal solid waste comes from buildings (Smith 2003). Many contractors,

[1] Department of Construction Management, 102 Guggenheim, Colorado State University, Fort Collins, CO, 80523-1584; PH (970) 491-5215; email: mary.nobe@cahs.colostate.edu

however, are not implementing waste recycling programs due to a lack of knowledge (Matthiessen & Morris July 2004).

In response to this lack of knowledge, undergraduate construction management programs have started to incorporate principles of sustainability into their curricula. While these educational efforts appear to be increasing knowledge about CWR programs, there is a concern that early construction experiences may be counter to educators' efforts. In a recent study, it was observed that senior students exhibited less willingness to participate in such programs (Nobe 2007). The purpose of this study is to examine differences in students' willingness to participate in CWR programs through the use of a cognitive framework from the area of social psychology.

Social psychology framework for studying environmentalism

Cognitive indicators of environmental behavior include individuals' value orientations, attitudes, and environmentally sensitive behaviours. These have been linked together into a cognitive hierarchy to serve as a framework for studying and understanding the role of cognitive determinants of behaviour. In this area of research, an extensive body of research exists on the relationship between measures of environmentalism, such as environmental concern and environmentally significant behaviours, and individuals' values and value orientations (Garling, Fujii, Garling, & Jakobsson 2003; Joireman, Van Lange, & Van Vugt 2003; Schultz et al. 2005; Stern & Dietz 1994; Vaske, Donnelly, Williams, & Jonker 2001). The components of the cognitive hierarchy are values and value orientations, which are few in number and difficult to change, and attitudes and norms, which are more numerous and easier to change. These cognitions are predicted to influence human behaviors. Nobe (2007), for example, found that construction management students' cognitions predicted their willingness to setup a construction waste recycling program (i.e., a behavioral intention). Students participating in the study ranged from freshmen CM majors and minors to CM graduate students.

HUMAN COGNITIONS RELATED TO ENVIRONMENTAL BEHAVIOR

This study focuses on three types of human cognitions that are precursors of environmental behavior. They are value orientations, attitudes, and behavior intentions, which are linked together with value orientations influencing attitudes and attitudes influencing behavior intentions, which is the precursor to actual behavior. Environmental value orientations are groupings of basic beliefs related to the environment; they are specific to a general context (e.g., the environment) and do not transcend situations (Vaske & Donnelly 1999). Individual's environmental value orientations are correlated with and influence individual's attitudes toward environmental behaviors. Therefore, they are an important starting point for understanding environmental behavior.

The construction of a value orientation starts with identifying individuals' basic beliefs in a broad context such as the environment. These individual beliefs are then grouped and placed on a continuum. For example, to assess environmental value

orientations, individuals' basic beliefs about the environment would first be identified. These beliefs might be that nature has as much right as humans to exist or that the primary function of forests is to provide resources for human use (Vaske et al. 2001). As more basic beliefs are identified and grouped together, they reveal an individual's value orientation which can be represented by the position of basic values groupings on a continuum (Fulton 1997; Fulton, Manfredo, & Lipscomb 1996; Vaske & Donnelly 1999). This continuum represents the possible groupings of basic beliefs that individuals might hold related to a context (i.e., the environment). For example, one environmental value orientation that has been identified in the literature is a biocentric – anthropocentric value orientation (Vaske & Donnelly 1999). One extreme of this value orientation is that the environment has intrinsic value separate from the benefits that it provides to humans; the other end represents the view that the environment is only valuable because of the resources and services it provides for human use.

Attitudes, which are influenced by value orientations, are direct predictors of individual's behavior intentions. Attitudes are expressions of disfavor or favor for a given situation or object (Eagly & Chaiken 1993). Attitudes can be general, referring to a group of behaviors (i.e. construction waste recycling) or they can be specific to a certain behavior (i.e. construction recycling on a specific construction job). Attitude formation is based on an individual's belief that a behavior will lead to certain outcomes and their evaluation of those outcomes (Ajzen & Fishbein 1980; Eagly & Chaiken 1993). For example, if an individual believes that recycling is good for the environment and that by recycling, s/he is helping conserve natural resources, then s/he would likely have a favorable attitude toward recycling.

Behaviors are the last step in the cognitive hierarchy; they represent actions by individuals. Behaviors are the most numerous, and therefore can change often and rapidly (Eagly & Chaiken 1993). Ajzen and Fishbein (1980) note that the majority of behaviors of social relevance are under volitional control; as a result, the direct antecedent to behavior is intention, not attitude.

PARTICIPANTS

This study uses secondary data taken from a larger study of linkages between construction management students' cognitions and their environmental behavior intentions. The data used for this paper comes from two courses: MC 365: Construction Cost Estimating, and MC 465: Construction Management Professional Practice. These courses were chosen based on differences in the observed difference in mean scores for the two courses. Both courses are required courses for undergraduate construction management students at Colorado State University.

In each course section, students were recruited to participate in the study through class announcements. In the recruitment, students were asked to voluntarily fill out the survey. They were assured that their responses would be completely anonymous and that their grade in the course would not be impacted by their choice to participate or not participate. After handing out the surveys, class was dismissed. All surveys

were turned into a box located at the front of the classroom. The hypotheses for this study are:

H1: Students in CON 465 will hold more anthropocentric value orientations.
H2: Students in CON 465 will have less favorable attitudes of construction waste management practices.
H3: Students in CON 465 will be less willing to participate in construction waste management programs.

INSTRUMENT

The survey instrument used for this study was designed specifically for the purpose of analyzing components of the construction management students' cognitive hierarchy in the context of construction waste recycling. Questions on the survey measure self-enhancement/self-transcendence values; environmental value orientation; CWR attitudes; and CWR behavior intentions; as well as basic demographics. All of the variables in this study were latent scaled variables. The survey instrument was piloted and revised based on the pilot results.

VARIABLES

Environmental value orientations: The environmental value orientation used in this study was the anthropocentric/biocentric value orientation previously identified by Vaske and associates (Vaske & Donnelly 1999; Vaske et al. 2001). Measures of environmental value orientations were based on responses to a series of 12 environmental beliefs. Of these twelve basic beliefs, five were anthropocentric: (a) the primary value of forests is to generate money and economic self-reliance for communities; (b) the primary value of forests is to provide timber, and grazing land for people who depend on them for their way of life; (c) forests are valuable only if they produce jobs and income for people; (d) nature's primary value is to provide products useful to people; (e) the value of forests exists only in the human mind; without people forests have no value.

The remaining seven basic belief statements represent biocentric views: (f) forests have as much right to exist as people; (g) nature has as much right to exist as people; (h) wildlife, plants, and people have equal rights to live and develop; (i) forests have value, whether people are present or not; (j) forests should be preserved so that future generations can enjoy them; (k) the opportunity for spiritual renewal is the most important value of forests; (l) the opportunity for spiritual renewal is the most important value of nature. For both sets of basic belief statements, respondents were asked to indicate their level of agreement or disagreement with each of the anthropocentric statements using a 7-point Likert scale ranging from *strongly agree* (1) to *strongly disagree* (7).

Construction waste recycling attitude: Student's CWR General Attitude was constructed from their responses to four questions pertaining to various opinions of construction waste recycling programs. Students were asked to indicate how they felt about each of the following statement: (a) Construction waste recycling is

unnecessary/necessary for the environment; (b) Construction waste recycling is personally punishing/rewarding; (c) Construction waste recycling is harmful/beneficial to the environment and (d) Construction waste recycling is bad/good for the environment. Responses used a scale that ranged from an extremely negative response (1) to an extremely positive response (7). For example, the response options for the first statement ranged from extremely unnecessary to extremely necessary.

Behavioral intentions: Behavioral intentions were identified through the use of six statements reflecting increasing levels of support for construction waste recycling. Behavioral intention statements were placed into a job site context by asking respondents to assume that they were 'starting a new construction job today'. These six behavior intentions included: (a) I intend to verbally support construction waste recycling program efforts (i.e., reminding people that they should recycle construction materials); (b) I intend to support construction waste recycling efforts through my actions (i.e. picking up materials that have been discarded and placing them in the appropriate recycle bin); (c) I intend to go out of my way to insure that all materials that can be recycled are being recycled; (d) I intend to volunteer to organize an on-site construction waste recycling program; (e) I intend to be a strong advocate for construction waste recycling programs; and (f) If given the chance, I would vote for mandatory construction waste recycling programs. Participants were asked to indicate the likelihood that they would engage in the listed behavior using a 7 point scale ranging from *extremely unlikely* (-3) to *extremely likely* (+3).

Demographic questions: Demographic variables included in the survey are: sex, age, major, construction and work experience.

DEVELOPMENT OF VARIABLES

Variables used to test the hypotheses of this study were value index, value orientation index, construction waste recycling attitude, and construction waste recycling behavior intention. In the following sections, methods for obtaining these variables from the survey data are presented. SPSS 16.0 statistical package was used for construction and analysis of all variables.

Anthropocentric / Biocentric Environmental Value Orientation Index

The anthropocentric/biocentric environmental value orientation index (referred to as the value orientation) was constructed using the same method used for the value index. For both the anthropocentric and biocentric basic belief statements, respondents were asked to indicate their level of agreement with the statement. Response options ranged from *strongly agree* (1) to *strongly disagree* (7). These items were then reverse coded so that response options were in the same direction as the value items.

Internal consistencies of the anthropocentric and biocentric basic beliefs were examined using Cronbach's alpha reliability coefficients. For the anthropocentric

basic beliefs, the reliability coefficient was 0.72. Deleting item *e* increased Cronbach's alpha to 0.74. The remaining belief statements were reverse coded prior to constructing value orientation. For the biocentric basic beliefs, the reliability coefficient was 0.83. Since deleting any of the belief items from the biocentric group did not increase alpha, all of the biocentric belief items were used in construction of the value orientation. Construction of the value orientation was based on mean responses to the basic belief statements.

Attitudes Index

Reponses to the four attitude questions were used to create the general CWR attitude index. The reliability coefficient for items included in the CWR General Attitude was 0.80. Since excluding any of the variables did not increase alpha, all four items were used to construct the attitude by taking the mean of all four responses.

Behavior Intention

The behavior intention for participating and or supporting a CWR program came from six survey items. The reliability coefficient for items included in the Behavior Intention was 0.90. Since excluding any of the variables did not increase alpha, all six items were used to construct the behavior intention response by taking the mean of all six responses.

Prior to analysis of the hypothesis, correlations between model variables were compared to check for possible collinearity between variables. All of the correlations between variables are below .45; therefore, it is assumed that collinearity between variables does not exist.

Measurement Validity

Content and construct validity were enhanced by grounding the study in accepted terms and definitions of social psychology relevant to the understanding of environmental behaviors. Further, previously developed and tested measures were used for components of the value index and the environmental value orientation. Measures of attitude and behavior intention were based on published recommendations that have also been widely used in similar survey instrument designs.

RESULTS

Of the 113 students enrolled in MC 365, 90 returned their surveys resulting in an 80% response rate. Of all the surveys returned, some were only partially completed, while most were completely filled out. All responses were entered into an SPSS data file with unanswered questions coded as missing data. In the following analysis, listwise deletion was used for all analyses; therefore, a participant had to answer all survey questions related to this study to be included in the analysis. As a result there were 136 valid responses; 58 were from MC 465 and 78 were from MC 365.

In both classes, the majority of respondents were less than 24 years old. For MC 365, 76% were between 19 and 24 years old. In MC 465, 81% were between 20 and 24

years old. With respect to work experience, all of the MC 465 students reported some level of construction related work experience and 44% reported having more than 24 months of construction work experience. In MC 365, 93% reported some level of construction work experience; 64% reported having 12 months or less experience. The majority of MC 365 participants, however, reported 6 months or less experience.

Table 1 Variable Means for Construction Management Students by Course .

	MC 465		MC 365		
	M	SD	M	SD	*t* (140)
Anthro/Bio Value Orientation[a]	4.79	0.90	5.29	0.85	-3.36***
CWR General Attitude[b]	1.85	1.02	2.23	0.55	-2.66**
CWR Behavior Intentions[c]	0.65	1.20	1.21	1.15	-2.81**

**$p < .01$ *** $p < .001$.

[a] Value Orientation Index is measured on a scale from 1 to 7. A higher score indicates higher agreement with biocentric basic beliefs.

[b] CWR attitude index is measured on a scale from 1 to 7. A higher, positive score indicates a more favorable attitude.

[c] Behavior intention is measured on a scale from -3 to 3. A higher score indicates a stronger behavior intention.

For the value orientation index, scores closer to 1 would indicate that respondents hold more anthropocentric value orientations. Index scores closer to 7 would indicate that respondents hold more biocentric basic beliefs. Based on the participants' mean responses, it appears that MC 365 students tend to hold slightly more biocentric than the MC 465 students.

CWR general attitude was measured on a scale from -3 (extremely unfavorable) to +3 (extremely favorable), with zero representing a neutral response. Lower scores indicate less favorable attitudes related to CWR, while higher scores indicate more favorable CWR attitudes. The mean for both classes was positive, however the MC 365 class mean of 2.23 indicates that those students hold more favorable attitudes related to CWR. Last was CWR behavior intention. Behavior intention was measured on a scale ranging from -3 (extremely unlikely) to +3 (extremely likely), with zero representing a neutral response. Although the mean for both classes were positive, the mean response for the MC 465 class indicates that those students are less willing to engage in CWR activities.

To test the hypotheses, an independent *t*-test was used to compare the mean for each variable between classes. In all cases, listwise deletion was used. The *t*-test results showed that statistically significant differences existed between MC 365 and MC 465 for all variables with the exception of the Value Index (Table 1). The first hypothesis stated that MC 465 students would hold more anthropocentric value orientations than MC 365 students. The *t*-test for this analysis returned a *t*-value of -3.36, which is significant at the $p < .001$. The large effect size ($d = 0.57$) indicates that the sample size was sufficient to detect a statistical difference. As a result, the second hypothesis is supported. The second hypothesis stated that MC 465 students would hold less favorable attitudes related to CWR programs. For this test, the *t*-value was -2.65, which is significant at the $p < .01$ level. For this test, the effect size was close to large

(d = 0.45), again indicating that the sample size was large enough to detect a statistical difference. The third hypothesis is also supported. The third hypothesis stated that MC 465 students would be less willing to engage in CWR programs. The results for this t-test were also significant (t = -2.81, $p < .01$). The effect size for this test was also close to large (d = 0.48), indicating that the sample size was large enough to determine if a significant difference did exist.

DISCUSSION/CONCLUSIONS

The result from the above t-tests, support the hypotheses that a statistically significant difference, although small, does exist between MC 465 and MC365 students in relation to their value orientation, CWR general attitude, and their CWR behavior intentions. There are several possible reasons for these differences including age, progression in program of study, work experience, and variations in survey administration. Of these, age is not likely the reason based on the demographic information. Additionally, guidelines were put in place to reduce variations in survey administrations. Work experience and/or progression in program of study are more plausible reasons for the differences between the two groups.

It is important also to note, that the observed differences go beyond the behavior intentions and attitudes to value orientations. As a result, educational efforts to move construction to a more sustainable industry through education of construction management students may be being undermined by students' early experiences in industry. For example, the fact that a construction company does not implement construction waste recycling may signal to students that the CWR is not applicable in the real world.

The significance of these finding is that they raise the question of whether industry experiences are undermining educators' efforts to encourage students to be more sustainable in their job site management behaviors. While these results are significant, they are not conclusive due shortcomings of the data available. These results do, however, warrant further research into the effects of students' early industry experience on their cognitive hierarchy in the form of a longitudinal study of a group of students is needed to clearly determine if and how industry experience may be impacting students' cognitions related to CWR. It is hoped that an outcome of this study will be to encourage educators' to follow up with students after completing their internships to counter negative experiences they may have had, while reinforcing their positive experiences.

REFERENCES

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behavior*. Englewood Cliffs, N.J.: Prentice-Hall.

Buckley, B. (2006, November). Winds of change? *GreenSource: The Magazine of Sustainable Design*, 23.

Drivers for sustainable construction. (2003). *UNEP Industry and Environment*, 22-25.

Eagly, A. H., & Chaiken, S. (1993). *The psychology of attitudes*. Fort Worth: Harcourt Brace Jovanovich College Publishers.

Fulton, D. C. (1997). *Development and assessment of a conceptual approach for measuring wildlife value orientations: Results from two studies (environment, social values)*. DAI, 58(06A), 159.

Fulton, D. C., Manfredo, M., & Lipscomb, J. (1996). Wildlife value orientations: A conceptual and measurment approach. *Human Dimensions of Wildlife*, 1(2), 24-47.

Garling, T., Fujii, S., Garling, A., & Jakobsson, C. (2003). Moderating effects of social value orientation on determinants of proenvironmental behavior intention. *Journal of Environmental Psychology*, 23, 1-9.

Green Building SmartMarket Report. (2005).). New York: McGraw Hill Construction

Joireman, J. A., Van Lange, P. A. M., & Van Vugt, M. (2003). Who cares about the environmental impact of cars? Those with an eye toward the future. *Environment and Behavior*, 35(10), 1-20.

Kibert, C. J. (2004). Green buildings: An overview of progress. *Journal of Land Use*, 19(2), 491-502.

Kibert, C. J. (2005a, April 6-9). Integrating sustainability into construction programs. Paper presented at the ASC proceedings of the 41th Annual Conference, University of Cincinnati-Cincinnati, Ohio.

Kibert, C. J. (2005b). *Sustainable construction: Green building design and delivery*. Hoboken, N.J.: John Wiley & Sons, Inc.

McCarthy, J. A., & Shrum, L. J. (2000). The measurement of personal values in survey research: A test of alternative rating procedures. *Public Opinion Quarterly*, 64, 271-98.

McDonough, W. (2004). Teaching design that goes from cradle to cradle. *Chronicle of Higher Education*, 50(46), B6.

Oskamp, S. (2000). Psychological contributions to achieving an ecologically sustainable future for humanity. *Journal of Social Issues*, 56(3), 373-90.

Rokeach, M. (1973). *The nature of human values*. New York: The Free Press.

Roodman, D. M., & Lenssen, N. (1995). *A building revolution: How ecology and health concern are transforming construction* (Vol. 124). Washington, D.C.: Worldwatch Institute.

Schultz, P. W., Gouveia, V. V., Cameron, L. D., Tankha, G., Schmuck, P., & Franek, M. (2005). Values and their relationship to environmental concern and conservation behavior. *Journal of Cross-Cultural Psychology*, 36(4), 457-75.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. *Advance in Experimental Social Psychology*, 25, 1-65.

Schwartz, S. H. (1994). Are there universal aspects in the structure and contents of human values? *Journal of Social Issues*, 50(4), 19-45.

Smith, A. (2003). *Building momentum: National trends and prospects for high-performance green buildings*. Washington, D.C.: U.S. Green Building Council.

Stern, P. C. (1992). Psychological dimensions of global environmental change. Annual *Review of Psychology*, 43, 269-302.

Stern, P. C., Dietz, T., Guagnano, G. A., & Kalof, L. (1999). A value-belief-norm theory of support for social movements: The case of environmentalism. *Human Ecology Review*, 6(2), 81-97.

Vaske, J. J., & Donnelly, M. P. (1999). A value-attitude-behavior model predicting wildland preservation voting intentions. *Society and Natural Resources*, 12, 523-37.

Vaske, J. J., Donnelly, M. P., Williams, D. R., & Jonker, S. (2001). Demographic Influences on environmental value orientations and normative beliefs about national forest management, *Society and Natural Resources,* 14, 761-776.

Wilson, A., Uncapher, J. L., McManigal, L., Lovins, L. H., Cureton, M., & Browning, W. D. (1998). *Green development: Integrating ecology and real estate*. New York John Wiley & Sons, Inc.

KEY SKILLS FOR GRADUATING CONSTRUCTION MANAGEMENT STUDENTS – A COMPARATIVE STUDY OF INDUSTRY AND ACADEMIC PERSPECTIVES

Rizwan U. Farooqui[1], and Syed M. Ahmed[2]

[1]Department of Construction Management, College of Engineering & Computing, Florida International University, 10555 West Flagler St. #2900, Miami, FL 33174, USA; PH (305)-348-3172; FAX (305)-348-6255; e-mail: rfaro001@fiu.edu

[2]Department of Construction Management, College of Engineering & Computing, Florida International University, 10555 West Flagler St. #2952, Miami, FL 33174, USA; PH (305)-348-3172; FAX (305)-348-6255; e-mail: ahmeds@fiu.edu

Abstract

This research attempts to determine the extent of agreement between industry and academia as to the required key skills from graduating construction management students, both undergraduate and graduate level, in order to identify any differences in perspectives. This is indeed important in order to develop a strategic plan for construction management educators with specific curriculum improvements so as to prepare construction management students for the contemporary construction industry. As such, the study endeavors to provide insights into possible future directions undergraduate and graduate construction management education might be heading for and highlights some of the priorities that should be part of the movement. An important conclusion from the study is that skills ranked high by the industry, including interpreting contract documents (for both undergraduates and graduates) , listening ability/ giving attention to details (for undergraduates), time management (for undergraduates), construction accounting (for graduates), value engineering/ constructability analysis/ design review (for graduates) and contract negotiations/ conflict resolution (for graduates) are given lesser significance by the educators. Hence, these skills signify areas that may require strategic curriculum improvement. Consequently, a collaborative effort to strategically assess and improve construction management curriculums is highly recommended.

1. INTRODUCTION

Construction managers today have to play a key role in improving the industry competitiveness and productivity. They need to serve as moderators between owners, engineers, architects, quantity surveyors, contractors, subcontractors and insurance

agents, as well as innovators in incorporating new technologies and management methodologies in the construction businesses. The skills which a construction manager can bring to a company largely determine the ultimate success of its business and its projects. Keeping in view the critical need for adequately skilled construction managers, construction management programs would be increasingly called upon in the future to produce candidates suitable to undertake these services for the industry. Hence it is inevitable that the construction management programs must be constantly revamped and enhanced to address the education needs of the industry and hence the students. The value of well defined and structured courses as well as industry experience and feedback must be inclusive to the programs.

Construction management programs are located within various colleges and universities; baccalaureate degrees have a wide range of titles and have a varied base of instruction. While accreditation helps to keep some semblance of uniformity, the variety of titles of degrees and locations within universities can reduce the merit given to these degrees. As can be noticed, construction management programs can be found in schools of construction, engineering, science, built environment, technology, business and management. Degree titles can be construction management, construction science, construction, construction engineering, and construction engineering technology to name the most common. So much variation between programs can lead to questions concerning knowledge and skill differentials between candidates produced by the programs and the agreement of necessary skills by the industry and education sector. With the need obviously being shown by the quantity of graduates being produced by these programs and hired by the construction industry, a major question that needs to be addressed is that concerning the agreement of necessary skills by the industry and education sectors, i.e. whether the skill set perceived significant by the education sector matches the skill set required by the construction industry. The above question forms the basis of this research.

Consequent to above, the purpose of this research is to determine the extent of agreement as to the required skills, between industry and academia, from graduating construction management students (both undergraduate and graduate level) and to identify differences in perceptions, if any. This is indeed important from the viewpoint of the industry, educators and students in an effort to attain the goal of meeting the required skills and providing adequately skilled graduates for the construction industry. This is, in particularly, significant to strategically update curricula, so that it reflects, at all times, the key skill set required by the industry.

2. OBJECTIVES

The objectives of the research are outlined below:

1. To identify the key skill set required by today's construction industry from graduating construction management students (both undergraduate and graduate) as perceived by the industry and academia.
2. To determine the extent of agreement between the industry and the academia as to the most important skills required from graduating construction management students (both undergraduate and graduate).

3. METHODOLOGY

The research methodology consists of the following steps:

1. Development of a questionnaire to elicit information about key skills required from graduating construction management students.
2. Conducting questionnaire survey through postal mail and personal interviews.
3. Assessment of feedback from questionnaire survey to identify the industry perspective, educator perspective, the overall perspective, and the relative difference in importance of skills as perceived by the industry and educators.

The questionnaire consisted of two parts – A and B. Part A consisted of requesting respondent's personal information (e.g. work experience, position in company) and company information (e.g. type of organization, types of construction works performed, years in business, annual volume of work, number of employees).

Part B consisted of a comprehensive skill set which was prepared after extensive literature review and a preliminary survey from industry experts. Literature review was done through books, conference proceedings, internet, and leading construction management and engineering journals (in particular: Baharudin, 2006; Egbu, 1999; Young, 1989). The preliminary survey was done to identify the key positions and duties that graduating construction management students assume in the industry as undergraduate and graduate level employees. This survey was targeted to two corporate managers of construction firms and three senior project managers, all responsible for hiring construction management personnel in their organizations/ projects. The formulated skill set, consisting of 80 skills, was categorized in a number of skill sub-sets, viz.; 1) personal attributes; 2) professional attributes; 3) technical skills; 4) managerial skills; 5) industry/ business skills; 6) people skills; and 7) legal/ contractual skills. The respondents were asked to evaluate the importance of the skills with 1 as the least degree of importance and 5 as the highest degree of importance.

Following the survey, few unstructured interviews with selected respondents were conducted to clarify their responses and to discuss the survey results. Based on the gathered information, descriptive analysis was performed and the results compiled.

4. ANALYSIS OF RESULTS AND DISCUSSION

4.1. Questionnaire Response Rate and Respondent Profile

The survey was forwarded to 36 members of the construction industry and 18 members of the education sector – with majority in the South Central and South East regions of the U.S. The response was excellent with all but 2 industry members responding; the overall survey count was 54 surveys sent out with 52 responses.

32 of the 34 respondents from industry (i.e. 95%) have remained involved with hiring for their organizations. This is important as the respondents provide insight into the reviewing process (qualification, specialized skill sets, etc.), and in determining what distinguishing factors they are looking for in potential job candidates.

The 18 educators that responded averaged approximately twenty years of teaching experience and 75% of the respondents noted approximately ten years of industry

experience. Most of the respondents were from programs in the South Central part of the United States with few coming from the South East and South West.

4.2. Skill Analysis

4.2.1. Key Skills for Graduating Construction Management Students as Perceived by the Industry

The industry respondents were requested to evaluate 80 skills, categorized in five skill sets, deemed significant for undergraduate and graduate level employees. The respondents were asked to assess the significance of each skill on a five-point scale. The mean level of significance for each skill (based on the scale rating of industry responses) was calculated to obtain the importance index for each skill. For the undergraduate and graduate level employments, the most important skills identified, from highest to lowest, as perceived by the industry, are as given in Tables 1 and 2 respectively. These tables also show the mean level of significance for these skills.

4.2.2. Key Skills for Graduating Construction Management Students as Perceived by the Educators

The same skill set was adopted to gather responses from the educators. For the undergraduate and graduate level employments, the most important skills identified, from highest to lowest, as perceived by the educators, are as given in Tables 3 and 4 respectively. These tables also show the mean level of significance for these skills.

Table 1. Skill Rating for Undergraduate Level Employment – Industry Perspective

Rank	Skill/ Attribute	Skill/ Attribute Category	Mean level of significance (on a scale of 5)
1	Knowledge of health and safety regulations	Industry & Business Skill	4.84
2	Interpreting contract documents	Legal & Contractual Skill	4.73
3	Listening ability/ Giving attention to details	Personal Attribute	4.65
4	Knowledge of building codes & regulations	Industry & Business Skill	4.62
5	Time Management	Personal Attribute	4.58
6	Scheduling	Technical Skill	4.54
7	Plans interpretation/ Blueprint reading/ Understanding shop drawings	Technical Skill	4.54
8	Knowledge of construction law and legal environment	Legal & Contractual Skill	4.52
9	Hands-on project experience prior to graduation/ Internship	Professional Attribute	4.48
10	Knowledge of construction operations	Technical Skill	4.48
11	Trade Coordination	People Skill	4.48
12	Communication – Verbal and Written	People Skill	4.47

Table 2. Skill Rating for Graduate Level Employment – Industry Perspective

Rank	Skill/ Attribute	Skill/ Attribute Category	Mean level of significance (on a scale of 5)
1	Knowledge of health and safety regulations	Industry & Business Skill	4.87
2	Interpreting contract documents	Legal & Contractual Skill	4.78
3	Knowledge of construction law and legal environment	Legal & Contractual Skill	4.68
4	Knowledge of building codes & regulations	Industry & Business Skill	4.60
5	Construction accounting	Technical Skill	4.59
6	Personnel/ Resource management	Managerial Skill	4.58
7	Contract Negotiations/ Conflict Resolution	People Skill	4.58
8	Communication – Verbal and Written	People Skill	4.56
9	Leadership/ Decision Making	Managerial Skill/ Professional Attribute	4.50
10	Value engineering / Constructability analysis/ Design Review	Technical Skill	4.48
11	Risk Planning, Assessment and Control	Managerial Skill	4.48
12	Marketing with clients/ Developing client relations	Industry & Business Skill	4.46

Table 3. Skill Rating for Undergraduate Level Employment – Educator Perspective

Rank	Skill/ Attribute	Skill/ Attribute Category	Mean level of significance (on a scale of 5)
1	Knowledge of health and safety regulations	Industry & Business Skill	4.91
2	Knowledge of construction operations	Technical Skill	4.88
3	Scheduling	Technical Skill	4.73
4	Communication	People Skill	4.72
5	Plans interpretation/ Blueprint reading/ Understanding shop drawings	Technical Skill	4.68
6	Interpreting contract documents	Legal & Contractual Skill	4.62
7	Knowledge of building codes & regulations	Legal & Contractual Skill	4.60
8	Teamwork/ Collaboration/ Managing relationships/ Networking	Professional Attribute/ People Skill	4.56
9	Proficiency in construction information technology/ software	Technical Skill	4.52
10	Hands-on project experience prior to graduation/ Internship	Professional Attribute	4.50
11	Knowledge of construction law and legal environment	Legal & Contractual Skill	4.50
12	Problem solving/ Analytical skills	Professional Attribute	4.48

4.2.3. Key Skills for Graduating Construction Management Students - Comparative Analysis

Table 5 shows a collective ranking of skills deemed most important for undergraduate and graduate level employment positions as perceived by the industry, educators and overall (average) respondents. Note that a weighted average approach has been adopted to get the overall response ranking.

The skills noted for the undergraduate level are all necessary for a proper start in the construction industry. Of the skills noted for the graduate level, most show how the industry views advancement for the construction management professional. An important consideration for graduate level skills is that some of these candidates are already active in their profession within the industry by the time they begin seeking their master's degree and their work experience will be very valuable towards their progress in some of these skill areas. Hence the skills, indicated by the industry members and educators, at the graduate level, are more focused on management with the areas of law, accounting, personnel management, negotiation and the like. These are more in line with someone whose career has brought them further into middle to upper management as compared to those noted for the undergraduate.

The compilation of survey responses (Table 5) shows, to a large extent, consensus between industry and educator perspectives as to the key skills required from today's graduating construction management students. However, some skills do reveal differences of opinion for importance level between the two respondent types. The major similarities and differences in perspectives are discussed below.

Key Skills Common to Undergraduate and Graduate Level Employments and Extent of Agreement between Industry and Educators

The skill with the highest mean level of significance for both undergraduate and graduate level employment is the knowledge of health and safety regulations. There is complete consensus in both groups as to the level of significance of this skill. This feedback can prove positive for the academicians in terms of the possibility of allocating more class time to educating safety policies, procedures and safety implementation issues such as Occupational Safety and Health Administration (OSHA) regulations, safety management programs, inspections and audits.

Table 4. Skill Rating for Graduate Level Employment – Educator Perspective

Rank	Skill/ Attribute	Skill/ Attribute Category	Mean level of significance (on a scale of 5)
1	Knowledge of health and safety regulations	Industry & Business Skill	4.93
2	Knowledge of construction law & legal environment	Legal & Contractual Skill	4.87
3	Personnel/ Resource management	Managerial Skill	4.74
4	Interpreting contract documents	Legal & Contractual Skill	4.72
5	Knowledge of building codes and regulations	Legal & Contractual Skill	4.68
6	Communication – Verbal and Written	People Skill	4.65
7	Teamwork/ Collaboration/ Managing relationships/ Networking	Professional Attribute/ People Skill	4.60
8	Leadership/ Decision making	Managerial Skill/ Professional Attribute	4.58
9	Risk Planning, Assessment and Control	Managerial Skill	4.54
10	Financial Management	Managerial Skill	4.50
11	Marketing with clients/ Developing client relations	Technical Skill	4.48
12	Proficiency in construction software/ IT	Industry & Business Skill	4.48

Table 5. Key Skills for Graduating Construction Management Students - Comparative Analysis

Skill/ Attribute	Undergraduate Employment			Graduate Employment		
	Rank			Rank		
	Average	Industry	Educators	Average	Industry	Education
Knowledge of health and safety regulations	1	1	1	1	1	1
Interpreting contract documents	2	2	6	2	2	4
Knowledge of construction operations	3	10	2	Not in Top 15	Not in Top 15	Not in Top 15
Knowledge of building codes and regulations	4	4	7	5	4	5
Scheduling	5	6	3	Not in Top 15	Not in Top 15	Not in Top 15
Plans interpretation/ Blueprint reading/ Understanding construction and shop drawings	6	7	5	Not in Top 15	Not in Top 15	Not in Top 15
Communication – Verbal and Written	7	12	4	6	8	6
Listening ability/ Giving attention to details	8	3	14	Not in Top 15	Not in Top 15	Not in Top 15
Time Management	9	5	13	Not in Top 15	Not in Top 15	Not in Top 15
Knowledge of construction law & legal environment	10	8	11	3	3	2
Teamwork/ Collaboration/ Managing relationships/ Networking	11	13	8	8	13	7
Hands-on project experience prior to graduation/ Internship	12	9	10	Not in Top 15	Not in Top 15	Not in Top 15
Problem solving/ Analytical skills	13	14	12	Not in Top 15	Not in Top 15	Not in Top 15
Trade Coordination	14	11	15	Not in Top 15	Not in Top 15	Not in Top 15
Proficiency in construction software/ IT	15	15	9	14	15	11
Construction accounting	Not in Top 15	Not in Top 15	Not in Top 15	12	5	14
Personnel/ Resource management	Not in Top 15	Not in Top 15	Not in Top 15	4	6	3
Contract Negotiations/ Conflict Resolution	Not in Top 15	Not in Top 15	Not in Top 15	15	7	15
Leadership/ Decision Making	Not in Top 15	Not in Top 15	Not in Top 15	7	9	8
Value engineering / Constructability/ Design Review	Not in Top 15	Not in Top 15	Not in Top 15	11	10	13
Risk Planning, Assessment and Control	Not in Top 15	Not in Top 15	Not in Top 15	9	11	9
Marketing with clients/ Developing client relations	Not in Top 15	Not in Top 15	Not in Top 15	10	12	12
Financial Management	Not in Top 15	Not in Top 15	Not in Top 15	13	14	10

A very high priority is placed by the industry on the ability of an individual (undergraduate and graduate) to interpret contract documents. This is much in line with the fact that the construction industry is build around contracts. A useful employee should be able to read and interpret contract documents in order to be a productive member and this ability is required at entry level and improves as tenure in the industry is maintained. Educators, however, emphasize significance of this skill to a slightly lesser extent. This perspective difference may accentuate a need for strategic assessment of current curriculums to bridge the gaps, if any.

Knowledge of building codes and regulations, and knowledge of construction law and legal environment have been unanimously considered to be a key skill for both undergraduate and graduate level employment positions (these skills are deemed more important for graduates than for undergraduates). This is quite understandable keeping in view the compliance requirements, claims, dispute resolution issues and legal bindings in the construction industry. The difference in perspectives of both groups with respect to the importance level of these skills is not significant.

Construction is an industry built on relationships and this is shown through the next set of recommended professional and people skills: communication – verbal and written, teamwork, collaboration, managing relationships and networking. As noted by the industry and educator respondents, all above are essential requirements for a positive employment situation in the industry, both for undergraduates and graduates. The construction management professional has to be able to motivate personnel, negotiate with owners, suppliers and subcontractors, and alleviate tensions between parties in order to maintain progression of projects as needed. He/ she must be able to effectively deal with members of the local authority such as building inspectors and plans examiners in order to receive timely inspections and permitting. Also, he/ she must be able to communicate and collaborate at a professional level with members of the design team and this also requires ability to interpret contract documents.

Proficiency in construction information technology/ technology is indeed essential in today's fast paced construction market, where deliverables need to be submitted on fast track basis. Hence, imparting this skill should form a core part of construction management curriculums nationwide. The educators seem to provide greater significance to it as compared to the industry.

Key Skills for Undergraduate Level Employment and Extent of Agreement between Industry and Educators

Knowledge of construction operations, scheduling, and plans interpretation are considered to be key technical skills for undergraduate level employment. Educators place slightly more importance to knowledge of construction operations as compared to the industry itself. For scheduling and plans interpretation skills, the difference in perspective between industry and educators as to the level of importance is not substantially significant.

Listening ability, giving attention to details, time management, problem solving, and analytical skills are all considered to be significant personal and professional traits for undergraduate level employment. The educators, however, place listening ability and time management skills at a much lower level of significance. This is an important finding and these perspective differences may emphasize a need for strategic improvement of current curriculums to bridge the gaps, if any.

Internship/ Capstone project has been unanimously considered to be a key requirement for undergraduate level employees. While some construction management programs do not see the need of intern programs or only encourage them to their students, most have made it a necessary requirement of graduation. Some place a very high priority on internship and consider the practical application of the knowledge learned in class a key component of the student's education process.

Construction accounting, personnel management, contract negotiations, conflict resolution, leadership, decision making, value engineering, constructability analysis, design review, risk planning, assessment and control, marketing with clients/ developing client relations and financial management are all considered to be less significant skills for entry-level (undergraduate) employment in the industry. This is understandable keeping in view that all above mentioned skills are more importantly required by employees in the middle and upper management levels and hence are more desirable skills for graduate level employees.

Key Skills for Graduate Level Employment and Extent of Agreement between Industry and Educators

Construction accounting, value engineering, constructability analysis and design review are deemed to be significant technical skills for graduate level employment. Educators, however, place comparatively lesser significance to these skills. This is, in particular, true for construction accounting. Strategic insight into current construction management curriculums is essential to bridge the gap, if any.

Personnel management, leadership, decision making, risk planning, assessment and control, and financial management are all deemed to be significant managerial skills for graduate level employment. Apparently, the educators seem to place much high emphasis on all these managerial. This, however, does not necessarily reflect that the current curriculums are focused as such.

Contract negotiations, conflict resolution, and marketing with clients are all deemed to be significant skills for graduate level employment. An important finding is that the educators place much less emphasis on contract negotiations and conflict resolution skills as compared to the industry. This infers that strategic insight into current construction management curriculums is essential to bridge the gap, if any.

5. CONCLUSIONS AND RECOMMENDATIONS

The skills noted for the undergraduate level are all necessary for a proper start in the construction industry, while the skills noted for the graduate level are more focused

on management with the areas of law, accounting, personnel management, negotiation and the like. These skills are more in line with careers into middle to upper management levels as compared to those noted for the undergraduate.

Although agreement exists between industry and academia for the following skills as being key skills, the level of emphasis placed by the educators on these skills is not the same as that placed by the industry. These skills include: interpreting contract documents (a common skill for both undergraduate and graduate level employment), listening ability/ giving attention to details (significant for undergraduate level employment), time management (significant for undergraduate level employment), construction accounting (significant for graduate level employment), value engineering/ constructability analysis/ design review (significant for graduate level employment), and contract negotiations/ conflict resolution (significant for graduate level employment). All above identify areas that may require strategic curriculum improvement. Hence it is recommended that an insight into current construction management curriculums need to be made in order to assess whether there are presently any gaps and, if identified, curriculum improvement may be initiated.

Construction management education programs and the construction industry are both connected to the lifeline of the industry's need for future leaders. The construction industry needs the construction management programs to not only provide an adequate number of candidates, but also properly train its future leaders in the skills required in order to quickly become productive workers within their organizations. The construction management education programs need the construction industry to provide support and input to improve the future construction manager's education and experience level before entry into the construction industry workforce. With construction having such a wide array of opportunity to graduates, it is hard to confine the education to specific areas. Therefore, educators must work to keep their programs meeting the requirements set forth by the industry, offering the widest array of opportunity to its graduates and still meet the accreditation requirements. Along with these restraints come the areas of time, money and faculty. There is only so much time allotted to provide the best education available and prepare students to meet the goals of entering the construction workforce. Also, all programs within a university are vying for every available dollar and some programs have taken note of the fact that support from industry and alumni can overcome the university shortcomings. Hence a collaborative effort to strategically assess, support and improve construction management curriculums is highly recommended.

REFERENCES

Baharudin, Khairul S. B. (2006). Construction Management Skills for the Global Market (News Article)

Egbu, Charles O. (1999). "Skills, knowledge and competencies for managing construction refurbishment works," Construction Management and Economics, Taylor and Francis Journals, 17(1), 29-43.

Young, Barbara A. (1989). Management Skills and Knowledge: A Case Example from the Construction Industry, Journal: Leadership & Organization Development Journal, 10 (6), 3-9.

RESEARCH VALIDATION IN THE CONSTRUCTION DOMAIN

Gunnar Lucko[1], Ph.D. and Eddy M. Rojas[2], Ph.D.

[1] Assistant Professor of Civil Engineering and Director of Construction Engineering and Management Program, Department of Civil Engineering, The Catholic University of America, 620 Michigan Avenue NE, Washington, DC 20064
PH (202) 319-4381; FAX (202) 319-6677; e-mail: lucko@cua.edu
[2] Associate Professor and Executive Director, Pacific Northwest Center for Construction Research and Education, Department of Construction Management, University of Washington, 130G Architecture Hall, Box 351610, Seattle, WA 98195
PH (206) 616-1917; FAX (206) 685-1976; e-mail: er@u.washington.edu

ABSTRACT

Validation of the research methodology and its results is a fundamental element of the process of scholarly endeavor. Construction engineering and management research has various methodological approaches, including surveys and observational studies, modeling and simulation, experiments, theory building, case studies, and other types. All of them required validation. This paper reviews techniques for internal, external, and face validation, illustrates them with examples from construction research, analyzes their challenges, and presents how they were successfully overcome to provide readers with recommendations to properly validate their own research efforts. It thus increases the awareness of the paramount role of validation in scholarly work.

INTRODUCTION

Construction engineering and management research examines real-world means and methods to improve their effectiveness and efficiency. It is essential for any scientific enquiry that researchers ensure the quality of their work with appropriate validation techniques in every step of its methodology, including data collection, analysis, and interpretation of results. The researchers must convincingly and clearly communicate the validity of each of these steps to the academic and the professional communities for them to accept the new knowledge. Only then can the research filter down to daily practice in the field, become a stepping stone toward advancing the state-of-the-art of the construction industry, and ultimately contribute to the overall welfare of society.

It is important to understand the difference between validation and verification before defining the different validity types. *Verification* establishes the technical correctness of a research product and is often performed internally by the researcher, who thoroughly checks all components and values akin to proof-reading. Errors that should be identified and eliminated can range from trivial and innocuous deviations to essential and destructive divergences. Examples are transposition errors in numerical data, transcription errors in survey answers, misconnections of schedule activities, 'bugs' in computer code, and omitted or doubled components. *Validation* is the more elusive one of the two concepts, as verification is primarily a comparison of measurable performance parameters. Generally speaking, verification is concerned with 'doing things right,' while validation is concerned with 'doing the right things.'

The process of validation can be broadly divided into two main areas: establishing internal and external validity. *Internal validity* is related to the concept of causality and is preoccupied with the derivability of relations within data (Leedy and Ormrod 2001). *External validity* is related to the concept of induction and focuses on the generalizability of results for prediction purposes (Leedy and Ormrod 2001). Internal validity is impaired by biases in data collection that invalidate comparisons, ill-defined theoretical models that contain spurious relationships or correlated explanatory variables, and ignoring alternative explanations. True causality can only be established in a controlled laboratory environment, not in observational studies that can only identify correlation. External validity is threatened by lack of statistical rigor in selecting sample sizes and collecting data, special circumstances that may be present during the research efforts, and oversimplifying the phenomena under study.

Other types of validity that are commonly referred to in the literature include face validity, content validity, criterion validity, and construct validity. *Face validity* is a subjective, non-statistical judgment that seeks the opinion of non-researchers regarding the validity of a particular study (Leedy and Ormrod 2001). For example, a simulation model of an earthmoving operation can be said to have face validity if earthmoving experts looking at the model and its output agree that it represents to a high degree what happens in reality. In a practical field of study like construction engineering and management, the collaboration with appropriate representatives from the private and public sectors, e.g. industry practitioners, government agencies, and also the public at large, is important to secure the face validity of research endeavors.

Content validity is another non-statistical approach that focuses on whether the content of a study fairly represents reality. Its concern is "the degree to which a measure covers the range of meanings included within the concept" (Babbie 1990). For example, a study of stress levels of construction supervisors is said to have content validity if the included tasks, activities, events, and environmental factors can be considered to be representative of those that generally occur in the larger industry.

Criterion validity has been defined as "the extent to which the results of an assessment instrument correlate with another, presumably related measure (the latter is called the *criterion*)" (Babbie 1990). Criterion validity is thus established when the findings of a research study on a particular aspect of the construction industry, e.g. factors that influence craft productivity, agree in general with the outcomes of related studies that e.g. investigated training programs for skill development or motivational effects of working conditions, even though their detailed approaches may differ.

Construct validity refers to whether operationalizations of theoretical constructs are appropriate. In other words, it seeks to ensure that a research effort is measuring what it is supposed to measure according to its stated objectives (Leedy and Ormrod 2001). Studying the relationship between the motivation and productivity of construction workers is said to have construct validity only if its instruments actually measure motivation and productivity. While this may seem obvious, there are many 'abstract' constructs for which many definitions without universally accepted metrics exist, e.g. traits of the human behavior or psyche. Researchers must then justify how exactly their instruments and their conceptual contents were developed.

Finally, another term that is sometimes confused with validity is *reliability*. It is related to consistency and repeatability in the data collection. According to Neuman (2000), it "is necessary for validity and is easier to achieve than validity." Law (2000) stressed that validation always depends on the specific purpose of the research. El-Diraby and O'Connor (2004) asserted that "no single definition of the ingredients or subsets of the concept of validity" exists. Numerous authors discuss validity, yet each study uses a slightly different definition of the concept (e.g. Roschke 1994, Kamat and Martínez 2003). Sargent (1991) elaborated further that "currently no algorithms or procedures [are] available to identify specific validation techniques, statistical tests, etc., to use in the validation process." While validation is a challenge to all researchers, it thus is especially difficult for an interdisciplinary field such as construction engineering and management. This paper focuses on proven ways to achieving the highest levels of quality in internal, external, and face validity.

VALIDATION OF CONSTRUCTION RESEARCH

Given the interdisciplinary nature of construction engineering and management research and the inherent difficulties of performing studies in real-life settings, validation in the construction domain encounters various challenges. The following sections present illustrative examples of how such difficulties have been successfully overcome by construction researchers in order to deliver meaningful, valid outcomes.

Internal Validity

As mentioned, internal validity is related to causality. Establishing causality is a significant challenge for construction researchers, given that many studies are performed in real-life settings where multiple variables interact with one another, many of them uncontrollable or unpredictable. While laboratory experiments are less common in the construction engineering and management domain than in other areas, e.g. structural engineering, they represent the best strategy to study causality whenever possible. The tight control of environmental factors that is possible in a laboratory setting strongly establishes internal validity. Ideally, the laboratory study should be augmented with field trials under realistic conditions, as performed e.g. for examining flowable backfill materials for pipelines (Wu 2005).

Internal validity can also be achieved by techniques other than controlled laboratory trials. For example, researchers can use multiple regression analysis to isolate the effect of individual independent variables within a model (Montgomery *et al.* 2001). A necessary condition for being valid is that the results of multiple regression analysis must exhibit internal consistency reliability. Statistical resampling

techniques can be used to ascertain internal consistency reliability without the need to collect new data. Smaller samples are repeatedly taken from an existing dataset, provided sample size is sufficiently large. *Cross-validation* is a well-known technique that can test the stability of a model. The existing dataset is randomly split into two portions and the independent and dependent variables of the first one are used to estimate the model coefficients. The fitted model then makes predictions from the independent variables of the second portion, which are compared statistically with its actual dependent variables. Zayed and Halpin (2005) split their dataset of pile construction productivities into 70% estimation and 30% prediction portions. Lucko *et al.* (2006) used a 50% to 50% split after checking Snee's (1977) recommendation of having at least $n \geq 2 \cdot p + 25$ data points to allow splitting, where n is the sample size and p is the number of estimated parameters in the regression model. Menches and Hanna (2006, p. 1290) used "leave-one-out cross validation, [where] one case is left out of the data set, and the remaining n - 1 cases are used to construct the model" for their performance index for project managers, similar to the resampling technique *jackknifing*. Multiple cross-validations yielded a misclassification rate, which was desired to be less than 10%. Resampling is also employed in *bootstrapping*, named after "pulling oneself up by one's own bootstraps," i.e. with existing data. It assumes that the dataset is representative of the population. Numerous new datasets of the same sample size n are created from the existing dataset by repeated resampling with replacement. Different from validation, this technique estimates distributions for particular statistics of interest, e.g. the mean or median (Barton and Schruben 2001).

Researchers often attempt to define models based on statistical techniques for goodness-of-fit. While such techniques can be useful in building a functioning model, researchers must still ascertain that all explanatory variables are related to the dependent variable by some theoretical construct to ensure internal validity. Beyond correlation with the dependent variable, a clear and straightforward reason must exist why a variable belongs in a model. Otherwise, these variables may be spurious, i.e. seemingly related, but in truth both caused by another, hitherto hidden third variable.

External Validity

External validity is related to generalizability of results. Samples must be representative of the population to be generalizable. The most common way to ensure representativeness is to randomize the sampling procedure. In a survey study on leadership characteristics among construction employees, Ozorovskaja *et al.* (2007) randomly selected companies from listings in the yellow pages. This ensured that all listed companies had an equal chance of being included. Consequently, conclusions that were drawn from the sample could be generalized to that population. Other techniques are sometimes employed to support generalizability. Stratification deliberately divides the population into groups that shall be represented in the sample. Davis and Songer (2003) used "company size, industry sector, and profession, age, and gender" as strata in their mail survey on resistance to technological change to ensure that the proportions of the U.S. construction industry were reflected in their samples. However, conscious sampling alone is insufficient for external validity. The sample size also determines whether the inherent variability within the population has been captured to a sufficient extent. In cross-sectional studies, this variation occurs between data at the same time; in longitudinal studies the dataset varies across time.

Statistical equations provide guidance on necessary minimum sample sizes for research studies, beyond the obvious rule-of-thumb that more samples are always better, especially for very heterogeneous populations (Leedy and Ormrod 2001). This differs from the resolution or 'fineness' of the dataset, which depends on the desired level of detail of the research results. Lucko *et al.* (2006) evaluated the sample size n of their existing datasets of heavy equipment resale values using recommendations from the literature that included the number of explanatory variables k in the model, e.g. $n \geq 15 \cdot k$ for multiple linear regression, $n \geq 50 + 8 \cdot k$ for multiple correlation, and $n \geq 104 + k$ for testing explanatory variables. These guidelines consider the 'level of detail' of the model by counting its variables. The population size also should be considered in determining the sample size *a priori*. Gay *et al.* (2006) provided sample size percentages for ranges of population sizes based on earlier research that had assumed a statistical significance level $\alpha = 0.05$ (Krejcie and Morgan 1970):

- "The larger the population size, the smaller the percentage of the population required to get a representative sample.
- For smaller populations, say N = 100 or fewer, there is little point in sampling; survey the entire population.
- If the population size is around 500 (give or take 100), 50% of the population should be sampled.
- If the population size is around 1,500, 20% should be sampled.
- Beyond a certain point (about N = 5,000), the population size is almost irrelevant, and a sample size of 400 will be adequate."

Recommendations for sample sizes differ for continuous and discrete data (Bartlett *et al.* 2001). Since sample size is closely related to statistical properties, e.g. "the variance, the desired significance level, the power of hypothesis tests… and the widths of the confidence and prediction intervals" (Lucko *et al.* 2006), the writers recommend to confer with a statistician on the external validity of new research.

If data are not measured directly by researchers but rather are created by respondents through a measuring instrument, e.g. a survey questionnaire, the response rate becomes especially important. As the ratio of actually received responses divided by randomly selected and requested responses, it directly influences the sample size. Achieving a high response rate is a challenge that construction researchers often face. However, simple techniques can boost the response rate and – by extension – increase their external validity. Davis and Songer (2003) used a combination of techniques, starting with telephone and personal announcements of the survey followed by mailing "a cover letter introducing the research study, an informed consent form, and the questionnaire, along with an envelope in which to place the completed questionnaire to be either picked up later or mailed back… Follow-up phone calls and office/site visits were performed as reminders for unreturned surveys," which yielded a response rate of 58.4%. Other techniques can seek to increase the motivation of respondents, e.g. by promising an executive summary of the results (Ling 2002) or a small remuneration, gift, or prize lottery in exchange for completing the survey.

Research is by definition an incremental process. Researchers need to be aware of the extent to which their work expands the body of knowledge. Describing the scope and limitations of a study is as important as revealing its assumptions,

possible bias, and possible error sources. External, content, and face validity arise from the research being placed into its proper context while clearly acknowledging what it can accomplish versus what remains for future study. Rojas and Kell (2008) described the limitations of their empirical comparison of project delivery systems in terms of geographic area, industry sector, time frame, convenience sampling from existing government records, and how the sample size related to the Gaussian distribution assumption of the central limit theorem for performing statistical tests.

The most pertinent, and arguably also most difficult form of external and face validation that can be accomplished is the deployment and application of a new model, method, or technology into the ongoing industry practice, referred to as pilot testing or prototyping. Since the construction industry is known to adopt innovations only hesitantly (Davis and Songer 2003), this can present a formidable challenge. Examples of construction research that reported actual implementation are owner-contractor work structures (Anderson *et al.* 2004), change management (Price and Chahal 2006), and interactive, collaborative, and computer-supported teaching of estimating and scheduling concepts (Jaafari *et al.* 2001) in the educational domain.

Face Validity

Face validity entails the 'approval' of non-researchers regarding the validity of a study. Performing research under the harsh and rather unpredictable conditions of a construction site can generate face validity, provided that such environmental factors are measured, documented, and made part of the analysis. For example, Thomas *et al.* (1999) studied how weather influences labor productivity for steel erection projects in the field. Navon and Berkovich (2005) evaluated a new materials management system on a commercial building project, which also allowed a comparison with the existing approach. While a laboratory setting works well for certain studies, e.g. testing new materials, the aforementioned practice-oriented nature of construction research often makes such a real-life setting necessary. Even though this makes creating internal validity challenging, it goes a long way towards securing face validity. Arguably the strongest way to establish face validity is involving domain experts, or subject matter experts, before (*a priori*), during, after (*a posteriori*), or throughout the research. Such participation can range from an advisory capacity to active collaboration.

Another useful technique for establishing face validity is interviewing. El-Diraby and O'Connor (2004) conducted many structured interviews with government agencies and consultants for their bridge plans evaluation model. They deliberately sought a diverse group to attain a wide range of opinions. Considerations for conducting meaningful interviews are similar to those for surveys. Structured questions provide internal reliability. However, interviews allow a richer feedback, as the interviewer can clarify and extend individual items ad hoc in a semi-structured manner. An audio recording or at least detailed notes during or directly after the session is vital. An approval of research with human subjects is typically required.

"Focus groups are carefully planned discussions stimulated within a predefined group environment to obtain perceptions about a defined area of interest in a permissive, nonjudgmental environment" (Yu *et al.* 2006). More extensive than interviews, they include "interaction and self-disclosure among participants" and thus can lead to a consensus among experts (Yu *et al.* 2006). However, they need to be carefully moderated to not deviate into tangential conversations. Refining the

technique, Yu *et al.* (2006) created transcriptions of their sessions on critical success factors and performed a content analysis on them. The latter is described in detail in the literature of the social sciences, where diverse qualitative data are often handled.

The *Delphi analysis*, named after the ancient Greek oracle, is a validation technique that formalizes the collection of expert feedback. Its characterizing feature is that it undergoes at least two iterations. The first phase often collects data through a survey or interviews with experts, which are compiled by the researcher. In the second phase the same experts comment on the initial results, akin to 'peer reviewing' themselves. Del Cano and de la Cruz (2002) used Delphi analysis with interviews for validating their study of risk management and meticulously reported demographic information, e.g. the age, education, position, and experience with different project types of the interviewed experts as well as their company sizes and industry sectors.

The *Turing test* is still uncommon in the literature on construction research, but its application in artificial intelligence is well known: A user is asked to decide whether the anonymous 'conversation' partner is a human or a machine. Considered "the most widely used qualitative method for validating expert systems," Roschke (1994) noted that the 'blind' Turing test conceals the identity of the evaluators and thus reduces bias. For his expert system for selecting bridge rails, an expert reviewed fifteen field cases, sought to distinguish the computer-generated decision from those of two human experts, and established face validity via the expert's inability to do so.

A technique that is specifically applicable for face validation of discrete-event simulation (DES) computer models is scrutinizing its trace file (Sargent 1991), also known as event log, as to the sequence of events that the model developer expects. This automatically generated record contains times at which any state changes occur, i.e. activities changing between idle and active or resources being sent and received. Following the entries in the trace file for at least one complete run of the simulation and comparing them with a 'manual' execution of the model can reveal various types of errors, e.g. in links between model elements, start and finish conditions, and the consistency of time and resource units, as mentioned previously under verification.

Beyond checking the trace file for validation, it also has an important use as input for simulation post-processing. Visualization and animation can help users in intuitively spotting inconsistencies in the simulation that have eluded the developers (Kamat and Martínez 2003). For users to accept the model as a truthful representation of reality, its behavior must mirror their 'mental image.' Research was performed on both ends of the spectrum, from simple abstractions with animated of icons (Zhang *et al.* 2002) to almost photorealistic environments of construction operations (Kamat and Martínez 2003). A particular advantage of 4D visualization is that face validation of systems with complex logic can be achieved without the need for users to learn a new specific computer interface (Ioannou and Martínez 1996). However, González-Quevedo (1995) reminded that realism alone does not guarantee a 'good' model and that trivialities that obscure its abstract essence should be avoided. Recent research turned the previous one-way flow of data from simulation to visualization into a two-way interaction, whereby users can dynamically manipulate the model that underlies the visualization and observe the impact of changes (Rekapalli and Martínez 2007).

Construction research often creates face validity through case studies, meaning the discussion of a self-contained, detailed example application of a new

model or method. The issues surrounding the assumptions, scope, limitations, and resolution of the case study are similar to those encountered in modeling. The challenge of striking a balance between realism and abstraction as well as between inclusiveness and manageability becomes a matter of parsimony, applying 'Occam's razor,' the principle of being "as simple as possible (but as complicated as necessary)" Addressing this issue, Karam *et al.* (2007) used a case study of a 2 km long tunnel in Korea to illustrate and validate their computer tool for decision-making for tunnel construction. Rojas and Dossick (2008) presented a comprehensive case study of an integrated construction research and education center that exemplified their experiential learning and interdisciplinary research approaches. Different from their use in research validation, case studies can also be found in the form of scholarly reports on innovations in construction engineering and management practice, e.g. on physically moving an existing concrete building with hydraulics (Telem *et al.* 2006).

CONCLUSION

Validation of the research methodology and its results is a fundamental element of the process of scholarly endeavor. Construction engineering and management research has various methodological approaches, including surveys and observational studies, modeling and simulation, experiments, theory building, case studies, and other types. All of them required validation. This paper reviewed techniques for internal, external, and face validation, illustrated them with examples from construction research, analyzes their challenges, and presented how they were successfully overcome to provide readers with recommendations to properly validate their own research efforts. It thus increased the awareness of the paramount role of validation in scholarly work.

REFERENCES

Anderson, S. D., Patil, S. S., Gibson, G. E., Sullivan, G. R. (2004). "Owner-contractor work structures: Process approach." *Journal of Construction Engineering and Management* 130(5): 680-690.

Babbie, E. (1990). *Survey research methods*. Wadsworth Publishing Company, Belmont, California.

Bartlett, J. E., Kotrlik, J. W., Higgins, C. C. (2001). "Organizational research: Determining appropriate sample size in survey research." *Information Technology, Learning, and Performance Journal* 19(1): 43-50.

Barton, R. R., Schruben, L. W. (2001). "Resampling methods for input modeling." Proceedings of the 2001 Winter Simulation Conference, eds. Peters, B. A., Smith, J. S., Medeiros, D. J., Rohrer, M. W., Arlington, Virginia, December 9-12, 2001, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey: 372-378.

Davis, K. A., Songer, A. D. (2003). "Individuals' resistance to technological change in the AEC industry." *Proceedings of the 2003 Construction Research Congress*, eds. Molenaar, K. R., Chinowsky, P. S., Honolulu, Hawaii, March 19-21, 2003, American Society of Civil Engineers, Reston, Virginia: 8p.

del Cano, A., de la Cruz, M. P. (2002). "Integrated methodology for project risk management." *Journal of Construction Engineering and Management* 128(6): 473-485.

El-Diraby, T. E., O'Connor, J. T. (2004). "Lessons learned in designing research methodology in field-based construction research." *Journal of Professional Issues in Engineering Education and Practice* 130(2): 109-114.

Gay, L. R., Mills, G. E, Ariasian, P. (2006). *Educational research: Competencies for analysis and applications.* 8th ed., Pearson Prentice Hall, Upper Saddle River, New Jersey.

González-Quevedo, A. A. (1995). "Sensitivity analysis of construction simulation." *Proceedings of the Second Congress on Computing in Civil Engineering*, eds. Mohsen, J. P., Atlanta, Georgia, June 5-9, 1995, American Society of Civil Engineers, New York, New York: 1427-1434.

Ioannou, P. G., Martínez, J. C. (1996). "Animation of complex construction simulation models." *Proceedings of the Third Congress on Computing in Civil Engineering*, eds. Vanegas, J. A., Chinowsky, P. S., Anaheim, California, June 17-19, 1996, American Society of Civil Engineers, Reston, Virginia: 620-626.

Jaafari, A., Manivong, K. K., Chaaya, M. (2001). "VIRCON: Interactive system for teaching construction management." *Journal of Construction Engineering and Management* 127(1): 66-75.

Kamat, V. R., Martínez, J. C. (2003). "Interactive Discrete-Event Simulation of Construction Processes in Dynamic Immersive 3D Virtual Worlds." *Proceedings of the 2003 Conference on Construction Applications of Virtual Reality*, eds. Thabet, W. Y., Bowman, D. A., Blacksburg, Virginia, September 24-26, 2003, Virginia Polytechnic Institute and State University, Blacksburg, Virginia: 197-201.

Karam, K. S., Karam, J. S., Einstein, H. H. (2007). "Decision analysis applied to tunnel exploration planning. I: Principles and case study." *Journal of Construction Engineering and Management* 133(5): 344–353.

Krejcie, R. V., Morgan, D. W. (1970). "Determining sample size for research activities." *Educational and Psychological Measurement* 30: 607-610.

Law, A. M. (2007). *Simulation Modeling and Analysis.* 4th ed., McGraw-Hill, New York, New York.

Leedy, P. D., Ormrod, J. E. (2001). *Practical Research Planning and Design.* 7th ed., Merrill / Prentice-Hall, Upper Saddle River, New Jersey.

Ling, Y. Y. (2002). "Model for predicting performance of architects and engineers." *Journal of Construction Engineering and Management* 128(5): 446-455.

Lucko, G., Anderson-Cook, C. M., Vorster, M. C. (2006). "Statistical considerations for predicting residual value of heavy equipment." *Journal of Construction Engineering and Management* 132(7), 723-732.

Menches, C. L., Hanna, A. S. (2006). "Quantitative measurement of successful performance from the project manager's perspective." *Journal of Construction Engineering and Management*, 132(12): 1284-1293.

Montgomery, D. C., Peck, E. A., Vining, G. G. (2001). *Introduction to linear regression analysis*. 3rd ed., John Wiley & Sons, New York, New York.

Navon, R., Berkovich, O. (2005). "Development and on-site evaluation of an automated materials management and control model. *Journal of Construction Engineering and Management* 131(12): 1328-1336.

Neuman, W. L. (2000). *Social research methods: Qualitative and quantitative approaches*. 4th ed., Allyn and Bacon, Boston, Massachusetts.

Ozorovskaja, R., Voordijk, J. T., Wilderom, C. P. M. (2007). "Leadership and cultures of Lithuanian and Dutch construction firms." *Journal of Construction Engineering and Management* 133(11): 900-911.

Price, A. D. F., Chahal, K. (2006). "A strategic framework for change management." *Construction Management and Economics* 24(3): 237-251.

Rekapalli, P. V., Martínez, J. C. (2007). "A message-based architecture to enable runtime user interaction on concurrent simulation-animations of construction operations." *Proceedings of the 2007 Winter Simulation Conference*, eds. Henderson, S. G., Biller, B., Hsieh, M.-H., Shortle, J., Tew, J. D., Barton, R. R., Washington, District of Columbia, December 9-12, 2007, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey: 2028-2031

Rojas, E. M., Dossick, C. S. (2008). "Developing a state-of-the-art facility to support construction research and education: A case study." *Journal of Professional Issues in Engineering Education and Practice*, ASCE, 134 (1), 67-74.

Rojas, E. M., Kell, I. (2008). "Comparative analysis of project delivery systems cost performance in Pacific Northwest public schools." *Journal of Construction Engineering and Management* 134(6): 387-397.

Roschke, P. N. (1994). "Validation of knowledge-based system with multiple bridge rail experts." *Journal of Transportation Engineering* 120(5): 787-806.

Sargent, R. G. (1991). "Simulation model verification and validation." *Proceedings of the 1991 Winter Simulation Conference*, eds. Kelton, W. D., Clark, G. M., Nelson, B. L., Phoenix, Arizona, December 8-11, 1991, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey: 37-47.

Snee, R. D. (1977). "Validation of regression models: Methods and examples." *Technometrics*, 19(4): 415-428.

Telem, D., Shapira, A., Goren, Y. D., Schexnayder, C. J. (2006). "Moving a reinforced-concrete building: case study." *Journal of Construction Engineering and Management* 132(2): 115-124.

Thomas, H. R., Riley, D. R., Sanvido, V. E. (1999). "Loss of labor productivity due to delivery methods and weather." *Journal of Construction Engineering and Management* 125(1): 39-46.

Wu, J. Y. (2005). "Soil-based flowable fill for pipeline construction." Proceedings of the 2005 Pipeline Division Specialty Conference, eds. Vipulanandan, C., Ortega, R. Houston, Texas, August 21-24, 2005, American Society of Civil Engineers, Reston, Virginia: 925-938.

Yu, A. T. W., Shen, Q., Kelly, J., Hunter, K. (2006). "Investigation of critical success factors in construction project briefing by way of content analysis." *Journal of Construction Engineering and Management* 132(11): 1178-1186.

Zayed, T. M., Halpin, D. W. (2005). "Pile construction productivity assessment." *Journal of Construction Engineering and Management* 131(6): 705-714.

Zhang, H., Shi, J. J., Tam, C. M. (2002). "Iconic animation for activity-based construction simulation." *Journal of Computing in Civil Engineering* 16(3): 157-164.

RESEARCH METHODS ASSOCIATED WITH SITUATIONAL SIMULATIONS IN CONSTRUCTION

Amlan Mukherjee, [1] Nilufer Onder[2] and Eddy M. Rojas[3]

[1]Assistant Professor, Department of Civil and Environmental Engineering, Michigan Tech, Houghton, MI 49931; email: amukherj@mtu.edu
[2]Associate Professor, Department of Computer Science, Michigan Tech, Houghton, MI 49931; email: nilufer@mtu.edu
[3]Associate Professor, Department of Construction Management, University of Washington, Seattle, WA 98195; email: er@u.washington.edu

Abstract:

Situational simulations create temporally dynamic clinical exercises of construction project scenarios that expose participants to rapidly unfolding events and the pressures of decision-making. They further construction research and education, by providing an interactive simulation platform that can be used to explore "what-if" construction scenarios, estimate risks and contingencies, test alternative plans during construction, and support the capture and analysis of real-time project data to support expert decision-making. The design, development, and use of situational simulations calls upon an inter-disciplinary approach which includes methodologies that are rooted in modeling of discrete event systems, intelligent planning, statistical data mining and cognitive psychology. We trace the development of two related situational simulation systems, the Virtual Coach and the Interactive Construction Decision-Making Aid (ICDMA) that have been developed by research groups at University of Washington and Michigan Tech. with technical support from industry. Over the last five years, the simulations have significantly evolved in their abilities to represent and reason about construction projects, as tools that enhance construction education and as experimental test beds that can be used to study construction decision-making. The research efforts have resulted in different aspects of this research to be funded by two funding agencies.

Introduction

Situational simulations are dynamic, interactive, context-sensitive, adaptive environments. They simulate construction project scenarios in keeping with rules that govern the construction management (CM) domain in general, and the project being simulated in particular. In such an environment, participants are exposed to diverse project management scenarios and situations that rapidly unfold in time. They can

react to these scenarios by making strategic decisions involving resource and activity scheduling, with the goal of completing the project at hand within schedule and under budget. The simulation allows them to explore "what-if" scenarios to test implications of their decisions in a safe environment, without the fear of incurring any real losses. In brief, construction situational simulations are akin to first-person construction manager strategy games. The participants of situational simulations come from both academia and industry, carrying diverse goals including education of construction managers as well as the interactive planning and management of construction projects.

The goals of developing CM situational simulations are: (i) provide undergraduate students with realistic, interactive learning environments that integrate related concepts, (ii) create interactive contingency planners that can be used to manage complex construction projects, and (iii) formally study dynamic decision-making under uncertainty in CM crisis scenarios. This research is motivated by the growing demand for qualified construction managers, and the need to improve planning in CM using advances in computing and simulations.

The genesis of situational simulations happened at the University of Washington. The first version was called Virtual Coach - a simulation of a simple eight-activity hypothetical construction project. The implementation had two goals: (i) illustrate the ability of developed models to represent and reason about CM information in a general-purpose simulation platform and (ii) illustrate the ability of situational simulations to improve construction management education. The next version, the Interactive Construction Decision-Making Aid (ICDMA), was implemented at Michigan Tech. using an improved constraint network representation and reasoning method. It simulated the construction of a real four-storey steel framed office building. The goals of this implementation were: (i) illustrate the general ability to simulate real construction projects and (ii) illustrate the use of situational simulations for construction planning. Currently a third version is being developed in a collaborative effort between University of Washington and Michigan Tech. This implementation combines the advances made with Virtual Coach and ICDMA, and also provides the ability to formally capture and analyze human decision-making data using the simulation. The goals of this implementation are: (i) rigorously deploy the simulation across multiple construction management classrooms in partner schools to assess undergraduate educational outcomes of using complex situational simulations, (ii) gain insight into decision-making in dynamic uncertain environments using situational simulation environments as experimental test beds to gather and analyze human decision-making data, and (iii) develop and test a significantly improved interface capable of efficiently visualizing construction management information.

The design, development, and use of situational simulations calls upon an inter-disciplinary approach which includes methodologies that are rooted in modeling of discrete event systems, intelligent planning, statistical data mining, and education. In addition, it requires a commitment from the construction industry to participate in experiments and provide access to construction project data. In this paper, we discuss ongoing and completed research in situational simulations, with a focus on the methodological questions that have been addressed in the process of modeling the CM domain, implementing and testing the interactive simulations as platforms for research and education. The paper is divided into four parts. The first part places this

research within the context of CM simulations and explains the underlying conceptual foundations. The second part defines the formal mathematical models driving the simulation. The third part explains the pragmatics of the design and implementation of situational simulation to generate general-purpose construction simulation environments. The final part discusses current and future applications of situational simulations in studying CM planning, CM decision-making, and furthering construction education.

Conceptual Foundation of Situational Simulations

Construction simulations can be classified using different approaches. One approach is whether they are simulating CM processes or construction operations. Simphony (Hajjar and AbouRizk 1999) and STROBOSCOPE (Martinez and Ioannou 1999) are examples of simulations that deal with construction operations such as tunneling and earthmoving. The second approach is based on whether they are of a special purpose or a general purpose in nature. Special purpose simulations are restricted in scope to a particular operation like tunneling or a particular management process like bidding, while general-purpose simulations allow for greater flexibility of scope since they are programmable. A survey of current research indicates that the general focus of simulation research as been in developing general purpose and special purpose simulation of construction operations (STROBOSCOPE and Simphony). There are few efforts at developing general-purpose simulation platforms of CM processes. This research has moved towards the development of a general-purpose framework (GPF) for an interactive situational simulation platform for CM processes.

Rojas and Mukherjee (2006) discuss the conceptual foundations of the GPF based on a classification of the preconstruction and construction phase processes into specific classes of problems. During the preconstruction phase, the problem at hand is that of creating a resource-loaded activity schedule, also referred to as the "As-Planned" schedule. This is classified as a constraint satisfaction problem (CSP). During the construction phase, managers face the challenge of completing the project while dynamically making critical decisions that satisfy the constraints encoded in the As-Planned schedule by reallocating resources, rescheduling activities, and making time-cost trade-offs. Hence, the manager's job during the construction phase is akin to a contingency planning problem In summary, the conceptual foundation of situational simulations is based on the abstraction of the CM domain to a planning problem during the project implementation phase, and a constraint satisfaction problem during the pre-construction phase. In the next section we discuss the development of a formal approach used to develop and implement the GPF that reflects the conceptual foundations discussed in this section.

Formal Foundation of Situational Simulations

The GPF is built using a "language" that represents and reasons about activities, actions, and events in the CM domain. The semantics of such a general representation are used to represent and reason about scenarios in the CM domain as a combination of constraint satisfaction problem within a dynamic partial-observability planning system. In addition, situational simulations use an underlying mathematical model that is used to update the productivity and cost in the simulated construction project as it progresses from simulation day to day.

Representation and Reasoning Model: Based on the axioms of time, using First Order Logic, a formal language was developed that allowed expressive representation and reasoning of CM information (Rojas and Mukherjee 2005a). The entire simulation environment is represented as a set of variables that take values from continuous or discrete ranges. Each such variable is attached to an interval of time, which specifies the interval over which the value of the variable is valid. A change in the status of one or more variables represents a situation when an event has occurred. This temporal representation of the construction environment as a combination of variables is used to reason about complex construction scenarios.

For example, consider the narrative: In the event of a labor strike of duration denoted by the time interval *t*, productivity for all activities is reduced to *0* due to a *0%* availability of labor. Formally, we represent productivity by the variable *prod* and labor by the variable *labor*. In the event of a labor strike the variables are set to the null state for the duration of the strike denoted by the time interval - *t*. This is represented across all activity contexts by the variable set: {*labor*(*null, t*), *prod*(*null, t*)}. Assuming there was 100% productivity for a time interval of *t'* before the strike, the situation before the strike started is represented by: {*labor*(*100%, t'*), *prod*(*100%, t'*)} where the predicate *Meets*(*t', t*) asserts that the time interval is *t'* immediately before *t*. This event represents a violation in a resource constraint, i.e., labor, which is a necessary resource, is missing. This can be logically asserted by the following:

$$t \cdot Act_Labor_Strike(t.start) \rightarrow t' \cdot labor(100\%, t') \wedge prod(100\%, t') \wedge Event(Labor_Strike, t) \wedge ImmBefore(t', t) \quad \ldots\ldots(1)$$

A detailed description of the representation and reasoning can be found in (Rojas and Mukherjee 2005).

Events are represented as an assertion of the pre-conditions that lead to its occurrence and post-conditions that describe the impact and duration of the event. Actions are immediate inputs that trigger the change in the states of the variables in the pre-condition set to reflect the post-conditions for the duration of the event. The action represents a simulation triggered random event (weather), the impact of a user decision (such as reduced productivity on site resulting in congestion). An event *E* is represented by triples $<E_{prec}, E_{eff}, E_{prob}>$ where E_{prec}, and E_{eff} are sets of variables and E_{prob} is the event probability. Hence, in the previous example, the action *Act_Labor_Strike* creates the event *Labor_Strike* that belongs to the set of events ***E***. The associated variable sets defining it are: E_{prec} = {*labor*(*100%, t'*), *prod*(*100%, t'*)} and E_{eff} ={*labor*(*null, t*), *prod*(*null, t*)}. The triples are defined in a knowledgebase that drives the simulation and allows it to identify a violation that can cause the event. In this way, action-event combinations, temporal variables and a set of rules are used to represent constraint violations and their impacts on the simulated CM environment.

The limitation of this method was that event definitions could be used to explicitly identify defined temporal and resource constraints. However, implicit constraints that drive the schedule, but are not defined using the action-event combinations needed a separate reasoning system. For example, a dependency

relationship between two unrelated activities that may result in a space conflict on site cannot be uniquely expressed using a typical action-event definition. It becomes more difficult to deterministically define E_{prec} whenever a constraint violation can be arrived at through more than one sequence of occurrences. Hence, the next step in the development process established a simple temporal constraint network called *TONAE* to establish a variety of constraint relationships to describe the construction domain – with the ability to express uncertainty and quantifiable consequences of constraint violations.

Simple Temporal Networks (STNs) (Dechter et al 1999) and their associated polynomial time algorithms are widely used in temporal reasoning. An STN includes nodes, representing time points, and edges connecting nodes, representing temporal constraints. The temporal constraints have a form such as $[2 \leq (x_2 - x_1) \leq 5]$ meaning that the duration between time points x_1 and x_2 can be between 2 to 5 units of time. This allows the definition of hard constraints and deadlines between two time points, as well as the definition of temporal tolerances associated with a constraint. While the existing representation defined intervals only as activities with deterministic durations – STNs extend the representation to include intervals that represent constraints between one or more activities, and events with variable durations.

The STN representation of the CM domain is called TONAE (**T**emp**O**ral **N**etwork with **A**ctivities and **E**vents) and it defines three classes of intervals that represent construction activities (relating the activity start time point and end time point), events (using a start time point and an end time point and relating each to the activities that are affected by the event) and constraints (relating start/end time points between activities and events). Each interval is defined by a duration upper bound and a duration lower bound indicating allowable temporal tolerances associated with the activities (float), constraints and events. In addition each interval is associated with a Cost Overrun Index (COI) that is indicative of the expenses/damages incurred when the duration of the specific interval exceeds the bounds. TONAEs advance the existing representation in three ways: 1.) They can represent intervals as well as constraints between individual time points defining such intervals, 2.) They provide an integrated approach to express all the constraints, activities and events using a temporal network and 3.) They provided the ability to develop general algorithms that could be used to traverse and query the network to aid decision-making and planning. A detailed discussion of the TONAE and its associated algorithms can be found in Anderson et al. (2007). The input to this model is an as-planned project schedule, with explicit identification of significant constraints that drive the schedule, external events likely to happen during the project and associated probabilities.

Mathematical Model: A model was developed to mathematically express the relationships between cost, schedule and productivity in the CM domain (Rojas and Mukherjee 2003). This model is based in the assumption that the construction domain consists of resources - labor, equipment and material – each of which are associated with costs, that can be summed across activities, and on a daily basis. The sum of costs across a project resource loaded schedule provides the estimated project direct costs when it is implemented on schedule. Constraint violations described in the previous sub-section can result in impacts on project performance. This model includes update functions that calculate remaining activity durations, forecast

productivity and expected cost over runs and compare As-Planned and As-Built performance. The input to this model is an extensive resource loaded schedule.

Situational Simulation Implementation

In this section we describe the pragmatics of the GPF, including descriptions of how it has been developed to represent simulations of construction projects and how participants can interact with it to explore "what-if" scenarios. The general architecture of the GPF implementation can be classified into three separate logical models: Process Model, Product Model, and the Information Model (Rojas and Mukherjee 2003). We discuss the pragmatics of implementing the ICDMA – a situational simulation of a real life steel framed office building built in 2003 (Daccarett and Mrozowski 2005) using the GPF within this framework.

Project Context: The building has four stories, has 80,000 square feet of built area, and weighs approximately 400 tons of structural steel or about 10 pounds per square foot. Fabrication and erection cost $9 per square foot. A total of 964 pre-fabricated structural steel members were used in the construction. The standard bay size in the building is 30 feet by 30 feet and there are 3 bays along the width and 7 bays along the length of the building.

Process Model: The process model consists of the Emulation Engine (EE). The EE is the fundamental underlying simulation engine and it implements the formal mathematical, representation and reasoning models discussed above. The granularity of the simulation in ICDMA is a week. Activity durations, and constraints are expressed using the TONAE. An example of a critical constraint is: the hoisting operation for a sequence of a higher storey has to start after a considerable portion of the decking operation for sequence of the immediately lower storey had been completed to afford safe fall distances. Given the numbering scheme of the sequences, this translated to a relationship between the mid-point of the Decking activity of sequence *i,* and the starting point of the hoisting activity of sequence (*i+2*). This and other similar constraints were expressed using the TONAE Event information was encoded as follows: Moderate rain on site can result in a 50% loss of productivity, last for a duration of a week, with a probability of 10%. The simulation also encoded events such as worker fatigue, labor strike and failed material delivery.

Information Model: The information model consists of all the relevant information that is necessary to simulate a specific construction project. While the EE define the machinery of the GPF, the information model includes schedule, cost and constraint information about specific construction projects that are simulated by the GPF. Specifically, the information used in ICDMA were:

- A resource-loaded schedule (32 weeks) representing the six sequences in which the steel framed structure was constructed. Each sequence consisted of hoisting, bolting and connection work and decking activities, and represented the order in which sections of the frame were erected.
- For each activity, the associated resource costs were also included. For example, each hoisting activity was associated with the specific steel members hoisted, the hoisting crew, the crane equipment used and the expected production rate of the activity. This was done for each activity in each of the six sequences.

- Information on events and constraints that were used to build the TONAE.

The project specific information is stored in a database server, accessible by the EE.

Product Model: The product model consists of the Visualization Engine (VE). It implements an interactive interface to the EE allowing human participants to run the simulation of a construction project and make critical decisions. It visualizes information regarding schedule, cost and commodity curves (Figure 1) and material, labor and equipment resources available (Figure 1.) to the decision-maker at any time in the simulation. In addition it provides an interface that captures the decisions provided by the participant and relays it to the EE. Participant decisions include purchase, allocation and re-allocation of resources to activities (labor and material), changes in productivity related variables. All updates in schedule and cost calculated by the EE in response due to decisions, and current simulation information regarding events and constraint violations, are communicated to the participant through the VE.

System Architecture: The database server, EE and VE together define a web-based architecture of situational simulations. The EE and the database server reside on a central server, while the VE is a thin client that is deployed to the participant's desktop. Via the web, the client communicates with the server and functions as the product interface between the simulation and the human participant. The motivation behind this architecture is to ensure that all data is securely stored on the web-server and to collect decision-making data from the human participants during the simulation for future data mining purposes. In addition, it avoids transferring heavy simulation computing and processing to the client running the simulation, only requiring them to be connected to the Internet. ICDMA was implemented using Java 1.5 SDK and a PostgreSQL database server. This ensured that the simulation remains platform independent and easily accessible by diverse operating systems used by participants across academia and industry.

Research Methods Using Situational Simulations

In this section, we discuss current research and future directions of applying situational simulations to construction education, construction contingency planning, and the study of decision-making in dynamic environments.

Construction Education: Situational simulations are used in construction education to provide students clinical exercises in decision-making within interactive dynamic virtual environments. There is evidence in education literature that interactive virtual environment allow students to explore and construct knowledge through authentic experience, thus enhancing their ability to learn by connecting ideas that are otherwise provided through fragmented classroom discourse (Rojas and Mukherjee 2005b).

The Virtual Coach implementation was used to test the ability of situational simulations in teaching undergraduates using a hypothetical 12-activity project. 19 senior level CM students tested the simulation, with the goal of completing the project within budget and schedule in the face developing crisis scenarios. They were provided a simple pen-paper test on crisis management before and after the simulation intervention – using the pre-test/post-test protocol. The hypothesis of the test was: a statistically significant difference in performance on the test can be attributed to improved conceptual understanding due to participation in the

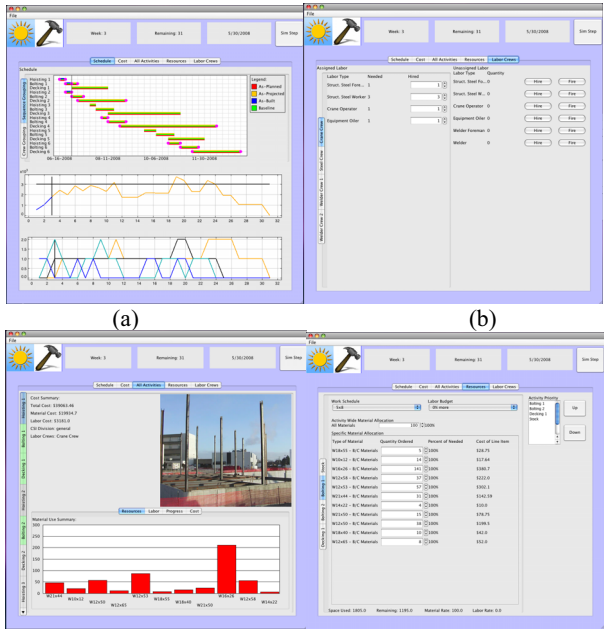
simulation. In addition, qualitative feedback was collected from the students. The results showed that student test scores significantly improved with respect to managing precedence and temporal constraints driving the construction project and in their ability to identify and relate critical path to construction cost (Rojas and Mukherjee 2006).

Currently a vastly improved version of the Virtual Coach, using a complex real life construction project is being developed with close collaboration with construction companies. In addition, the interface is significantly being improved to display multi-modal construction information. In the course of the next academic year the system will be deployed and tested as an educational intervention across several participating partner schools in the US and Canada. This is a significant contribution of this research to construction education.

Construction Contingency Planning: Based on the formal models driving situational simulations, it can be used as a conformant planner – a system that can automatically create contingency plans in two ways: (i) accounting for typical contingent situations (such as weather events) and (ii) automatically estimating contingencies that are difficult to foresee, by exploring combinatorial future spaces resulting from constraint violations as expressed on the TONAE. The querying algorithm discussed in Anderson et al. (2007) can estimate and classify risks in dynamic construction scenarios as situations evolve and classify the associated risks by impact and probability by enumerating Monte Carlo samples of the combinatorial future paces. The approach was validated using ICDMA to classify risk in the construction of the steel framed building. The project involved three external events and 12 temporal and resource constraints with varying probabilities of occurrence (see project context).

Traditional contingency estimation in construction primarily uses probabilistic approaches based on pre-defined risk scenarios with limited dynamic exploration of decision outcomes. This approach builds on existing methods, and further enhances them by including the ability to estimate contingencies from scenarios that can be simulated as combinations of possible constraint violations in a dynamic environment. This is a step toward the development of systems capable of automatically generating and classifying contingency scenarios during the planning phase of construction projects (Anderson et al. 2007).

Decision-Making in Dynamic Environments: Situational Simulations can also be used as experimental test beds for studying decision-making in dynamic, uncertain environments – specifically the impact of critical decisions in construction crisis scenarios. This research draws on methods in dynamic decision-making and construction data mining. The goal of this research is to use data mining approaches to classify decisions based on their project impacts. The hypothesis is that efficient decisions have structure that reflects underlying project constraints, and the relationship between how expert decision-makers organize and relate general domain knowledge to specific situation awareness. The data to be analyzed consists of decisions taken by construction managers with varying levels of expertise in fast evolving crisis scenarios. Given that it is very difficult to collect human decision-making data in controlled crisis scenarios – situational simulations of realistic construction projects provide the necessary experimental test beds to collect and analyze data.



(a) (b)

(c) (d)

Figure 1. ICDMA: (a) Schedule and Commodity curves (b) Labor resources (c) Activity specific information (d) Material Resources

Current research (Watkins et al. 2008) addresses challenges in the collection, organization and analysis of human subject data using situational simulations such as the ICDMA. A formal data collection framework has been developed that can prescribe data collection protocols in a situational simulation and establishes mathematical approaches to organizing and classifying them. Preliminary results show that situational simulations can be used to successfully collect decision-making by controlling the simulation environment by situation and user particulars. In addition, such data can be used to mathematically construct decision shape vectors that can be used to quantify and classify decisions. Preliminary validation of the system has been conducted using participants from the industry and academia.

This research furthers our understanding of construction decision-making in particular and decision-making in dynamic uncertain crisis scenarios in general. Situational simulations can also be extended to study critical decision-making in fast evolving crisis scenarios involving multiple co-dependent infrastructure systems – a necessary and important area of investigation.

Conclusions

In this paper we have summarized the conceptual and formal models driving situational simulations, associated research methods, current results and theoretical contributions, and future directions in construction research and education. It is

important to note that the interdisciplinary scope of this research involves diverse teams from engineering, construction management, computer science, education and the construction industry.

Acknowledgement

This research in this paper was developed under a grant from the NSF grant *#SES 0624118* to PI: Amlan Mukherjee, and Fund for the Improvement of Postsecondary Education (FIPSE), U.S. Department of Education, grant *#P116B060047* to PI: Eddy Rojas (University of Washington), Amlan Mukherjee (Michigan Tech). However, these contents do not necessarily represent the policy of the NSF or the Department of Education, and there should be no assumption of endorsement by the Federal Government.

Reference

Anderson, G. R., Onder, N., and Mukherjee, A. (2007). "Expecting the unexpected: representing, reasoning about, and assessing construction pro ject contingencies." Winter Simulation Conference, S. G. Henderson, B. Biller, M. H. Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, eds. WSC, 2041–2050.

Daccarett, V., and Mrozowski, T. (2005) "Aisc digital library: Construction management of steel construction." Available via <http://www.aisc.org/>[accessed 01/10/2007].

Dechter, R., I. Meiri, and J. Pearl. (1991). "Temporal constraint networks." Artificial Intelligence 49:61–95.

Hajjar, D. and AbouRizk, S. (1999) "Simphony: an Environment for building Special Purpose Construction Simulation Tools" Proceedings of the Winter Simulation Conference, 1999, P.A.Farrington, H.B.Newbhard, D.T.Sturrock and G.W.Evans, eds.

Martinez, J. and Ioannou, P. (1999). "General-purpose systems for effective construction simulation," Journal of Construction Engineering and Management, 125 (4), 265-276.

Rojas, E., and Mukherjee, A. (2003) "Modeling the Construction Management Process to Support Situational Simulations." Journal of Computing in Civil Engineering, ASCE, 17(4) pp 273-280.

Rojas, E. and Mukherjee A. (2006) "A Multi-Agent Framework for General Purpose Situational Simulations in the Construction Management Domain," Accepted by the Journal of Computing in Civil Engineering, ASCE, 20(6) pp 1-12

Rojas, E. and Mukherjee A. (2005a) "Interval Temporal Logic in General Purpose Situational Simulations," Journal of Computing in Civil Engineering, ASCE, 19(1) pp 83-93

Rojas, E. and Mukherjee A. (2005b) "A General Purpose Situational Simulation Environment for Construction Education," Journal of Construction Engineering and Management, ASCE, 131(3) pp 319-329

Watkins, M.T., Mukherjee, A. and Onder. N. (2008) "Using situational simulations to collect and analyze dynamic construction management decision-making data." In Proceedings of the Winter Simulation Conference (ACM/SIGSIM), 2008.

CONSTRUCTING RESEARCH WITH CASE STUDIES

J. E. Taylor[1], C. S. Dossick[2] and M. J. Garvin[3]

Abstract
A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context. The case study research method is popular across various disciplines, however, critics of the method argue that results from this form of research are applicable only to the case studied and cannot be generalized further. In the field of construction engineering and management, the number of papers employing case study research methods over the past decade has increased substantially. The question that arises as the method proliferates is whether case studies are being performed with sufficient validity and reliability to maximize the extent to which the findings can be generalized. Given the unique, project-based nature of the construction industry, in this manuscript, we discuss research design and data collection strategies construction engineering and management researchers can employ to improve validity, reliability and the extent to which they can generalize from their findings.

Introduction

In his definitive work on the case study research methodology, Yin (2003) defines a case study as "an empirical inquiry that: 1) investigates a contemporary phenomenon within its real-life context, especially when 2) the boundaries between the phenomenon and context are not clearly evident." Yin continues his definition with a technical distinction between method and the characteristics of data collection and data analysis strategies. He argues that with case studies there will be many more variables of interest than data points and therefore case studies require collecting and triangulating data from multiple sources of evidence. This broad definition encompasses a variety of research design logics, data collection techniques and data analysis strategies, including but not limited to demonstrations, ethnography, evaluation, experiments, grounded theory and quasi-experiments (Yin 1993). Under

[1] Assistant Professor, Department of Civil Engineering and Engineering Mechanics, Columbia University, 618 S.W. Mudd Bldg., 500 West 120th Street, New York, NY 10027; PH (212) 854-1182; FAX (212) 854-6267; e-mail: taylor@civil.columbia.edu.

[2] Assistant Professor, University of Washington, e-mail: cdossick@u.washington.edu.

[3] Associate Professor, Virginia Tech, e-mail: garvin@vt.edu.

this definition, the case study method encompasses both qualitative as well as quantitative methods.

Research questions specific to Construction Engineering and Management (CEM) include how and why individuals, organizations and markets behave the way they do and require qualitative as well as quantitative methods to understand organizational and human behavior issues surrounding our work and our industry. Most often we think of case study observations as qualitative research; however researchers from engineering, business and social science disciplines alike have shown that case studies are often mixed-method projects with both qualitative and quantitative aspects (Esteves and Pastor 2004; Green et al. 2002; Kaplan and Duchon 1988; Yin 2003). There are a variety of methods we can employ in case study research to both collect and then analyze complex data. For a discussion of the case study method in the CEM domain, we adopt Yin's definition of case studies as a research strategy to review a specific instance, scenario or project in-depth wherein a variety of both qualitative and quantitative methods can be used in combination to generate rich datasets and robust analysis of very complex questions (Yin 2003).

Criticism of the Case Study Research Method

One of the main criticisms of case studies is that they are limited to one or perhaps a handful of examples. Hence, criticisms focus on how investigators can justify making generalizations from a limited number of samples (Flyvbjerg 2006; Yin 2003). For those who work primarily in the statistical domain, the limited number of data points is intuitively a "statistical significance" problem. Platt (1992) suggests that cases should be chosen for specific intellectual purposes. They should be selected for their ability to support analytic generalization as opposed to statistical generalization. Platt argues that the logic of sampling should be grounded and that the grounding depends on the theoretical argument investigated (Platt 1992).

A second criticism is that many manuscripts based on case study research are executed with insufficient precision, quantification, objectivity or rigor where investigators have not followed standard procedures, or have allowed a biased view to influence the direction of the findings. Manuscripts in this category have tainted the research method as a whole (Yin 2003). Cause for this, Yin points out, may be a lack of standards for the method and guidance for researchers trying to use the method. Furthermore, critics may confuse case study teaching with case study research. When developing a case, teachers may modify the case to fit the learning objectives and create an optimal example for instructional purposes. Critics that misinterpret case study research methodologies as teaching cases would reasonably be concerned about the control of bias. However, bias on the part of the researcher can occur and be controlled with any research method.

The Case Study Method and CEM Research

CEM researchers most often receive their graduate education in colleges of engineering that focus on quantitative and experimental methods; consequently, CEM researchers have limited training in the case study methodology. However, many construction industry phenomena of interest are often too large or too expensive to test in a more traditional experimental fashion and the variables in play can be too

numerous for a meaningful quantitative analysis. The CEM area is characterized by large unique projects, temporarily aligned teams of experts, regional variation, and material and technical innovation. Case studies allow CEM researchers to study phenomenon in a real-life project where actors are making decisions about real issues that impact such factors as time, cost, quality and safety. As with other methods, researchers are challenged by 1) access to projects for observation and data collection, 2) access to personnel in the office and field, and 3) access to information that is often considered proprietary or confidential. However, as a researcher establishes a relationship with a case study project, these barriers are often overcome because the researcher is committed to an in-depth study and can be accepted as part of the project team.

One of the biggest challenges of statistical studies in CEM research is the number of variables that determine the success or failure of projects and the unique nature of construction activities. For instance, correlations between the introduction of new technologies or work processes and the resulting benefits on a project are often very difficult to measure. Researchers at Purdue University identified no less then *42 factors* that influence the success or failure of the implementation for web-based project management systems on construction projects (Nitithamyong and Skibniewski 2003). Causation is even more difficult to prove, where individual attitudes, group dynamics, local market conditions, luck, and project momentum can impact the performance on projects before we even begin to consider variations across business practices, management techniques and technology applications. In quantitative research, variables are often treated as if they have an autonomous existence (Regin and Becker 1992). Case studies (either qualitatively or quantitatively designed) provide context and description for the data and variables collected. This allows for associations or similarities to be observed where they were not anticipated, or it allows investigators to more deeply substantiate the correlations they find in the data. Case studies allow CEM researchers to observe and document causal factors and quantify the impact of new technologies or techniques on a project by exploring the details of particular application, and capturing the actor's own observations about how the case in question is different from other projects

Furthermore, case study methods allow researchers to work at a variety of levels of granularity. A case study can be an exploration of national industry standards, a city agency, a company, a project or an individual (Regin and Becker 1992). In CEM research, this allows investigators to review a company, a project, a government or an individual. Comparative case studies focus on separate but comparable instances of the same general phenomenon (for example, comparison between Japanese companies and U.S. companies and their approach to web-based project management (Dossick and Sakagami 2008).) This allows the CEM researcher to contextualize phenomenon accounting for the complex set of variables characteristic of the built environment, and then define how the phenomenon plays out in the different contexts.

Case Research in the Journal of Construction Engineering and Management

The use of the case study research method in the Journal of Construction Engineering and Management has significantly gained in popularity over the past fifteen years. In

the five year period from 1992 through 1996, the number of papers citing Yin's case study research method ranged from 0 to 5 with an average of approximately 2 per year. In the next five year period the average rose to about 4 papers per year using the method. However, in the five year period from 2002 through 2006, the use of cases rose to about 11 manuscripts published per year. Table 2 contains the number of manuscripts published each year in the Journal of Construction Engineering and Management that utilized Yin's case method from 1992 through 2006 according to the ISI Web of Science.

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
# Case Research Articles Published in Journal of Construction Engineering and Management	0	2	3	5	2	0	1	6	8	6	5	5	19	11	15

Table 2 - Increase in Case Study Research in CEM (Source: ISI Web of Science)

This reflects a general trend across the sciences. In a review of papers across the same time period, the number of papers in the ISI Web of Science that reference Yin's case method book trends upward as significantly. In the 1990s, Yin's Case Study Research book was cited an average of over 100 times per year. However, over the last five years that average has increased to over 250 manuscripts citing Yin's method book per year.

It would appear that CEM case study research is growing in popularity but the growth in use is not coupled with a consistent and comprehensive approach. As our colleagues in Business Managament and Information Systems have shown, case studies can generate new insights and meaningful research (Benbasat et al. 1987; Dube and Pare 2003; Dyer Jr. and Wilkins 1991; Eisenhardt 1989; Eisenhardt 1991; Lee 1989) and as such case studies are an important and vital part of CEM research. However, we have not yet developed standards or guidance for CEM investigators to develop and improve the rigor of their research studies.

To address the specific challenges of CEM research, case studies are a vital part of the CEM researchers' methods portfolio. As this research method can yield new constructs, propositions and theoretical models to create new research questions for exploration by other methods, we need to initiate a dialogue in the literature about how to improve the validity, reliability and the extent to which we can generalize from case study research in CEM. It is critical there be a dialogue within the CEM community as there are idiosyncratic issues unique to CEM research that must be addressed. This is particularly relevant given the substantial increase in the use of case study research among the CEM research community. With this paper we seek to outline strategies for developing and executing rigorous case study research in the CEM domain. As CEM researchers who conduct case studies, we seek to open a dialogue regarding the standards for rigor for case study research in the CEM academic community.

Planning Case Study Research in CEM

Posing the Right Questions

Generally speaking, research should answer questions not solve problems (Levitt

2004). Accordingly, identifying appropriate research questions is a prerequisite of a research plan or design. For example, a researcher might ask "How and why do public agencies that are responsible for the implementation of public-private partnership (P3) programs organize themselves?" or "How do often temporary and global inter-organizational networks within and across the construction industry share information and allocate work?" Each of these questions meets the basic criteria for when the case study strategy has a distinct advantage over other methods since the questions being asked are "how and why" questions about contemporary events over which the researcher has little or no control.

Once the questions of interest are identified and they suggest that a case-based research approach is appropriate, the researcher should then consider whether the nature of the inquiry supports the definition of preliminary propositions. Preliminary propositions can serve two important functions. First, they will provide the researcher with direction, a compass to guide the study. Second, they help to identify what evidence or metrics are appropriate for the case study. For instance, a preliminary proposition for the first question posed above might be: *P3 program administrations are organized to maximize the economic value of projects delivered*. While this may or may not be the true, the proposition acts in many respects like a hypothesis in a statistical study.

In some situations, propositions may not be appropriate. For research that is very preliminary or exploratory, propositions may impose unnecessary constraints. This more exploratory case study research can lead to the formulation of new propositions that the CEM community can test through hypothesis-driven research. For example, a proposition that emerged from case based research on a version of the second question above yielded the following proposition: *if the organizational boundary between firms in a project network is impermeable and work redistribution is impeded, the networks will have significant difficulty adapting to misaligned innovations* (Taylor and Levitt 2007).

Research Design and Execution

A critical aspect of case study research is the unit of analysis; in other words, what is the case under investigation? At its birth, the unit of analysis for this style of research was quite clear, the case was an individual (Platt 1992). In CEM research, the unit of analysis might be an individual (such as CEO's in CEM leadership research), but more than likely the case will be processes, programs, projects, or organizations. Clearly, the unit of analysis should follow from the research questions posed and propositions stated. Like any other research approach, the boundaries of the unit of analysis must then be established such as geographic limits and time periods. In some situations, multiple units of analysis might be appropriate. Often, additional units of analysis are sub-sets of the primary unit (Yin 2003). For instance, the case may be an organization's capital program and its individual projects are further units of analysis, which are sometimes referred to as embedded units. Furthermore, the unit of analysis should be generally consistent with existing case study literature of a similar nature. Prior work can provide a solid basis for defining a unit of analysis or clarifying how it deviates from previous research.

Once the case is defined, a researcher must determine whether the research

questions posed are appropriate for single or multiple case studies. Some might consider a single case rather indefensible since it is not unlike having a single data point. Single cases are quite justifiable when the case is a vital test of an existing theory, is a rare or extreme event, or represents an opportunity to observe an event that was previously inaccessible (Yin 2003). The frequency of a multiple case methodology has increased in recent years, but unlike statistical analyses where increasing the number of events observed is crucial to ensuring that the sample represents the population being studied, the decision to use multiple cases is akin to the decision to conduct multiple experiments. The intent is to follow replication logic, which means that each case must produce similar results or predictable contrasting results.

Replication is highly dependent upon the quality of the case research methods. Most empirical social research relies heavily upon four tests (Judd et. al. 1991):

- Construct validity: establishing correct operational measures
- Internal validity: establishing credible causal relationships
- External validity: establishing the domain where results may be generalized
- Reliability: demonstrating that the operational procedures can be repeated to produce the same results.

Construct validity is particularly significant as well as vulnerable in case study research. Without credible operational procedures, case study research is likely to be criticized as subjective. This test depends upon three key tenets: (a) utilizing multiple sources of evidence, (b) creating a chain of evidence, and (c) reviewing draft case results with key participants/informants. Clearly, the first two tenets depend heavily upon the data collection methods followed. A common refrain in this regard is triangulation. For instance, Garvin and Bosso (2008) used primary source documents (such as RFP's and contracts), secondary source documents (such as third-party analyses and periodical articles), and structured interviews with participants to study P3 programs and projects.

In addition to the tests of validity, data collection techniques in case study research are fundamental to achieving defensible outcomes. Foremost is the case study protocol, which is more than the instrument for collecting information. The protocol includes the explicit procedures for administration of the instrument. This is particularly crucial for heightening the reliability of the results. Additional considerations include pilot efforts, sources of evidence, and record-keeping (Yin 2003). Finally, modes of data analysis are varied. Pattern matching, time-series analysis, and program logic models are some of the more common techniques employed. Multiple sources describe their applicability and implementation.

Strategies for Achieving Rigor in CEM Case Research

To initiate a dialogue with the CEM case study research community, we present several strategies based on our experiences conducting case study research in the often difficult to capture project-based, customized end product, highly fragmented industry we investigate. We also present the discussion in consideration of a review of the 88 papers we identified earlier in this manuscript as having used the case research method in the Journal of Construction Engineering and Management

(according to ISI Web of Science) in order to identify trends in methodological utilization and opportunities for improvement.

The Case for Longitudinal Data Collection

Case study research is an opportunity to describe the process by which a complex phenomenon unfolds. In CEM research, we find complexity at many levels. We have observed complexities in terms of conflicting obligations at the level of teams in studies of subcontractor coordination with building information models. At the level of the organization we have observed complexity in public private partnerships and cross-national differences in innovation alignment. Individuals interviewed in case research may not be able to describe the many details that bear upon the focal examination of the case. To deal with this complexity researchers should pursue longitudinal data collection strategies. Interviews should be conducted at multiple points in time and, if possible, include periods of direct observation.

Often initial discussions with the participants in case study research are focused on addressing issues of confidentiality. Multiple interviews with the same interviewees and with multiple individuals from the same organization should be planned to allow time to get past initial concerns of confidentiality and for the researcher to develop a rapport with the interviewees and with the organization being examined in the case. By collecting data from multiple sources and by collecting it over time the researcher can improve the internal validity of their findings when consistent patterns of responses are observed across interviewees and over time.

The Case for Comprehensive Model-building from Case Study Research

Manuscripts presenting case study research (including that of the authors of this manuscript) must spend more time moving beyond descriptive accounts of the cases we study. We certainly must emphasize details about the cases themselves and provide descriptive statistics about the projects, companies, markets or other cases we study. However, we need to move beyond description to the specification of new theories or elements of theories that emerge from the case study research. If a new construct of interest emerges in the research, we must argue the internal validity of that construct by presenting specific quotes from interviews, points of quantitative data collected, company primary documentation or other data points. If we argue in the methodology section that we will be triangulating data across data collection types, then that triangulation argument should be made as constructs are defined.

In our analysis of the 88 papers published in the Journal of Construction Engineering and Management over the past 15 years that cite Yin's case research method, 21 were descriptive case studies, 44 were used to validate pre-established models or theories, and only 23 were used to develop and/or propose new models. Of the 23 papers that developed and/or proposed new models, only 14 provided evidence for the underlying validity of the models developed. Only 60% of the papers developing new models comprehensively included validation of the findings. This raises concerns in the minds of the critics of the case research methodology that researchers who fail to address validity may merely be presenting a stylized interpretation of the case heavily biased by the author's preconceptions of the data. For CEM case study research to achieve a higher level of rigor we must provide clear

evidence for the validity of our findings.

Yin (2003) stresses the importance of moving beyond specification of constructs to the formulation of propositions based on those constructs. To begin to develop new or extend existing theories we must be more comprehensive in our approach and include formally stated propositional statements that give an indication of how the constructs identified in the research relate to each other and to already-identified constructs from the literature. A well-formulated proposition should be stated with as much precision as hypotheses are in other forms of research. Propositions should present opportunities for researchers that wish to extend from the work to perform computational simulation models, survey-based statistical research, or other methodological approaches to test the propositions.

Propositions are an opportunity for CEM case study researchers to begin to formulate new theoretical models. However, inducing a new explanatory model requires the researcher to combine a set of propositions into a coherent model built upon the constructs and propositions. In our analysis of the 88 papers published using the case research method in the Journal of Construction Engineering and Management over the past 15 years, we found no examples of papers that introduced formally stated propositions. For CEM researchers to comprehensively build theory from case studies, we must move beyond introducing new constructs and (1) increase efforts to argue for the validity of our findings and (2) provide formally stated propositions resulting from the research that provide the basis for new or extended theoretical models.

The Case for Depth in Multiple Case Research Designs

As CEM researchers we have the difficulty of often trying to collect data on projects which can involve dozens of firms and hundreds of individuals working in complex task and resource interdependent relationships. In fact, this is the kind of complexity Yin (2003) argued case study research methods were ideally situated to examine. However, to collect data in this complex scenario, CEM researchers need to strive to deepen their case study designs. An analysis of the 88 papers reveals that only 31 (or approximately 35%) employed multiple case research designs. To create a compelling case that the findings from case based research are applicable beyond a single case, a critical strategy is to employ multiple case research designs or other validation techniques.

When employing multiple case research designs, we must seek to establish depth along two dimensions. On one axis, we often pursue comparative case studies where we compare polar cases that might vary in terms of the market (e.g., liberal market economy CEM project networks vs. coordinated market economy CEM project networks in Taylor and Levitt (2007)). This analytic replication logic implies at least two cases be examined to capture data at the two analytically determined extremes. One important additional reason to pursue analytic replication in the case design is to avoid sampling on the dependent variable. Case research papers should avoid, for example, studying how firms succeed at some process while only collecting data on successful cases. In this instance there would be no basis of comparison to ascertain what process leads to success versus failure.

The second axis where we need depth in case study research is in terms of

literal replication logic. Because projects (as an example unit of analysis) can be so different given the customized nature of the products we build, we need to collect data also on multiple analytically similar cases in which we develop depth in each of the two (or more) analytic cross-case comparative projects. There is also an opportunity for CEM researchers to avail themselves of embedded subunits of analysis that may exist to deepen the base of data. Increasing the number of cases along the two dimensions we described and the additional dimension of embedded subunits of analysis can enable the researcher to also better argue for the extent to which they can generalize their findings. CEM researchers that achieve depth with literal and analytic replication and by analyzing embedded subunits of analysis will be able to argue more convincingly both the internal validity of their findings and the extent to which those findings can be generalized to a broader population.

Involving Multiple Perspectives in the Construction of Case Research

A final strategy we will discuss in this paper is the importance of involving multiple perspectives in case research. Involving multiple researchers in the data collection can allow a research team to be in more than one place at one time. This is critically important in some comparative case designs where the two cases being investigated may be occurring simultaneously. Involving multiple researchers in the data analysis is also a key strategy for refining the constructs, propositions and theoretical models that emerge from the research. However, if multiple researchers cannot be involved in the data collection and analysis, a critical strategy for arguing validity is the inter-rater reliability test (Bers and Smith 1990). With this test, a researcher not involved in the research is given a sample of the data points or quotes collected in the research and asked to classify them into the constructs identified by the researcher. The measure of the alignment between the independent rater's categorization and the researcher's categorization is an important measure for the internal validity of the constructs, propositions and models presented in a paper.

Conclusion

The case study method is popular across disciplines and growing in popularity among the CEM research community. However, we must be consistent and comprehensive in our approach to case study research if we are to achieve the advantages of and respond to critics of the method. This paper begins a dialogue within the CEM academic community on how to improve the rigor of case study research within the CEM domain. If we can achieve a higher level of rigor, we can both improve our ability to generalize from case research findings and respond to critics who find the application of the method in CEM research to be lacking in rigor. If we achieve this as a research community, case based research can yield new lines of inquiry and new theoretical models to enrich CEM research across all methodological approaches.

References

Benbasat, I., Goldstein, D. K., and Mead, M. (1987). "The Case Research Strategy in Studies of Information Systems." MIS Quarterly, 11(3), 369-386.

Dossick, C. S., and Sakagami, M. (2008). "Implementing Web-Based Project Management Systems in the US and Japan." Journal of Construction

Engineering and Management, 134(3).
Dube, L., and Pare, G. (2003). "Rigor in Information Systems Positivist Case Research: Current Practices, Trends, and Recommendations." MIS Quarterly, 27(4), 597-635.
Dyer Jr., W. G., and Wilkins, A. L. (1991). "Better Stories, Not Better Constructs, to Generate Better Theory: A Rejoinder to Eisenhardt." The Academy of Management Review, 16(3), 613-619.
Eisenhardt, K. M. (1989). "Building Theories from Case Study Research." The Academy of Management Review, 14(4), 532-550.
Eisenhardt, K. M. (1991). "Better Stories and Better Constructs: The Case for Rigor and Comparative Logic." The Academy of Management Review, 16(3), 620-627.
Esteves, J., and Pastor, J. (2004). "Using a Multimethod Approach to Research Enterprise Systems Implementations." Electronic Journal of Business Research Methods, 2(2).
Flyvbjerg, B. (2006). "Five Misunderstandings about Case-Study Research." Qualitative Inquiry, 12(2), 219-245.
Garvin, M. J. and Bosso, D. J. (2008). “Assessing the effectiveness of infrastructure public-private partnership programs and projects.” Forthcoming in Public Works Management & Policy.
Green, G., Kennedy, P., and McGown, A. (2002). "Management of Multi-method Engineering Design Research: A Case Study." Journal of Engineering and Technology Management, 19(2), 131-140.
Kaplan, B., and Duchon, D. (1988). "Combining Qualitative and Quantitative Methods in Information Systems Research: A Case Study." MIS Quarterly, 12(4), 571-586.
Judd, C. M., Smith, C. R., and Kidder, L. H. (1991). Research Methods in Social Relations, 6th edition, Harcourt Brace College Publishers: Fort Worth, TX.
Lee, A. S. (1989). "A Scientific Methodology for MIS Case Studies." MIS Quarterly, 13(1), 33-50.
Levitt, R. E. (2004). "Overview of Research Design: The Larger Picture." Presentation at Workshop on Research, ASCE Construction Research Council, Hilton Head, SC, March 27.
Nitithamyoung, P., and Skibniewski, N. (2003). "Critical Succss/Failure Factors in Implementation of Web-Based Construction Project Management Systems." Construction Research.
Platt, J. (1992). "Case Study in American Methodological Thought." Current Sociology, 40, 17-48.
Regin, C. C., and Becker, H. S. (1992). What is a Case? Exploring the foundation of social inquiry, Cambridge University Press, Cambridge.
Taylor, J. and Levitt, R. (2007). “Innovation Alignment and Project Network Dynamics: An Integrative Model for Change.” Project Management Journal, 38(3), 22-35.
Yin, R. K. (1993). Applications of Case Study Research, Sage, New York.
Yin, R. K. (2003). Case Study Research, Sage Publications, Thousand Oaks, CA.

TECHNIQUES FOR EVALUATING AUTOMATED KNOWLEDGE ACQUISITION FROM CONTRACT DOCUMENTS

Mohammed Al Qady[1], and Amr Kandil[2], Associate Member, ASCE

ABSTRACT

Knowledge Management (KM) has become the focus of a lot of scientific research during the second half of the twentieth century as researchers discovered the importance of the knowledge resource to business organizations. Recent research recommended the use of semantic representation of knowledge that is expressed in natural language to enhance knowledge management systems (KMS). In order to address this need, the CRISP technique (Concept Relation Identification using Shallow Parsing) was developed utilizing a natural language processing tool for extracting concept and concept relations from construction contract documents. The extracted concepts and relations are then used to develop semantic representations of the important knowledge expressed in the documents. The process of knowledge extraction from textual documents is, however, a subjective task that may differ from one person to another. This paper presents the two evaluation methods used to compare the performance of the CRISP technique with human evaluators. In the first method, Kappa was used to measure the level of agreement of human evaluators on the concepts extracted from an evaluation set, and the level of agreement between human evaluators and CRISP on the same evaluation set. In the second method, a Gold Standard was developed from the results of the human evaluators and precision and recall for CRISP and the human evaluators were calculated based on the Gold Standard. F-measure was used to combine precision and recall and to consequently compare between the performance of CRISP and the performance of the human evaluators. Results from both evaluation methods were relatively comparable.

INTRODUCTION

Construction projects are described as complex and diverse projects that produce non-standard components (Clough et al. 2000). Yet there exists amongst this

[1] Research Assistant, Construction Engineering and Management; Department of Civil, Construction, and Environmental Engineering, Iowa State University, Ames, IA 50011-3232; PH (515) 294-8553; email: malqady@iastate.edu

[2] Assistant Professor, Construction Engineering and Management; Department of Civil, Construction, and Environmental Engineering; Iowa State University, Ames, IA 50011-3232; PH (515) 294-8824; email: kandil@iastate.edu

complexity and diversity vast amounts of knowledge. The construction industry is a perfect example of a knowledge-intensive industry that has offered and still has the ability to offer many contributions to research in the field of KM (Rezgui 2001). The dynamic business environment of the industry requires construction firms to effectively implement knowledge management systems in order to acquire a competitive edge in the market (Jung et al. 2006). How an organization manages knowledge has a significant impact on the organization's learning capabilities (Wetherill et al. 2007). These factors have led many construction firms to invest resources in developing effective KMS's. One study in the United Kingdom estimates that 40% of construction and design firms implement some type of KM strategy (Carrillo et al. 2004). Yet despite this importance and despite the wealth of knowledge generated in construction projects, the application of KM in construction is described as "immature and underutilized" (Asprey 2004, Laudon and Laudon 1998, McGee and Prusak 1993, Rezgui 2001).

Construction organizations have different perspectives regarding the KM issue. Whereas some organizations invest in developing an infrastructure for communicating knowledge (the functionalist perspective), other organizations follow the interpretive approach by focusing on developing and supporting social networks through which knowledge is shared (Chinowsky and Molenaar 2005). Some researchers recognized the increased benefits from having a KMS that not only focuses on manipulating formal knowledge but also supports developing social networks that increase knowledge creation and dissemination. Accordingly, their research attempted to combine both perspectives by providing a social aspect to the KMS's functions through facilitating and encouraging user interaction. An example for this type of research is the C-Sand project by Wetherill et al. (2007). The objective of the C-Sand project is twofold: to provide a framework that operates within and across organizations for the extraction and sharing of knowledge related to sustainability in construction, and to foster the necessary social functions required to develop such a framework. For developing the C-Sand model, interviews with industry professionals were conducted to identify current practices and industry needs which were then modeled in UML. Based on the UML diagrams and the above mentioned objectives, the architecture of the C-Sand system was developed. The C-Sand model is composed of nodes (representations of knowledge) and links between the nodes defining the relations between the knowledge representations. The researchers note that the C-Sand project does not address the issue of creating links between knowledge resources based on their semantic relationship. The researchers also state that the results of the system's evaluation express the need for formalizing the concepts of the research domain into a sustainability ontology by producing semantic representations of the knowledge resources and identifying semantic relations between the resources.

Current research in KM investigates the possibility of using the semantic knowledge expressed in knowledge resources to enhance KMS. Rezgui (2001) proposes a knowledge environment that attempts to objectify knowledge by using information retrieval techniques, while also maintaining the social aspect of KM through user profiling. In this research, the proposed knowledge environment is centered on an ontology that is used as a semantic reference to provide knowledge consistency.

Ontologies have been used in various fields including e-commerce, information retrieval, the semantic web and KM (Gómez-Pérez et al. 2004). An ontology could be defined as "an explicit specification of a conceptualization" (Gruber 1993), where 'conceptualization' refers to modeling an abstract world phenomenon by identifying the concepts pertaining to that phenomenon, and 'explicit' implies that the concepts, the relations between the concepts and the constraints on the concepts are explicitly defined (Studer et al. 1998). Ontologies have also been used in the legal domain for information retrieval (Lame 2004, Saias and Quaresma 2004). The use of ontologies for KM in the construction industry is considered a relatively new field of research (El-Diraby and Kashif 2005). El-Diraby and Kashif (2005) developed HiOnto, an ontology for enhancing knowledge consistency thus improving knowledge sharing and collaboration between the various participants in highway design and construction projects. The architecture of HiOnto is composed of three levels connected by inheritance and mapping mechanisms. The upper most level, the domain level, consists of the e-COGNOS ontology, a process-oriented construction domain ontology developed during research in the area of Information Society Technologies (IST), part of the sixth program of the European Union's Framework Programme for Research and Technological Development. The second level in HiOnto, the application level, consists of a set of application ontologies for the same general concepts used in e-COGNOS (project, process, product, actor, resource), however only as they apply to the specific field of highway construction. The third level of HiOnto, the user level, represents actual instances of concepts from actual ongoing enterprises. A taxonomy of the highway construction domain was developed based on the 'is-a' relation to allow interaction between the various application ontologies. A list of 4,000 terms related to highway construction was identified from technical texts (research papers, textbooks, construction handbooks) and interviews with experts. Using process-based competency questions, the terms were then categorized into the main e-COGNOS concepts and structured into a hierarchy.

There are many advantages for modeling domains using ontologies. Ontologies support the development of common terms within a domain and the standardization of its concepts (Rezgui 2001). El-Diraby and Kashif (2005) also state another important advantage resulting from the use of ontologies: an ontology can be used to provide a representation of natural language that can be processed by a computer.

However, despite the advantages offered by ontologies, not many researcher projects have attempted to utilize ontologies for KM in the construction industry. Shamsfard and Barforoush (2004) state several problems that limit the use of ontologies. Despite recent efforts, standards for the integration of existing ontologies to enable sharing and reuse are largely unavailable. In addition, the extraction of concepts and concept relations is a difficult and time-consuming process. Finally, consensual agreement on the concepts of a certain phenomenon is very hard to achieve, even if the phenomenon was limited to a very specific domain. The first problem is a transitional problem that will be gradually solved as more and more ontologies are put into use and the appropriate standards for sharing are developed. To overcome the knowledge acquisition difficulties, the CRISP technique (Concept Relation Identification using Shallow Parsing) was developed (Al Qady 2008). The technique utilizes a natural language processing tool (shallow parser) to perform the conceptualization stage- the

process of extracting concepts and the relationships between the concepts from construction contract documents. The problem of subjectivity was encountered during evaluation of the performance of CRISP, specifically when comparing the outcome of the system with that of human evaluators. This paper describes the evaluation techniques used to overcome this problem and presents the results of the system's evaluation.

SEMANTIC REPRESENTATION OF CONTRACTUAL KNOWLEDGE

Semantic information expressed in documents can be utilized to enhance KMS's used in the construction industry. To achieve this, semantic information must be extracted from the documents and structured into a formal representation which can be applied to KM-related tasks. In this study, the object-oriented approach described by Gómez-Pérez (1998) is used, in which concepts are identified by nouns and relations identified by verbs. Accordingly, a 'concept set' is a set made up of the following three components:

- Active Concept: the concept doing the action, or the subject of the relation.
- Relation: the action, or the verb of the relation.
- Passive Concept: the concept that is being acted upon, or the object of the relation.

For example, suppose the following sentence:

The Contract Documents form the Contract for Construction.

The Active Concept is the 'Contract Documents', the Relation is 'form' and the Passive Concept is the 'Contract for Construction'. In semantic notation, the sentence can be expressed as follows:

form (Contract Documents, Contract for Construction), where the Active Concept *'Contract Documents'* and the Passive Concept *'Contract for Construction'* are related by the relation *'form'*. Figure 1 illustrates the relationship between the two concepts.

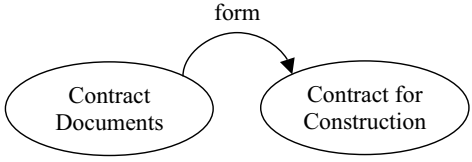


Figure 1: Sample concept set

Based on this semantic representation, the following standard contract clause can be modeled as shown in Figure 2:

> *The Owner shall furnish surveys describing physical characteristics, legal limitations and utility locations for the site of the Project, and a legal description of the site. The Contractor shall be entitled to rely on the accuracy of information furnished by the Owner but shall exercise proper precautions relating to the safe performance of the Work.*

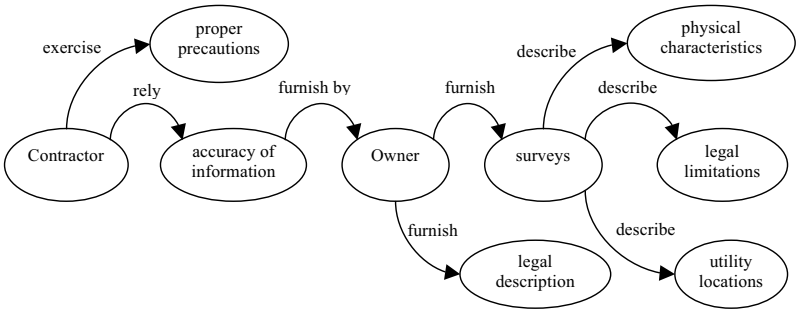


Figure 2: Semantic modeling of a sample contract clause

The CRISP technique utilizes Sundance, a natural language parser developed by the School of Computing at the University of Utah (Riloff and Phillips 2004), to automatically identify and extract possible concept sets from construction contract documents. For the purpose of this research, the document used to evaluate CRISP was AIA Document A201™ – 1997, the American Institute of Architect's General Conditions of the Contract for Construction. Evaluation of CRISP was to be performed by comparing the system's output to the results of seven human evaluators. Since the evaluation of the whole test document by human evaluators was not possible, a sample set of provisions was prepared for the evaluation taking care to avoid any bias in the selection of provisions. Out of the 264 provisions in AIA Document A201™ – 1997, 15 provisions were randomly selected. Of the 15 provisions, six provisions were chosen for the final evaluation set taking into consideration that the evaluation set resembles the original full document in terms of average words per provision and common text features (e.g. lists and enumerations). The evaluation set was processed by CRISP and the extracted concept sets were compiled. Table 1 shows a sample of the output of the system for provision 2.2.3 of Document A201™ – 1997.

Table 1: Sample CRISP output for provision 2.2.3

Ser.	Provision #	Active Concept	Relation	Passive Concept
1	<2.2.3>	the Owner	shall furnish	surveys
2	<2.2.3>	surveys	describing	physical characteristics
3	<2.2.3>	the Contractor	shall be entitled to rely	on the accuracy of information
4	<2.2.3>	the accuracy of information	furnished	by the Owner
5	<2.2.3>	the Owner	shall exercise	proper precautions

HUMAN EVALUATION

Because it is unpractical to have human evaluators evaluating all 264 provisions of AIA Document A201™ – 1997, an evaluation set of provisions was developed as

explained above. A two hour evaluation session was organized for the seven human evaluators. All evaluators were graduate students in civil engineering with practical experience in the construction industry. All of them had previously completed at least one course in construction contracts, the majority completing two or more. A short ten minute presentation was given to outline the objective of the exercise, explain what concept sets are and demonstrate the extraction of Active Concepts, Relations and Passive Concepts from simple sentences. The evaluation exercise was then presented to the evaluators and the evaluators were instructed to try to be as comprehensive as possible in identifying the concept sets. The results of the human evaluators were compiled and prepared in a spreadsheet format similar to the one prepared for the system's output in order to facilitate comparison between both. Figure 3 illustrates the number of concept sets identified by each evaluator for each provision in the evaluation set. Despite the fact that the same provisions were evaluated by all the human evaluators, the results show significant variations in the number of concept sets extracted by the evaluators in most of the provisions. These results clearly highlight the subjectivity of the exercise. Accordingly, two evaluation techniques were used assess the performance of CRISP when compared to the performance of humans: kappa and F-measure.

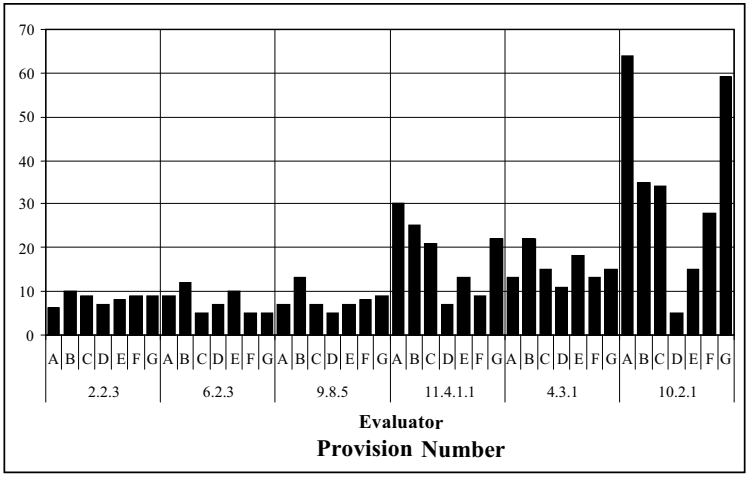


Figure 3: Number of concept sets extracted by human evaluators

KAPPA

Kappa measures the pairwise agreement between two human evaluators, or a human evaluator and the system's output after adjusting for chance agreement (Jurafsky and Martin 2000). Kappa is calculated according to the following equation:

$$k = \frac{P(A) - P(E)}{1 - P(E)}$$

where P(A) is the probability of agreement and P(E) is the probability of chance agreement.

The result of each human evaluator was compared in a pairwise comparison with the results of the other human evaluators and the results of CRISP. In a pairwise comparison, kappa is calculated between the concept sets extracted by the two evaluators for each subsection. All in all, there were 28 comparisons; 21 human-human comparisons, and seven human-computer comparisons.

An average kappa over the six subsections is calculated representing the average agreement between the two evaluators over the complete evaluation set. Finally an average kappa is calculated over the 21 human-human comparisons which is compared to the average kappa of the seven human-computer comparisons. The results emphasized the subjectivity of the investigated issue; on average human evaluators agreed only 41% of the time. On average, CRISP agreed with the human evaluators 19% of the time, achieving slightly less than 50% of the performance achieved by the human evaluators. Table 2 presents the detailed results of this evaluation technique.

Table 2: Kappa scores

Evaluator	A	B	C	D	E	F	G	Average Evaluators
A	--	0.280	0.403	0.394	0.353	0.289	0.433	0.359
B	0.280	--	0.469	0.289	0.282	0.302	0.482	0.351
C	0.403	0.469	--	0.485	0.382	0.479	0.759	0.496
D	0.394	0.289	0.485	--	0.366	0.370	0.469	0.396
E	0.353	0.282	0.382	0.366	--	0.369	0.382	0.356
F	0.289	0.302	0.479	0.370	0.369	--	0.566	0.396
G	0.433	0.482	0.759	0.469	0.382	0.566	--	0.515
Average Evaluators	0.359	0.351	0.496	0.396	0.356	0.396	0.515	0.410
Computer	0.098	0.203	0.230	0.186	0.194	0.172	0.213	0.185

F-MEASURE – PRECISION AND RECALL

Precision, or accuracy, measures the percentage of correct concept sets from the total number of concept sets extracted by the evaluator/system, while recall, or coverage, measures the percentage of correct concept sets extracted by the evaluator/system from the total number of correct concept sets. In order to measure precision and recall, concept sets extracted by the human evaluator and by the system must be identified as either 'correct' or 'incorrect'. The Gold Standard represents the truth, in this case the concept sets that are deemed to be correct. However, because of the subjectivity of the results of the study, the Gold Standard is not readily apparent and must therefore be determined from the results of the human evaluation. The arithmetic total of the concept set extracted by the human evaluators was 640. The number of repetitions of each concept set extracted by the evaluators was identified. Repetition values ranged from a maximum of seven (for a concept set identified by all the evaluators) to a minimum of one (for a concept set identified by only one evaluator). Considering repetition, the actual total number of concept sets was

determined at 314. The next step was to determine a threshold of repetitions according to which a concept set is considered 'correct'. A low threshold increases precision and reduces recall, while a high threshold decreases precision and increases recall. In determining the threshold, the kappa scores achieved by the evaluators were considered. High agreement between the evaluators would justify the use of a high threshold. However, since evaluator agreement proved to be relatively low, a threshold that is slightly towards the low end was used. A concept set is considered correct if at least three evaluators agreed on the concept set. Concept sets that satisfy this criteria were gathered to develop the Gold Standard. Of the 314 concept sets, 71 concept sets made the Gold Standard.

Precision and recall were calculated by comparing the results of the human evaluators and computer output with the Gold standard for each subsection in the evaluation set. Precision and recall values are averaged over the six subsections in the evaluation set to determine the average precision and recall of a human evaluator or the computer output. F-measure is used to combine precision and recall into one measure (Jurafsky and Martin 2000). F-measure is calculated as follows:

$$\text{F - measure} = \frac{(\beta^2 + 1)PR}{\beta^2 P + R}$$

where P is the precision value and R is the recall value.

β is a parameter that is used to assign relative weights to the precision and recall values. At this stage, precision and recall are considered of equal importance; accordingly the value for β is one.

Table 3 lists the precision, recall and F-measure scores for all seven human evaluators and the computer output. Compared with the Gold Standard, the human evaluators achieved an F-measure score of 0.76, while CRISP achieved an F-measure score of 0.42. Similar to the kappa results, CRISP achieved slightly more than 50% of the performance achieved by the human evaluators.

Table 3: Precision, Recall and F-measure scores

Evaluator	Precision	Recall	F-measure
A	0.834	0.615	0.708
B	0.561	0.858	0.678
C	0.904	0.929	0.917
D	0.895	0.588	0.710
E	0.734	0.633	0.679
F	0.708	0.712	0.710
G	0.842	0.978	0.905
Average Evaluators	0.783	0.759	0.758
Computer	0.476	0.376	0.420

CONCLUSIONS

Human interpretation of written text varies from one person to the next depending on many factors such as knowledge, experience, priorities and effort. This observation holds even when the evaluated text is well-structured and with minimum ambiguity such as standard forms of contract. Accordingly, the evaluation of a computer system that tries to resemble humans in their linguistic abilities is not straightforward since there is no clear baseline to judge the performance of the system against.

In this study, two methods were presented for evaluating the performance a computer system that tries to emulate humans in there ability to identify related concepts from text expressed in natural language. In the first method, the degree of agreement of the human evaluators over the investigated task was measured to identify a threshold for what is expected of human performance. The degree of agreement of the computer system with the human evaluators was then compared to this threshold to determine the level of human performance the system was able to achieve. In the second method, a baseline or Gold Standard was developed from the results of the human evaluation, and both the human evaluators and the computer system were compared to this baseline to determine to what degree the performance of the computer system resembled the performance of the human evaluators. The degree of agreement of the human evaluators as determined from the first evaluation method was used for guidance in developing the Gold Standard. From the results of implementing both evaluation methods on the CRISP technique, it can be seen that both evaluation methods produced relatively comparable results which testifies to the validity of both evaluation methods.

ACKNOWLEDGEMENTS

The research team would like to thank Ellen Riloff and Siddharth Patwardhan from the University of Utah for providing us with a copy of Sundance and for their valuable assistance.

REFERENCES

Al Qady, M. (2008). “Concept relation extraction using natural language processing – the CRISP technique.” Master Thesis, Iowa State University, Ames, Iowa, USA.

Asprey, L. (2004). “Information strategies: Are we aligning the business case with enterprise planning?” *Rec. Manage. J.*, 14(1), 7–13.

Carrillo, P.M., Robinson, H.S., Al-Ghassani, A.M. and Anumba, C.J., (2004). “Knowledge management in UK construction: strategies, resources and barriers.” *Proj Manage J*, 35(1), 46-56.

Chinowsky, Paul and Molenaar, Keith (2005). “Learning organizations in construction.” *Proc., Construction Research Congress 2005: Broadening Perspectives*, ASCE, Reston, Va., 839-848.

Clough, Richard H., Sears, Clenn A., and Sears, S, Keoki. (2000). *Construction project management*, 4th Ed., Wiley, New York.

El-Diraby, T. E., and Kashif, K. F. (2005). “Distributed Ontology Architecture for Knowledge Management in Highway Construction.” *J. Constr. Engrg. and Mgmt.*, 131(5), 591-603.

Gomez- Pérez, A. (1998). "Knowledge sharing and re-use." *Handbook of applied expert systems*, J. Liebowitz, ed., CRC, Boston.

Gómez-Pérez, Asunción, Fernández-Lopez, Mariano, and Corcho, Oscar (2004). *Ontological engineering: with examples from the areas of knowledge management, e-commerce and the semantic web*, Springer-Verlag, London.

Gruber, T.R. (1993). "A translation approach to portable ontology specification." *Knowledge Acquisition*, 5(2), 199-220.

Jung, Youngsoo, Kang, Seunghee, and Choi, In-Sung (2006). "Strategic knowledge management for building engineering and construction." *Proc., 2006 Architectural Engineering National Conference: Building Integration Solutions*, ASCE, Reston, Va., 56-66.

Jurafsky, Daniel, and Martin, James H. (2000). *Speech and language processing*, Prentice Hall, New Jersey.

Lame, Guiraude (2004). "Using NLP techniques to identify legal ontology components: Concepts and relations." *Artificial Intelligence and Law*, 12(4), 379-3.

Laudon, K. C., and Laudon, J. P. (1998). *Management information systems*, Prentice-Hall, Englewood Cliffs, N.J.

McGee, J., and Prusak, L. (1993). *Managing information strategically*, Wiley, New York.

Rezgui, Y. (2001). "Review of information and knowledge management practices state of the art in the construction industry." *Knowl. Eng. Rev.*, 16(3), 241–254.

Riloff, Ellen and Phillips, William (2004). "An introduction to the Sundance and AutoSlog system." <http://www.cs.utah.edu/~riloff/pdfs/official-sundance-tr.pdf> August 2007.

Saias, Jose, and Quaresma, Paulo (2004). "A methodology to create legal ontologies in a logic programming based web information retrieval system." *Artificial Intelligence and Law*, 12(4), 397-417.

Shamsfard, Mehrnoush, Barforoush, Ahmad Abdollahzadeh (2004). "Learning ontologies from natural language texts." *Int. J. Human-Computer Studies*, 60(1), 17-63.

Studer, R., Benjamins, V.R., Fensel, D. (1998). "Knowledge engineering: Principles and methods." *IEEE Transactions on Data and Knowledge Engineering*, 25(1-2), 161-197.

Wetherill, M., Rezgui, Y., Boddy, S., and Cooper, G. S. (2007). "Intra- and interorganizational knowledge services to promote informed sustainability practices." *J. Comp. in Civ. Engrg.*, 21(2), 78-89.

TECHNIQUES TO MINIMIZE BIAS WHEN USING THE DELPHI METHOD TO QUANTIFY CONSTRUCTION SAFETY AND HEALTH RISKS

Matthew R. Hallowell[1]

ABSTRACT

The dynamic and transient nature of construction projects makes construction engineering and management research particularly challenging. For example, experimental research on safety, risk management, innovation, and technology forecasting is often unrealistic due to the sensitivity and complexity of these topics. The Delphi technique, originally developed by the Rand Corporation to study the impact of technology on warfare, allows researchers to maintain significant control over bias in a well-structured, academically-rigorous process using the judgment of qualified experts. The Delphi method is particularly useful when objective data is unattainable, there is a lack of empirical evidence, experimental research is unrealistic or unethical, or when the heterogeneity of the participants must be preserved to assure validity of the results. In this paper, the authors review eight forms of bias that literature in the field of social psychology identifies as detrimental to judgment-based studies such as the Delphi method. Additionally, several techniques are reviewed that should be incorporated into the Delphi method to control for the identified biases. Special attention is focused on the use of these techniques when using the Delphi method to identify and quantify construction safety and health risks.

INTRODUCTION

Conducting research in the field of construction engineering and management (CEM) is often difficult because of the complex and transient nature of modern projects. Characteristics such as dynamic work environments, industry fragmentation, multilingual work crews, customized projects, and exposure to weather often make traditional, objective research methods unrealistic. As a result, many CEM researchers must rely on subjective methods that sometimes compromise academic rigor. For example, researchers tend to rely on surveys, interviews and focus groups to collect safety data. The use of such methods is especially prevalent in construction

[1]Ph.D., A.M. ASCE, Asst. Prof., Civ., Envir., and Arch. Engrg., University of Colorado at Boulder, 428 UCB, Boulder, CO 80309-0428; Tel.: 570-205-6233; Fax: 303-492-7317; E-mail: matthew.hallowell@colorado.edu.

safety and health research. These research techniques, while appropriate in some circumstances, are limited by the knowledge of the facilitator, are constrained to one geographic location, or may be biased by respondents' subconscious cognitive shortcuts. Using biased results to influence safety management activities or work processes may have negative impacts on the welfare of the construction workforce. Therefore, researchers must take all possible efforts to minimize forms of bias during safety and health research studies.

Highly-rigorous construction safety and health research is particularly challenging. Since most studies involve the investigation of worker-hazard interactions, experimental research techniques are inappropriate because of their potential impact on the health and welfare of the workers. While archival data is collected by the Occupational Health and Safety Administration (OSHA) and the Bureau of Labor Statistics (BLS), the data is incomplete and only reflects high-severity injuries reported by large contractors. Despite these challenges, rigorous construction safety and health research is essential.

In 2004, the National Safety Council found that the construction industry accounted for over 460,000 disabling injuries resulting in an estimated cost of $15.64 billion (NSC 2006). When compared to other industries, construction accounts for approximately twelve percent of the occupational fatalities in the US and consistently has the third highest fatality rate of all US industries. Furthermore, the construction industry for a recordable injury rate of nearly five times the all-industry average.

The figures cited above suggest a strong need for construction safety and health research with findings that can be used to significantly improve site safety. The sensitive and complex nature of this research field, however, make traditional, objective research methods infeasible. This is true because of the numerous interrelated factors that often confound construction safety and health research topics. Therefore, a highly-rigorous, subjective research technique with application to safety and health research is clearly needed.

The primary objective of this paper is to present a well-structured research method that can be used to collect highly-reliable subjective safety and health data. Included is a brief overview of the Delphi method, a discussion of the applicability of the method to construction safety and health research, a review of the benefits and limitations of the method, and a summary of techniques that can be implemented to minimize judgment-based bias. The Delphi method will be shown to be a strong research technique with great potential for collecting highly-reliable and unbiased construction safety and health data.

Before proceeding, several essential terms must be described or distinguished. In this paper, rigorous research includes any disciplined and systematic data collection method that results in data that are both valid and reliable. Subjective research methods are distinguished from objective research methods because they rely on the collection of data from individual experiences and opinions rather than experiments

or observation. Finally, qualitative data are different from quantitative data in that they do not require the collection of measurements, ratings, or numbers.

OVERVIEW OF THE DELPHI METHOD

The Delphi technique, originally developed by the Rand Corporation to study the impact of technology on warfare, allows researchers the ability to maintain significant control over bias in a well-structured, academically-rigorous process using the judgment of qualified experts. The method is defined as a systematic and interactive research technique designed to obtain consensus in judgment of a panel of independent experts. The Delphi method is particularly useful when objective data is unattainable, there is a lack of empirical evidence, experimental research is unrealistic or unethical, or when the heterogeneity of the participants must be preserved to assure validity of the results. Despite its application to construction engineering and management, this well-defined and highly successful research method has not seen widespread use.

Effective implementation of the Delphi method requires the careful and deliberate execution of several steps. Typically, the process begins by selecting expert panelists according to predefined guidelines. Potential panelists are provided with a description of the study and are asked to participate in two or more rounds of structured surveys. After each round, the facilitator provides an anonymous summary of the experts' input from the previous round. In each subsequent round, participants are encouraged to review the anonymous opinion of the other panelists and consider revising their previous response. During this process the variability of the responses is expected to decrease until a reasonable level of consensus is achieved. Finally, the process is concluded after a pre-defined criterion (e.g., number of rounds, achievement of consensus, etc.) is met and the mean scores of the final round or the qualitative conclusions determine the results. Unlike traditional surveys, the Delphi method requires multiple rounds, controlled feedback, and the use of certified experts.

Delphi should be considered when selecting a subjective research method because it offers a highly-structured method of obtaining high quality results. In an extensive study of research methods, Rowe and Wright (1999) found that the Delphi method produced the most accurate and reliable results when compared with other commonly-used subjective research techniques. Other literature supports the Delphi method for the following reasons:

- Consensus can be achieved in an area of uncertainty or when objective data is unavailable (Murphy, Black, et al. 1998)
- Anonymity leads to more creative outcomes and adds richness to data (Linstone and Turoff 1975)
- Anonymity and controlled feedback eliminates issues such as dominance, conflict of interest, and group pressures that are commonly associated with expert panels (Murphy, Black, et al. 1998)

- A geographically dispersed group of expert panelists may be selected extending the potential scope of inference of any conclusions (Hallowell 2008)
- Bias can be limited by specific techniques executed by an effective facilitator by strategically constructing questionnaires, administration of controlled feedback, and careful analysis of the group response (Hallowell 2008)

As one can clearly see, the Delphi method has many benefits over traditional subjective research methods. The ability to draw conclusions from expert judgment in a controlled process is especially beneficial in safety and health studies due to the limitations in the field of safety and health research. The following section of the paper discusses the applicability of the Delphi method to safety and health research.

As indicated previously, there are several challenges associated with construction safety and health research. Figure 1 illustrates the salient challenges of safety and health research and notes how the Delphi method can be used to counteract each of the challenges. According to Figure 1, the Delphi method is inherently well-suited to construction safety and health research. Despite the benefits and applicability, however, the Delphi method has received harsh criticism in some publications.

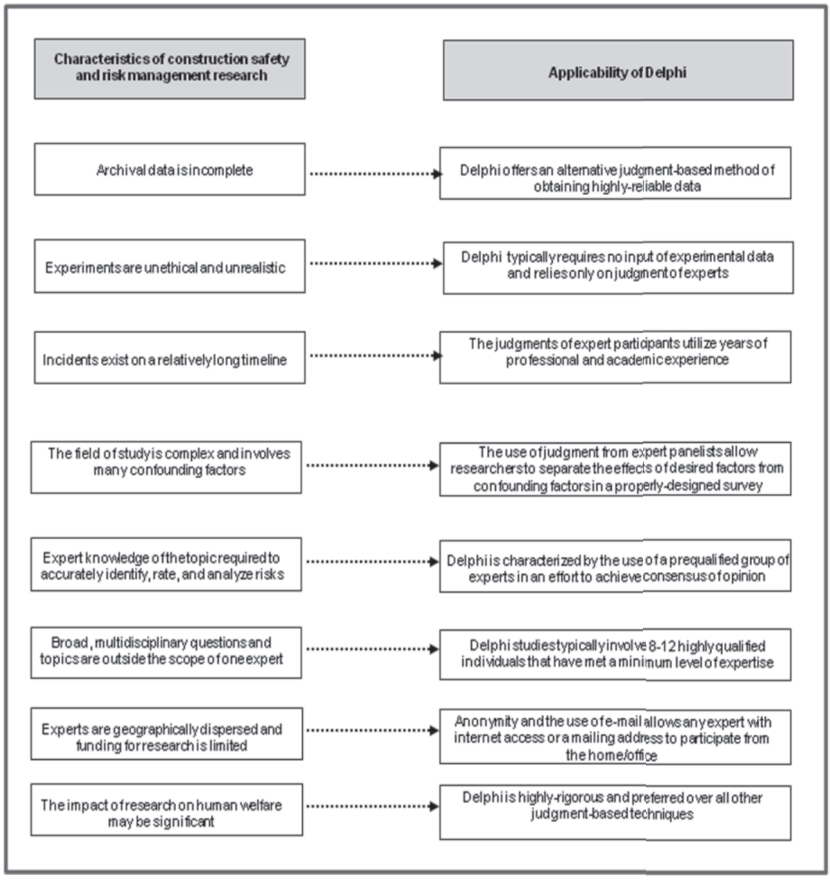


Figure 1 – Applicability of the Delphi method to safety and health risk research

LIMITATIONS OF THE DELPHI METHOD

The implementation of the Delphi method has been criticized because variations in methodology have resulted in poor execution and questionable results. In fact, some authors suggest that the Delphi method as it has been traditionally implemented is unscientific (Sackman 1974). Specific criticisms include the following: the quality of the conclusions are limited by the expertise of the panel members (Veltri 1985), convergence of opinion is actually conformity (Rowe and Wright 1999), the results are often limited because of the poor quality of the facilitator's survey instruments (Gupta and Clark 1996), bias can occur if questions are poorly worded (Lang 1998), and the procedure can be overly time intensive creating a burden for the facilitator and participants (Rajendran 2007). The most worrisome criticisms for academic researchers are those that indicate that Delphi is a technique which allows for significant bias.

Any highly rigorous and defendable research study must hold the minimization of bias paramount. Bias in judgment is important to consider because cognitive shortcuts that distort the true nature of opinion or observation may lead to inaccuracies resulting from the shortcuts (Heath, Tindale et al. 1994). Unlike objective methods where bias is mainly introduced by the researcher, the success of the Delphi process depends on the unbiased judgment of experts. Studies that focus on safety and health should involve the absolute minimum bias as the results of the study may influence the welfare of the construction workforce. Because of the potential influence of cognitive biases in Delphi studies, the salient biases that affect risk quantification were identified in social science literature and several techniques were designed for a recent safety and health risk study (Hallowell 2008). This research resulted in the collection and validation of highly complex safety and health risk data.

It is important to note that the Delphi technique is not suitable for all types of research. For example, when expert panelists reside or work in the same geographical region and the timeline for the research project is relatively short, focus groups or the Nominal Group Technique are preferable. Furthermore, Delphi studies are not ideal for studying "how" or "why" questions that require specific context. Such research is better-suited for case studies or case histories. Rather, Delphi is better-suited for "what," "when," and "where" questions that focus on contemporary events or complex relationships.

ENHANCING THE RIGOR OF THE DELPHI METHOD

The success of a Delphi study primarily depends on the quality of the judgment of the expert panelists. Judgment is a skill that is used in decision making when factual information is absent and is the primary mechanism for data collection in any Delphi study. Judgment is typically manifested as a result of one or more of the following cognitive processes: diagnostic judgment, induction, and interpretive reasoning. Diagnostic judgment utilizes intuition, visualization, organization and structuring of evidence, and the understanding of relationships to reach a conclusion. Inductive reasoning requires the synthesis of evidence and information from a variety of sources. Lastly, one may utilize interpretive reasoning where conclusions are drawn based on the recognition of patterns, spatial relationships, correlations, and causal relationships. The ability to use one or more of these mechanisms to draw correct conclusions is directly related to an individual's experience, observations, and ability to recognize and process evidence.

In a Delphi study it is assumed that identified experts are uniquely capable of providing proficient judgment using one or more of the three reasoning methods identified above due to their extraordinary experience or intelligence. Despite the expert status of the panelists, bias may still exist. Bias may occur when one subconsciously uses cognitive shortcuts to reach erroneous conclusions. Eight salient judgment-based biases that may affect risk perceptions are defined in Table 1.

The biases in Table 1 represent the salient biases for most construction-related studies involving the use of questionnaires. Depending on the nature of the research, the facilitator may need to review social psychology literature to identify other potential biases. Once biases are identified, it is essential to take all reasonable steps available to control and minimize their potential effects. The following section of the paper defines some methods for designing a Delphi study to minimize and avoid the eight biases discussed.

Techniques that may be implemented to minimize bias

In order to prevent the negative impact of bias on the results of a recent study, the author used six techniques aimed at minimizing or eliminating each of the biases defined in Table 1. A brief description of the six controls and the specific biases that they target are described below.

Randomize of questions in the survey

In the field of statistics, the most prominent method of bias reduction is the use of randomization. Randomization is a control available to researchers that ensures that every subset of the greater population has an equal chance of being selected. Randomization may be achieved through the use of many methods. For example, researchers can use workbooks with random number tables, the last four digits in telephone directories, or a pseudo-random number generator such as MS Excel. The order of questions in the Delphi questionnaires may be randomized for each panel member and a new randomized order may be created for each round. Randomization of the question order is an effective method for eliminating the primacy and contrast biases provided that the panel size and questionnaire length is sufficiently large.

Require individual probability and severity ratings

In a recent study, the Delphi method was employed to quantify the probability and severity of the safety and health risks associated with the activities required to construct concrete formwork. Methods to reduce probability were specifically targeted to risk quantification. One specific technique was the requirement of separate probability and severity ratings when quantifying risk. By requiring independent ratings, the potential effect of the neglect of probability bias is eliminated.

Table 1 – Judgment-based biases

Bias	Source(s)	Description
Collective unconscious	Durkheim (1982)	The theory of collective unconscious (i.e., the bandwagon effect), states that decision makers tend to join a popular trend. In other words, individuals are likely to unconsciously feel pressure to conform to the common or standard beliefs within a particular group.
Contrast effect	Bjarnason and Jonsson (2005)	The contrast effect occurs when the perception of a given subject is enhanced or diminished by the value of the immediately preceding subject. In theory, the contrast effect can cause significant bias, especially when individuals are asked to rate back-to-back factors .

Neglect of probability	Martin (2006); Rottenstreich and Hsee (2001)	There are many cases where individuals underestimate the role of probability in the subjective quantification of risk. This bias involves the disregard of likelihood when making a decision under uncertainty. Any study that involves risk quantification or ratings of likelihood may be susceptible to the neglect of probability bias.
Von Restorff effect	Restorff (1933); Krimsky and Golding (1992)	The Von Restorff Effect was first introduced to the field of psychology when subjects were found to recognize and remember relatively extreme events more often and more accurately than less extreme events. In theory, individuals are more likely to remember events associated with severe outcomes thereby distorting the perception of probability. This effectively creates an artificially inflated risk score for potential events associated with a higher level of severity.
Myside bias	Perkins (1989); Baron (2003)	Myside bias occurs when an individual generates arguments only on one side of an issue. Participants can be easily prompted for additional arguments on the other side, although prompting for further arguments on their favored side is less effective. The persistence of irrational belief is generally a result of one's personal opinion with little basis in pure fact.
Recency effect		The recency effect occurs when subjects are more likely to artificially inflate risk ratings because similar incidents have recently occurred in their personal lives (i.e., recent events are given inappropriate levels of salience in relation to others). The effect of recency is relatively common.
Primacy Effect		The primacy effect results from the unconscious assignment of importance to initial questions, observations, or other stimuli. The theory states that individuals are inherently more concerned with initial stimuli.
Dominance	Linstone and Turoff (1975)	Dominance occurs when one, usually very vocal group member, exhibits great control over the ratings of the other members. This common source of bias is typical in studies that attempt to gather group opinion such as the Nominal Group Technique or focus groups.

Include reasons in controlled feedback

Best (1974) found that Delphi groups that were given feedback of reasons in addition to median and range of estimates were significantly more accurate than Delphi groups that were provided with only the latter. In addition to probability and severity ratings, expert panel members may be asked to provide a very brief justification for their ratings as a part of each round. This control minimizes the potential effects of the Von Restorff Effect, myside bias, and the Collective Unconscious.

Conduct multiple rounds of surveys

Iteration is an essential component of any Delphi study. The primary role of iteration is to achieve a high degree of consensus among panel members. Iteration involves the redistribution of the Delphi survey accompanied with controlled feedback (i.e., simple statistical summaries of the responses). This action combined with the preservation of anonymity eliminates the dominance bias and minimizes the effects of the Von Restorff Effect.

Identify individuals that have experienced recent, relevant events

In the introductory survey Delphi potential panel members may be asked a series of questions related to relevant recent personal experiences. Respondents who indicate recent exposure to a relevant condition should be monitored during or removed from the Delphi process. This control minimizes the potential effects of the recency effect.

Report results as medians rather than means

Results of safety risk studies should be reported using median values instead of mean values. Reporting medians minimizes the effects of all forms of bias as singular outlying responses typically have little or no impact on the final value.

Each of the methods described are easy to implement though some, such as repeated randomization, may require a significant time investment. After using these techniques in a recent study, the author noted that the study produced a high level of consensus among participants, thoughtful responses, and easily validated data.

CONCLUSIONS

Construction safety and health is a uniquely challenging research field. Subjective research techniques typically used to investigate safety and health topics do not offer sufficient controls to minimize bias. The Delphi method is an alternative research technique that can be used to obtain expert judgment through a controlled process. The method is well-suited to construction safety and health research and specific controls may be implemented to minimize judgment-based bias that affects other subjective research methods.

This paper reviewed the objectives, benefits, and limitations of the Delphi method and illustrates how the method is well-suited to construction safety and health research. Additionally, judgment-based biases that may impact the quality of Delphi results were reviewed and several techniques developed to minimize or eliminate the biases in a recent study were reviewed.

Methods of bias reduction in safety and health risk studies include randomizing questions in the survey, requiring individual probability and severity ratings, including reasons in controlled feedback, conducting multiple rounds of surveys, identifying individuals that have experienced recent, relevant events, and reporting results as medians rather than means. By following the techniques suggested in this paper, the Delphi research method can be used produce highly-reliable results when traditional objective methods are inappropriate or when other subjective methods fail.

REFERENCES

Baron, J. (2003). *Myside bias in thinking about abortion,* University of Pennsylvania Press, Philadelphia, PA.

Best, R. J. (1974). "An experiment in Delphi estimation in marketing decision making." *Journal of Marketing Research,* 11(1), 448-452.

Bjarnason, T. and Jonsson, S. H. (2005). "Contrast Effects in Perceived Risk of Substance Use." *Substance Use and Misuse,* 40(1), 1733-1748.

Durkheim, E. (1982). *The Rules of the Sociological Method,* Free Press, New York.

Gupta, U. G. and Clarke, R. E. (1996). "Theory and applications of the Delphi technique: a bibliography (1975-1994)." *Technological Forecasting & Social Change* 53(2), 185-211.

Hallowell (2008) "A Formal Model of Construction Safety and Health Risk Management." Doctoral dissertation, Oregon State University, Corvallis, OR.

Heath, L. and Tindale, R. S. (1994). *Applications of Heuristics and Biases to Social Issues*, Plenum Press, New York.

Lang, T. (1998). "An overview of four futures methodologies." <http://www.soc.hawaii.edu/~future/j7/LANG.html.> (Jul. 31, 2008).

Linstone, H.A. and Turoff, M. (1975). *The Delphi Method: Techniques and Applications*, Addison Wesley, Reading, MA.

Martin, W. (2006). *Theories of Judgment*, University Press, Cambridge.

Murphy, M. K., and Black, N.A. (1998). "Consensus development methods and their use in clinical guideline development." *Health Technology Assessment,* 2(3), 1-21.

National Safety Council (2006). *Accident facts*, Itasca, Ill.

Perkins, D. N. (1989) "Reasoning as it is and could be: An empirical perspective." *Thinking across cultures: The third international conference on thinking*, Erlbaum, Hillsdale, NJ.

Rajendran, S. (2006). "Sustainable construction safety and health rating system." Ph.D. dissertation, Oregon State University, Corvallis, OR.

Restorff, H. V. (1933). "Über die Wirkung von Bereichsbildungen im Spurenfeld." *Psychologie Forschung*, 18, 299-334.

Rogers, M. R. and E. C. Lopez (2002). "Identifying critical cross-cultural school psychology competencies." *Journal of school psychology*, 40(2), 115-141.

Rottenstreich, Y. and C. K. Hsee (2001). "Money, kisses, and electric shocks: on the affective psychology of risk." *Psychological Science*, 12, 185-190.

Rowe, G. and G. Wright (1999). "The Delphi technique as a forecasting tool: issue and analysis." *International Journal of Forecasting,* 15, 1-23.

Veltri, A. T. (1985). "Expected use of Management Principles for Safety Function Management." Doctoral dissertation,"West Virginia University, Morgantown, WV.

OPINION-BASED RESEARCH: LESSONS LEARNED FROM FOUR APPROACHES

David N. Sillars[1] and Matthew R. Hallowell[2]

ABSTRACT

Selecting an appropriate research method is a critical step in any rigorous research effort. The selected research methodology impacts the data collected, the scope of inference, and the ability to draw defendable conclusions. Many times the nature of the construction industry and the sensitivity of information limit researchers' ability to conduct experimental, empirical, or observational studies that rely on objective data. In such circumstances, alternative methods of research that utilize expert judgment and opinion may be considered. Several techniques such as group-brainstorming, the Delphi method, the Nominal Group Technique, and surveys may be appropriate. However, selecting one or more of these research methods depends largely on the nature, resources, and limitations of the research study. This paper reviews four major approaches of obtaining expert opinion, describes lessons learned on four independent, major studies, and provides a framework to consider when selecting a specific method given project characteristics. The resulting flowchart can be used to aid in selection of a research method given the specific characteristics of the study such as limitations in time and funding, desired information, and location and availability of participants.

INTRODUCTION

Researchers that study the construction industry often find it difficult to draw strong conclusions from traditional objective research methods, such as experimental research and data mining. Unlike some fields such as biology, chemistry, and structural engineering, experiments in controlled environments are typically

[1] Assoc. Prof., School of Civil and Constr. Engrg., Oregon State University, Corvallis, OR 97331; Tel.: 541-737-8058; E-mail: david.sillars@oregonstate.edu

[2] Asst. Prof., Civ., Envir., and Arch. Engrg., University of Colorado, Boulder, CO 80309-0428; Tel.: 303-492-7994; E-mail: matthew.hallowell@colorado.edu

impractical or unethical. Because the scale of construction is typically very large and long in duration, it is impractical to replicate in an experimental setting. Researchers must often rely on extensive and expensive site-based observations (case studies) or the recollections of industry players in order to obtain any results. Further, in an effort to achieve generalization within tight margins of error, a statistically-appropriate number of cases must be examined, increasing time and cost quite often to the point of impracticability. When implementing these methods, the inherent characteristics of the construction industry often complicate research studies. Examples of confounding factors include: the lack of standardized procedures, complex building and infrastructure systems, multiple firms with conflicting goals, and the transient nature of construction projects.

Due to these characteristics, it may be difficult to draw strong and statistically-justifiable conclusions from objective research techniques and statistical comparisons because p-values and correlation coefficients often indicate very low statistical strength, owing to a paucity of data points. In these circumstances, researchers often use opinion-based subjective data to support, validate, or verify conclusions. For example, Hallowell and Rogge (2007) used subjective data from interviews to bolster moderately-strong statistical comparisons of benchmarking data. While this research approach was successful with benchmarking data, other types of studies such as risk quantification, safety and health management, and identification of influential factors are especially vulnerable to confounding factors and lack of research resources, and often cannot produce even moderate statistical evidence in objective studies.

When studying fields like risk and safety, researchers tend to rely on subjective methods that require the input of well-qualified respondents to obtain data (Tang et al. 2007). For the purpose of this article, subjective methods rely on opinion-based information, generally gathered from experts or participants; conversely, objective methods rely on data (such as recorded schedule information) that is measured in a fashion that is subject to interpretation and therefore is likely less subject to the bias of the subject from which the information is obtained. When selecting a subjective research method there are several options including: traditional surveys or interviews, the Delphi technique, the Nominal Group technique (NGT), or focus groups. While there are many variations on these research methods, these four methods dominate subjective research studies. In fact, a review of construction safety and health literature indicates that over seventy percent of studies published in the ASCE *Journal of Construction Engineering and Management* rely on one or more of the subjective research methods listed above.

When implementing subjective research methods, the quality of the results is largely dependent on the rigor of the research method implemented, the knowledge and effort of the researcher, and the expert judgment of the respondents (Hallowell 2008). While some of the subjective techniques are inherently more rigorous, there are varying degrees of rigor within each method that depend on the specific structure and controls of the methods.

The objectives of this paper are to provide the reader with a brief overview of four subjective research methods, identify the benefits and limitations of each, and to create a flowchart that can be used to aid researchers with the selection of an appropriate research methodology given the characteristics of their study.

LITERATURE REVIEW

Four major research methods for obtaining expert opinion will be discussed in this paper with the objective of providing a structure for selecting the appropriate research method given specific project characteristics. Before proceeding, it is necessary to define the typical characteristics of each of the four methods. While there are many similarities among these methods, this literature review will focus on the subtle differences. One should note that there may be many variations or alternative techniques of the four methods reviewed below.

Staticized Group Techniques

Surveys and structured interviews are grouped into one category known as Staticized Group Techniques (SGTs). SGTs are characterized by one round of information gathering from knowledgeable individuals with moderate interaction between the facilitator and the respondents, and little to no communication among the respondents (Dayananda 2002). Also, study participants may be geographically dispersed. Both surveys and structured interviews involve the collection of subjective input from qualified respondents and the subsequent aggregation of the results. Surveys are typically used when the instructions and objectives are clear and the desired input can be organized on a survey form. Structured interviews, however, are typically used when the objectives of the study are complex and difficult to explain concisely on a survey form and when detailed information is required (Burleson et al. 2006). The structure of these methods is similar to Delphi except that they do not include feedback or multiple rounds. That is, staticized group techniques involve aggregate responses of experts from one round of questioning.

Focus Groups

Studies that use focus groups, otherwise known as ‘interacting groups’, involve collecting experts in one physical location where they may communicate with one another face-to-face in real time (Webb and Keveren 2001). With this method, the panel members are not anonymous and participate in a single round of intense information gathering. The goal of a focus group is to obtain consensus among the group of expert participants. While focus groups are helpful in expediting information-gathering, the main pitfalls are that opinions are swayed by other member’s dominance and status and that it is often infeasible to collect groups of experts in one location.

Delphi

The Delphi method is a systematic and interactive research technique used to obtain the judgment of a panel of independent experts on a specific topic. Individuals are

selected according to predefined guidelines and are asked to participate in two or more rounds of structured surveys. After each round, the facilitator provides an anonymous summary of the experts' input from the previous survey. In each subsequent round, participants are encouraged to independently review the anonymous opinion of the other panelists and consider revising their previous response. The goal during this process is to decrease the variability of the responses and achieve group consensus about the correct value. Finally, the process is concluded after a pre-defined criterion is met and a statistical aggregation of the responses in the final round determines the results. Respondents are certified as experts according to predefined guidelines before the survey process begins, and consensus is achieved through the use of controlled and anonymous feedback provided by the facilitator during each round (Hallowell 2008).

Nominal group technique

The Nominal Group technique (NGT) is also referred to as 'estimate-talk-estimate' or 'Brainstorming NGT'. The NGT procedure uses the Delphi process except that feedback is delivered through face-to-face meetings and discussions between rounds (Sample 1984). This method has been proven effective in expediting the data collection procedure but sometimes results in biased outcomes and conformity (Erffmeyer and Lane 1984). Like focus groups, NGT may also be difficult to conduct because it requires the collection of experts in one geographical location.

SELECTING AN APPROPRIATE RESEARCH METHOD

Each of the four research methods reviewed has benefits and limitations. For example, studies that use surveys can be completed much more quickly than studies that rely on the Delphi method. Additionally, studies that use the nominal group technique may be more rigorous than surveys when expert participants are available and are located in one geographic region. Table 1 summarizes the characteristics of the various research methods. Selecting an appropriate method depends largely on the characteristics of the study, intended use of the data, time available for the study, the geographic location of the informants, and the knowledge and qualifications of the facilitator.

Table 1 – Method Characteristics

	Staticized Group Techniques	**Focus Groups**	**Delphi**	**Nominal Group Technique**
Informant-informant communication level	Low	High	Low	High
Researcher-informant communication level	Low	Medium	High	High
Number of rounds/feedback	none	1/none	2-3/controlled	2-3/controlled

As one can see from Table 1, the SGTs and the Delphi method involve a relatively low level of communication among participants whereas focus groups and the NGT

are characterized by a high level of face-to-face communication. Furthermore, the Delphi method and the NGT have a high level of communication between the informants and the facilitator of the study and involve multiple rounds of questionnaires while focus groups and SGTs usually have a lower level of informant-researcher communication and require only one round of questioning.

The characteristics summarized in Table 1 lead to benefits and limitations associated with each method. For example, the Delphi method is highly rigorous and may utilize a geographically-dispersed panel of experts but requires a relatively long timeline to complete the data collection phase of the study. Alternatively, studies that implement focus groups tend to be less capable of reducing bias (e.g., dominance bias), typically utilize a group of panelists from one major geographic location but can be completed in a very short timeline. The benefits and limitations of the four studies are summarized in Table 2.

As one may infer from Table 2, there is no one method that is appropriate for all studies. Therefore, one must compare the options available with the characteristics of the study. During the course of many years of research in the construction industry, the authors have implemented or participated in each of the four methods of obtaining expert opinion. The lessons learned during these studies, and the benefits and limitations presented in Table 2 are complemented by the decision tree depicted in Figure 1.

Table 2 – Relative Benefits and Limitations

	Staticized Group Techniques	**Focus Groups**	**Delphi**	**Nominal Group Technique**
Timeline required	Medium	Low	Long	Low
Ability to involve diverse geographical regions	High	Low	High	Low
Ability to reduce bias	Medium	Low	High	Medium
Typical qualifications of informants	Low	Medium	High	Medium

Limiting
Neutral
Beneficial

Lessons learned

To provide practical examples of the use of each of the four methods, the following section of the paper briefly discusses four large-scale studies, each involving the use of one of the four research methods described in this paper. The lessons learned and justification for implementation of each method is highlighted.

Staticized Group Technique (Survey)

As part of a research study into construction joint ventures (Sillars 2003), a survey form of research was used to determine the practices and experiences of joint venturers in the A/E/C industry. This form of study was chosen in order to provide data that could be generalized across the U.S. industry and to provide data that would be suitable for inference-based statistical analysis and hypothesis testing. The study group consisted of the ENR Top 400 Contractors and the ENR Top 500 Designers. The research was undertaken largely following the procedures outlined by Salant and Dillman (1994).

The survey instrument was developed to draw on the respondent's recent experience with a joint venture, asked for facts surrounding the joint venture at its inception, and asked for evaluations on success and the post-operational factors of success.

A survey pretest was conducted, soliciting the opinions of 13 experts in the architectural, construction and academic communities; the comments provided were useful in correcting deficiencies which would have been disastrous if left undiscovered during the actual survey. The survey was sent to the entire population of design and construction firms in two major waves, using the following methodology:

- **Notification 1** consisted of a short note informing the population of the coming survey.
- **Notification 2 (Wave 1)** was the initial transmittal of the final survey with a cover letter. This wave resulted in a return of 19.6 percent of the population.
- **Notification 3** was sent approximately two weeks after Wave 1, requesting that the non-respondents complete and return the survey.
- **Notification 4 (Wave 2)** was a new transmittal of the entire survey to non-respondents with a new cover letter, resulting in an additional 15.8 percent of the population.

The survey generated a total 35.4 percent response, and was a successful application of this technique. The survey produced data which were sufficient for reliable statistical analyses. Some of the key features which contributed to the success were a careful preparation of the survey itself, ensuring that the questions were carefully crafted to parsimoniously include those questions targeted for specific hypotheses, thus keeping the respondents' time to a minimum. Further, although most of the survey questions were closed questions to provide for statistical comparison among the answers, a few open-ended questions were included. The open-ended questions provided additional, valuable insight into the problem.

Focus Groups

Focus groups are commonly used to discover problem solutions for which solution choices are not well-formulated. Using focus groups for problem is often desired because participants are located in one physical area and the desired timeline for data collection is short. In construction research, where participants from multiple firms are desired, this research method may be difficult to implement due to competitive secrecy.

In 2006, the NEXCON Conference was held in Portland, Oregon. The purpose of this conference was to collect individuals from the local construction industry to address construction safety and health issues. Participants in the conference included representatives of government agencies (e.g., OSHA inspectors), researchers from local universities, and owner, contractor, and designer representatives from the local construction industry.

The conference was unique in that it was not dominated by speaker presentations. Rather, the facilitator posed a series of questions to focus groups comprised of diverse interests. Using scribes, laptops and a specialized data collection platform, the responses from the focus groups were collected and analyzed by the facilitators.

The study was successful because the data collection was completed over the course of the two-day conference and data was used to improve construction safety and health issues in the Pacific Northwest. However, the results of the study were limited because a few individuals tended to dominate the conversations, leading to bias. Further, the scope of inference of the results was limited because the majority of the participants were from the Portland area. Nevertheless, the methodology was appropriate for this study because the objective was to collect information for the Pacific Northwest construction industry, congregate a diverse group of participants for face-to-face meetings, and to collect data quickly.

Delphi

The Delphi method was implemented in recently-completed research on construction safety risk management (Hallowell 2008). One of the objectives of this study was to quantify the probability and severity of construction safety and health risks for the activities associated with the construction of concrete formwork. Initially, objective research methods were considered in lieu of subjective techniques. However, it was determined that archival data was incomplete and objective research methods were unethical and inappropriate.

The Delphi method was chosen for the study because academic rigor was of the utmost importance, a relative long timeline was acceptable, and the researchers desired to involve extremely well-qualified and geographically-dispersed participants. The study was successful because participants were allotted sufficient time to respond, experts were objectively qualified and verified as experts, and specific controls were developed to minimize bias during the research process.

Nominal Group Technique

A current research project conducted for the Oregon Department of Transportation (ODOT) involved establishment of an expert system for contracting alternative decisions. The intent of this project was to recreate and systematize the collective decision-making of a group of well-experienced individuals at ODOT. It was determined that the Nominal Group Technique (NGT) would be the best choice to meet these needs as it most closely simulated the actual, collective process by which the contracting alternative decisions are made at ODOT.

Six individuals were chosen for their expertise and contrasting perspectives in the area of study. These individuals were provided material explaining the proposed model and its theoretical underpinnings, and when gathered, an additional discussion of the proposed model was undertaken.

The individuals were gathered for a half-day meeting to collect data to populate the model; this was a difficult task as these important individuals were extremely busy. The meeting consisted of asking for a collective opinion about the degree of success of a particular contracting method, given various project factors. To obtain the collective opinion, each individual was first asked to form their opinion (Round 1), and the opinions were exposed to the group and significant discussion ensued. Then, the data was reviewed and the group re-evaluated the data and came to consensus on the values (Round 2). This process continued for each of the contracting techniques. Finally, toward the end of the meeting, the data was once again reviewed openly (Round 3), and final adjustments were made. Round 3 was helpful as insight had been gained through the entire session that could be applied to the initial data values.

This technique was useful for gathering expert opinion. The selection of the initial group with multiple perspectives and open discussion helped avoid myopic biases that may occur with just one or two individuals. Although there was some indication of control biases (individuals deferring opinion to others with more organizational power), this bias was reduced through the Round 1 private opinion gathering and through the use of a third-party facilitator. A tendency to defer to the highest organizationally-placed individual was observed. Certainly, in longer session this would be a threat to the freedom of expression expected of this technique. Facilitation in an NGT session over an extended period of time would be strengthened if the facilitator had an understanding of group dynamics.

SELECTION OF AN APPROPRIATE RESEARCH METHOD

The experiences of the authors and the benefits and limitations of each of the four research methods discussed in this paper were used to create a flowchart that can inform the selection of an appropriate research method. Figure 1 depicts the various elements of the decision; in order to use this flowchart, the researcher must have decided whether experts can be collected in one physical location, the degree of proof of validity required, if bias reduction is essential, and whether a significant number of expert panelists are available and willing to participate. It should be noted that the

flow of decision-making implies an inherent strength in first choosing objective, data-based research methods over more subjective techniques. The reasoning behind this approach is two-fold. First, objective data (assumingly screened for reliability and validity) is not generally subject to broad interpretation and therefore similar analyses and conclusions may be reached by others working independently; second, there is little bias in such data, while subjective, opinion-based information may contain biases that may or may not be evident to the researcher.

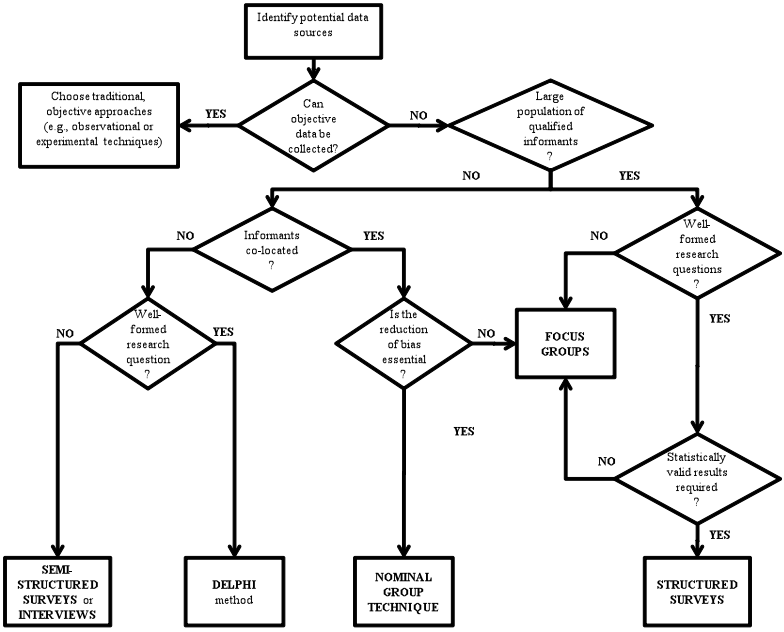


Figure 1 – Method Selection Flowchart

CONCLUSIONS

This paper reviews four commonly-used techniques for obtaining expert opinion in construction engineering and management research. Each of the techniques is described and compared and the benefits and limitations of each method are discussed. Because of the diversity of CEM research, each of the methods may be appropriate given the specific characteristics of the study. In order to illustrate several examples, the authors describe the use of each of the four research methods in four independent, large-scale studies. Finally, a flowchart is presented that can be used to aid researchers in their selection of a subjective research method.

The authors determined that important characteristics to consider when selecting a subjective research method are the geographic dispersion of the potential participants,

the desired timeline of the study, the importance of academic rigor, the number and availability of potential participants, and potential of bias among co-located study participants.

REFERENCES

Burleson, D.R., Levine, B.J., and Samter, W. (2006). "Decision making and decision quality." *Human Communication Research*, 10(4), 557-574.

Dayananda, Don, Irons, Rischard, Harrison, Steve, Herbohn, John, and Rowland, Patrick. (2002). Capital Bidgeting. Cambridge University Press, Cambridge.

Erffmeyer, R. C., and Lane, I. M. (1984). "Quality and acceptance of an evaluative task: the effects of four group decision-making formats." *Group and Organizational Studies*, 9(4), 509-529.

Hallowell, M.R. (2008). "A formal model of construction safety and health risk management." Ph.d. Dissertation, Oregon State University, Corvallis, OR.

Hallowell, M.R. and Rogge, D.F. (2007). "Evaluation of Outsourcing in the Oregon Department of Transportation" *Proceedings of the 2007 Construction Research Congress*, ASCE, Grand Bahama Island, Bahamas, May 6-8, 2007.

Salant, P., and Dillman, D. A. (1994). *How to conduct your own survey*, John Wiley & Sons, Inc., New York, NY.

Sample, John A. (1984). "The nominal group technique: an alternative to brainstorming." *Journal of Extension*, 22(2), 1-2.

Sillars, D. N. (2003). "Joint Ventures in the A/E/C Industry--Use and Success Factors." Construction Research Congress 2003, McGraw-Hill, Honolulu, HI.

Tang, Whenzhe, Qiang, Maoshan, Duffield, Colin F., Young, David M., and Lon, Yonnei (2007). "Incentives in the Chinese Construction Industry". *Journal of Construction Engineering and Management*, 133(12), 944-956.

Webb, C. and Keven, J. (2001). "Focus groups as a research method: a critique of some aspects of their use in nursing." *Journal of Advanced Nursing*, 33(6), 798-805.

Author Index

Page number refers to first page of paper.

Abdelhamid, Tariq S., 705, 766
Abdel-Wahhab, Osama, 1068
AbouRizk, S. M., 1223, 1270, 1290
Abraham, Dulcy M., 1154
Ahmed, Syed M., 1439
Akinci, Burcu, 416, 1164
Al Qady, Mohammed, 1479
Al-Bataineh, M., 1223
Al-Derham, Hassan, 1145
Al-Hussein, Mohamed, 386, 406
Allread, Ben S., 31
Alvanchi, A., 1290
Ammar, Mohammad, 350
An, Sang-Mok, 816
Angelides, Demos C., 81
Ariaratnam, Samuel T., 618, 1233
Aslani, Pooyan, 467
Awwad, Rita E., 249
Azambuja, Marcelo M., 259
Aziz, Ahmed M. Abdel, 896

Bae, Jin-Woo, 1009
Bai, Yong, 11, 131
Baik, Kyeong Geun, 151
Ballard, Glenn, 360, 866, 1029, 1038
Bates, A. J., 1368
Batson, Robert G., 746
Behzadan, Amir H., 1214
Beliveau, Yvan, 568
Bode, Thaddaeus, 516
Bogus, Susan M., 876
Bohn, Jeffrey S., 21
Botteicher, Richard (Bo), 1233
Bouferguene, Ahmed, 406
Boukamp, Frank, 457
Bowen, Paul A., 279, 776
Brilakis, Ioannis, 81, 1204
Brummett, Jenna, 161

Carey, Brad D., 269
Castro-Lacouture, Daniel, 211, 608, 1079
Cattell, K. S., 279
Chae, M., 497
Chan, Albert P. C., 955
Chang, Chen-Yu, 288
Chang, Chul-Ki, 1308
Charalambides, Jason, 628
Chasey, Allan D., 665
Chen, Qian, 588
Cheung, Sai On, 298
Chiang, Y. H., 955
Chiara, Nicola, 1174
Chiarelli, Lawrence, 467
Cho, M., 497
Cho, Yong K., 516
Chong, Wai K. (Oswald), 526, 537
Cline, R. Casey, 1409
Cloud, Joshua, 598
Conger, Robert F., 726
Cooper, Casey, 1318
Cordova, Francisco, 81
Costa, George S., 1105

da C. L. Alves, Thaís, 1105
Dai, Jiukun, 1087
Dainty, Andrew R. J., 309
Darnell, Brent, 1358
Davis, Kirsten A., 1409
de la Garza, Jesús M., 916
de P. Barros Neto, José, 1105
Devkar, Ganesh A., 201
Dossick, Carrie S., 396, 1469
Dyer, Bryan D., 121

Edwards, Peter J., 776
El Asmar, Mounir, 1308

El-adaway, Islam H., 675
El-Anwar, Omar, 1135
Elazouni, Ashraf, 1068
Elghamrawy, Tarek E., 457, 936
Ellis, Ralph D., 1096
Elnashai, Amr, 1135
El-Rayes, Khaled, 806, 846, 1135, 1145
Elwakil, Emad, 350
Enache-Pommer, Elena, 636
Everett, John G., 705
Eweda, Ahmed, 350

Fard, Mani Golparvar, 51
Fares, H., 1125
Farooqui, Rizwan U., 1439
Fayek, Aminah Robinson, 219
Feng, Peter P., 866
Fernando, S., 1223
Finnsson, Siggi, 1233
Fiori, Christine M., 1388, 1398
Fischer, Martin, 926,608
Ford, George, 380
Froese, Thomas, 71, 979
Fullerton, Clare E., 31

Gaikwat, Yogesh, 1378
Garrett, James H., Jr., 416, 1194
Garvin, Michael J., 191, 1469
Gastrock, Brian, 1260
Ghosh, Arnab, 1233
Gibson, G. Edward, 685, 1348
Glick, Scott, 655
Golparvar-Fard, Mani, 41
Goodrum, Paul M., 111, 121
Grant, Denise, 1338
Griffis, F. H. (Bud), 467
Gross, Martha E., 191
Guggemos, Angela Acree, 655
Gunhan, Suat, 320
Guo, W., 1194

Haddad, Gilbert, 171
Hague, S., 1223
Hallowell, Matthew R., 1489, 1499
Han, SangUk, 51
Han, Seung Heon, 756
Han, Zonghai, 71
Hanna, Awad S., 171, 1308
Hardcastle, Cliff, 776
Hasan, Shafiul, 386
Hassan, Marwa, 568, 836
Hermann, R., 1270
Hermann, U. H., 386
Hermreck, Christopher, 526
Hewage, Kasun N., 487, 989
Hicks, Carolyn, 101
Ho, Peggy, 926
Homayouni, Hoda, 396
Horman, Michael, 558, 636
Huan, Luke, 11, 131
Hwang, Seokyon, 1300

Ioannou, Photios G., 1250, 249
Isaac, Shabtai, 1

Jain, Atul Kumar, 665
Javernick-Will, Amy, 338
Jay, C. I., 279
Jenicek, Elisabeth, 426
Jergeas, George F., 989
Johnson, Lisa M., 588
Johnston, David W., 1328
Jooste, Stephan F., 1184
Jun, Dho Heon, 806
Jung, Youngsoo, 816

Kalidindi, Satyanarayana N., 201
Kamat, Vineet R., 1214
Kandil, Amr, 239, 1479
Kang, Sang Hyeok, 151
Karshenas, Saeed, 1419
Kashiwagi, Dean T., 370
Kashiwagi, Jacob S., 370
Kim, Byungil, 756
Kim, Du Yon, 756
Kim, Ho-Sung, 457
Kim, Hyunjoo, 426

Kim, J., 497
Kim, Jin-Lee, 1096
Kim, Kyunghwan, 916
Kim, Seonghoon, 11, 131
Kim, Yong-Rak, 516
Kim, Yong-Woo, 1009
Klotz, Leidy, 1338
Kong, Robert Tiong Lee, 716
Korkmaz, Sinem, 558
Korman, Thomas M., 999
Ku, Kihong, 969, 1378

Lai, Wally S. W., 298
Lawrence, M., 506
Lee, Bok Nam, 816
Lee, G., 497
Lee, Namhun, 826
Lee, S., 1290
Lee, Sang-Hoon, 1318
Lee, Young Hwan, 816
Leicht, Robert M., 437, 1358
Leite, Fernanda, 416
Levitt, Raymond E., 338, 1184
Lewis, Angela, 1358
Liao, Pin-Chao, 1087
Likhitruangsilp, Veerasak, 1250
Lin, Yu-Cheng, 477, 906
Lu, Na, 946
Lucko, Gunnar, 1115, 1449
Luna, Eduardo, 370

Mahalingam, Ashwin, 201
Mahfouz, Tarek, 239
Mahmoud, Muhammad, 350
Malhotra, Neha, 370
Mannering, Fred L., 1154
Marsh, Krista, 219
Martinez, Adam A., 886
Mashhour, Ibarhim, 350
McCabe, Brenda, 101
McCoy, Andrew P., 91
Medaglia, Andrés L., 608, 1079
Menassa, Carol, 646, 726
Menches, Cindy L., 796
Messner, John I., 437, 1358
Michael, John K., 269
Migliaccio, Giovanni C., 229, 886
Mirsky, Rebecca, 330
Mitchell, Zane W., Jr., 1115, 1368
Mitropoulos, Panagiotis 'Takis', 695, 766
Mohamed, Dalia, 736
Mohamed, Y., 1270
Molenaar, Keith R., 786
Mrozowski, T., 766
Muga, Helen, 548
Mukherjee, Amlan, 548, 1459
Mulva, Stephen P., 1087

Nahmens, Isabelina, 1058
Namboodiri, Manoj, 695
Nasr, Ziad Bou, 796
Neff, Gina, 396
Nepal, M. P., 506
Ng, S. Thomas, 955
Nguyen, Thuy, 141
Nobe, MaryEllen C., 161, 1429

Oberle, Rita, 211
O'Brien, William J., 141, 259, 1087
Oh, Young-Seok, 816
Olearczyk, Jacek, 406
Onder, Nilufer, 1459
Orabi, Wallied, 1145

Park, J., 497
Parra-Montesinos, Gustavo, 1204
Parrish, Kristen, 360
Partouche, Rebecca, 1019
Patterson, John, 380
Pearce, Annie R., 1398
Peddi, Abhinav, 11, 131
Peña-Mora, Feniosky, 41, 51, 646, 726
Peralta, María L., 1154
Phillips, H. Clay, 876
Pocock, J. B., 1368
Pottinger, R., 506

Prakash, Santosh, 655

Qian, Qiyu, 716

Ramos, Michelle, 1243, 1260
Rendall, Joseph, 537
Riecke Smith, Valerie R., 211
Riley, David R., 558, 1358
Roh, Seungjun, 51
Rojas, Eddy M., 826, 856, 1449, 1459
Ronie Navon, 1
Ross, Timothy J., 876
Russell, Jeffrey S., 1308
Ruwanpura, Janaka Y., 61, 487, 989
Rybkowski, Zofia K., 1038

Sacks, Rafael, 1019
Safouhi, Hassan, 386
Said, Hisham, 846
Sauer, Michael, 578
Savarese, Silvio, 41
Schafer, D., 766
Schaufelberger, John, 598
Schmidt, Kathy, 141
Sefair, Jorge A., 608, 1079
Senouci, Ahmed, 1145
Seo, Jong Won, 151
Shrestha, Pramen P., 229
Siddiqi, Khalid, 578
Sideris, Dimitris, 81
Sihabuddin, Shaik, 618
Sillars, David N., 1499
Silva, Lahiru P., 487
Sims, Bradford, 380
Singh, Amarjit, 181
Soetanto, Robby, 309
Soibelman, L., 1194
Son, JeongWook, 856
Song, Lingguang, 1318
Song, Xinyi, 726
Songer, Anthony D., 330, 1388
Srour, Florida, 736
Staheli, Kimberlie, 1243
Staub-French, S., 506
Stewart, Peter J., 776
Stumpf, Annette, 426
Sullivan, Kenneth T., 269, 370

Taam, Thomas, 181
Tabra, Wael, 736
Taghaddos, H., 1270
Tang, Pingbo, 1164
Taylor, J. E., 1280, 1469
Teizer, Jochen, 21, 31, 447
Teizer, Winfried, 447
Telyas, Avi, 406
Thomas, Stephen R., 1087
Tighe, Susan, 101
Tommelein, Iris D., 360, 866, 1048
Tuholski, Stan J., 1048

Unsal, H. I., 1280

Venugopal, Manu, 447

Webster, A., 506
Weerasinghe, I. P. Tharindu, 61
Whittington, Donald A., 685, 1348
Wilson, Craig R., 786
Wong, James M. W., 955
Wong, Peter S. P., 298
Woo, Sungkwon, 816

Xi, Lili, 705

Yang, Jin-Soo, 816
Ye, Jianguo David, 979

Zandbergen, Paul, 886
Zayed, Tarek, 350, 736, 1125
Zhai, Dong, 111
Zhang, J., 506, 936
Zhu, Zhenhua, 1204

Subject Index

Page number refers to first page of paper.

Alaska, 1260
Algorithms, 11
Asphalts, 526
Assembling, 406
Assessments, 141, 1154, 1358
Assets, 548
Automation, 61, 406, 628, 816, 826, 1135

Bids, 249
Building design, 426, 467, 506, 537, 558, 568, 628, 665
Buildings, high-rise, 1009, 1019, 1154
Buildings, residential, 181, 578, 655, 1009
Business management, 330, 350

California, 866
Cameras, 21
Canada, 101
Carbon, 618
Case reports, 71, 457, 816, 866, 969, 1243, 1260, 1469
Classification, 876
Coating, 836
Communication, 396, 487, 776, 856
Comparative studies, 1439
Computer software, 497, 1105
Concrete, 1204
Concrete columns, 1214
Concrete pavements, 695
Configuration, 979
Construction costs, 588, 886, 1038, 1419
Construction equipment, 31, 1318
Construction industry, 121
Construction materials, 608, 1079
Construction sites, 31, 91, 406, 497, 846
Contractors, 330, 598
Contracts, 171, 219, 269, 288, 1250
Costs, 121
Cranes, 386, 1300
Critical path method, 916

Damage, 1204, 1214
Data analysis, 705, 979
Data collection, 61
Data processing, 416
Databases, 380, 1115
Decision making, 360, 548
Delay time, 380
Delivery, 211, 229, 279, 969
Design/build, 229
Developing countries, 1154
Dispute resolution, 239, 726
Drilling, 1233, 1243

Economic factors, 249, 655, 955, 1115, 1184
Electrical systems, 171, 416, 796, 999
Emergency services, 1135
Energy, 426, 537, 558, 598, 646, 1174
Energy efficiency, 628
Engineering education, 1328, 1358, 1368, 1378, 1388, 1409, 1419, 1429, 1439
Environmental issues, 211, 558, 598, 608, 636, 655, 665, 1009, 1058
Estimation, 886
Expert systems, 219

Failures, 1125
Financial management, 675

Forecasting, 955
Foreign projects, 756
Fuzzy sets, 219, 1125

Geographic information systems, 151, 886

Health care facilities, 636, 866
Highway and road construction, 101, 191, 526, 786, 896
Highway and road management, 229
Hong Kong, 298
Housing, 588, 1105, 1135
Human factors, 11
Hybrid methods, 1290

Identification, 41, 416
Imaging techniques, 51, 81, 979, 1194, 1204, 1214, 1419
Implementation, 1
India, 201
Information management, 71, 81, 396, 457, 467, 506, 1164, 1479
Information technology (IT), 111, 989
Infrastructure, 716, 1154, 1164, 1174, 1184, 1214, 1308
Innovation, 71, 91, 1029, 1164
Insurance, 675, 726
Integrated systems, 969, 1270, 1280
Interfaces, 477
International factors, 320, 338, 756
Internet, 1378
Internships, 1398
Inventories, 1029
Investments, 111

Knowledge-based systems, 338, 906, 936, 1479

Labor, 161
Lean construction, 360, 1058, 1115
Life cycles, 836
Litigation, 239, 726
Local governments, 279

Location, 886
Logistics, 239, 1300

Maintenance, 191
Mapping, 279, 906, 936
Measurement, 131
Measuring instruments, 141
Mechanical systems, 999
Minority groups, 161
Monitoring, 21, 41, 51, 1068
Monte Carlo method, 1308
Multimedia, 1419
Multiple objective analysis, 806
Municipal engineering, 201

Natural disasters, 1135, 1145
Nebraska, 526
Neural networks, 1068
North America, 989
North Carolina, 380
Numerical models, 1233

Occupational health, 1489
Optimization, 846, 1105, 1135
Optimization models, 608
Organizations, 350, 370
Owners, 219, 776, 989, 1038

Partnerships, 201, 269, 716
Pavements, 516
Personnel management, 61, 705, 955
Pipes, 1233
Plumbing, 416, 999
Predictions, 705, 736, 896, 1233
Pricing, 726
Procurement, 229, 259, 288, 646, 1009
Productivity, 11, 111, 121, 131, 151, 171, 695, 946, 1019, 1029, 1087, 1096
Public health, 1184

Quality control, 516, 1328

Rainfall, 380
Reconstruction, 1145
Recycling, 526, 1429
Regression analysis, 896, 1115
Regression models, 239
Regulations, 211
Rehabilitation, 1048, 1194
Renewable resources, 646, 1174
Renovation, 685, 926
Research, 1038, 1348, 1449, 1459, 1469, 1499
Residential location, 181
Resource allocation, 816, 1145
Risk management, 675, 716, 746, 776, 786, 1125, 174, 1250, 1308
Rivers, 1243

Safety, 31, 386, 695, 766, 1489
Scheduling, 806, 816, 826, 856, 876, 916, 926, 1105, 1270, 1318
Seismic effects, 1048
Sensors, 516
Simulation, 1223, 1270, 1280, 1290, 1318, 1459
Solar energy, 568
South Africa, 279
Stochastic processes, 1
Storms, 675
Structural design, 1048
Students, 141, 1398, 1409, 1429, 1439
Subcontractors, 1280
Surveys, 141, 161, 1164
Sustainable development, 330, 537, 548, 578, 588, 598, 636, 665, 1338, 1368

Temporary structures, 1300
Three-dimensional models, 497
Time factors, 736, 896, 916
Tolls, 191
Transportation networks, 1145
Trenchless technology, 1260
Tunneling, 1223, 1250

U.S. Army Corps of Engineers, 370
Uncertainty principles, 309
Undergraduate study, 1328, 1368
Underground construction, 618, 1214
United Kingdom, 969
United States, 946
Urban areas, 201
Utilities, 618

Validation, 81, 926

Washington, 1243
Water distribution systems, 1125
Water pipelines, 1194, 1204
Workspace, 101, 437