The Data-Driven Project Manager

A Statistical Battle Against Project Obstacles

A business novel

Mario Vanhoucke

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Printed on acid-free paper

To the memory of Koen De Vilder and Thierry Beernaert.

To my daily coffee, black, no sugar.

Contents

About the Author

Mario Vanhoucke is a professor at both Ghent University (Belgium) and Vlerick Business School (Belgium) as well as a senior teaching fellow at UCL School of Management (University College London, UK). He has previously written books about project scheduling, risk analysis, and project control. As a professor and researcher, Mario is constantly looking for better ways to measure, improve, and optimize the performance of projects in progress and their resource efficiency. Mario has a background in operations research and management science and aims at combining research with practice. As a founder of the Operations Research & Scheduling research group and leader of a more than a million euro research project, Mario sets up collaborations between national and international companies and universities in the United Kingdom, the United States, and China. He is very active in the Belgian Chapter of the Project Management Institute (PMI) and has been awarded by the International Project Management Association (IPMA) for his research in project management and control. Mario also writes his own project management software tools, both as standalone desktop versions and as integrative tools in company software environments. Mario shares his ideas at various international conferences.

Acknowledgments

It goes without saying that this book couldn't have been written without the help of my dearly beloved and close friends. I especially wish to thank Gaëtane Beernaert, William Wright, and Louis-Philippe Kerkhove for their valuable contributions to the manuscript. Gaëtane and William have worked their way through the various drafts of the manuscript, each time highlighting errors and suggesting improvements, and therefore any errors that have remained in the final manuscript are mine. Louis-Philippe was my sounding board and partner in developing the schedule risk-analysis sheets.

Introduction

Before you dive into the book and start reading the story about GlobalConstruct's tennis stadium construction project, here is a short summary of each of the chapters. If you're wondering whether this book will be worth a read, please read the next pages and then decide.

Chapter 1: Background

- Cast of characters
- Emily Reed (the protagonist)
- Global Construct Ltd. (the company)

Chapter 2: PLAN

- How planning works or fails
- How multiple estimates improve planning quality
- How variances should be added and compared
- How statistical simplifications lead to small errors
- How times have changed over the years

Chapter 3: RISK

- How a time machine works
- How probability and impact define risk
- How controllability reduces the fear of risk
- How sensitivity to changes helps detect bottlenecks
- How black swans should be ignored

Chapter 4: BUFFER

- How to avoid a burnout
- How to cope with a scarcity of resources
- How change is easy to propose but difficult to implement
- How buffering is a matter of giving and taking

Chapter 5: MONITOR

- How to collect data
- How time and cost can be integrated
- How planning finally gets a *raison d'être*
- How good performance can be misleading
- How predictions depend on past experiences and future expectations
- How the beauty of a unified system lies in its simplicity
- How value is not the same as progress

Chapter 6: CONTROL

- How to set your alarm
- How focusing always pays off
- How to aim and shoot in one motion
- How effort and quality are different sides of the same coin
- How efficiency is a goal in management
- How a control freak gets crazy
- How being lazy always turns out to be bad

Chapter 7: Exciting times ahead

- How to say goodbye
- How successes and failures define someone's career
- How the future always looks bright

Chapter 8: Afterword

- How I wrote this book
- How research drives teaching
- How books and papers are written
- How artificial and empirical data are merged
- How academics and professionals work together
- How I endlessly rely on my family and friends

Written as a business novel, this book demonstrates the highly interactive discussions among the main characters of a team responsible for a challenging project. It allows the reader to participate and consider options—as a project manager would—at each stage of a project. The main characters of this story and the company they work for are briefly introduced in Chapter 1.

Chapters 2 through 7 tell the story of Emily Reed and her colleagues, who are in charge of the management of a new tennis stadium construction project. Most of these chapters can be used in any data-driven project management lecture for university students, MBA students, and professional project managers.

The first part of each chapter always ends with an "action list summary" in a section entitled "Assignment." The text of each chapter, up to and including this assignment, can be used as a case study to be solved and discussed by anyone with an interest in data-driven project management.

I use these case studies in my project management lectures at several universities and business schools, as well as in company trainings. But as a reader of this book, you can also use each chapter's assignment as a challenging exercise to test whether you understand the relevance of data-driven methodologies for your own projects.

The second part of each chapter contains the solution to each assignment. I use this as a general framework for my feedback sessions to kickstart a discussion about the case study. For you, Dear Reader, it can be a tool to check whether you have solved each chapter's assignment correctly.

In Chapter 8, I have provided references to academic papers and technical books that were my main inspiration for writing this book. I have tried to keep the technical details out of the story as much as possible. So, this book is not only a story about data and projects; it's intended to be a reference tool for applying the newly presented concepts in practice and also (if desired) for diving more deeply into the advanced material presented in the afterword.

As a matter of fact, many of the chapters were initially a loose collection of exercises and case-study drafts before they were brought together into a book. The first part of each chapter has been tested, revised, sometimes completely rewritten, and finally fine-tuned in various project management lectures at Ghent University (Belgium), Vlerick Business School (Belgium), and the UCL School of Management (UK). The valuable feedback that we've received from students and project managers has been carefully taken into account and has contributed to the final version of this book.

If you have a passion for project management, an appetite for decision-making, and an affinity with numbers, then I invite you to read this book.

CHAPTER

1

Background

All of the characters in this book are ordinary, but nevertheless interesting, human beings. They are real people, living in real situations, trying to achieve their ambitions the best they can. They could be you or me or your colleague at your job.

The core team of GlobalConstruct's tennis stadium construction project consists of:

- Jacob Mitchell: Chief Executive Officer (CEO)
- Mark Rogers: Chief Financial Officer (CFO)
- Emily Reed: Chief Operations Officer (COO)

During the numerous meetings, Jacob decided to also involve the following people from GlobalConstruct:

- Ruth Bowman: Head of the Accounting Department and Data Scientist
- Joanna Barnes: Head of the Human Resource Management Department
- Mick Hudson: Computer Scientist in the IT Department, known as The IT Wonder-boy and Spreadsheet Guy

As needed, data collection was done by external experts, such as:

- Victoria: Expert 1
- Andrew: Expert 2

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Emily Reed (the Protagonist)

Emily Reed is a young project manager who is always in search of a better way. With her affinity for numbers, her ingenuity in problem solving, and her dyed-in-the-wool belief that data should be the driver in all decision-making processes, she ultimately tries to change the GlobalConstruct company's project management style. With the support of her mentor and CEO, Jacob Mitchell, and fed by the enthusiasm of her number-crunching colleague Mark Rogers, she starts a journey of team meetings and discussions to better prepare and manage a tennis stadium construction project—with the goal of paving the way toward a more data-driven project management methodology. In her typical interactive discussion style, and with a deep respect for wisdom and experience, she convinces her team members that the price of exploring data is less than the risk of battling the unexpected project obstacles with experience alone.

GlobalConstruct Ltd. (the Company)

GlobalConstruct Ltd. is a project management consultancy company headquartered in Brussels, Belgium, with affiliations all over Europe, America, and Asia. The company was founded by Jacob Mitchell, a young twentysomething looking for a temporary endeavor, and quickly grew into an internationally renowned project management consultancy company. After more than 30 years, Jacob is now the CEO of a company of over 2,000 employees in more than 30 offices worldwide.

Over the last decades, GlobalConstruct has provided solutions to improve project performance with proven project management consulting and sound approaches that have been implemented in hundreds of organizations all over the world. The company is known for diagnosing problems and the quick recovery of projects in trouble, an intuitive solution-based approach built on years of experience, and better management of key project issues. From the very beginning, the company mission expressed a strong focus on providing key resources to monitor and follow up on its clients' projects.

GlobalConstruct's aim is to provide senior project management consultants to its clients to help them manage their projects and to deliver better value from the early project phases to the final delivery. To that purpose, these project management consultants assist GlobalConstruct's clients during the project's entire life cycle—from negotiation and planning, to monitoring and supervision, and even to successful delivery and post-delivery once the project is finished. Their tasks include setting up project plans with the client, managing key resource dependencies during project progress, and providing advice when labor shortages start to bring the project objectives into the danger zone. GlobalConstruct's client remains the owner of the project and has the final responsibility in communicating with its stakeholders. Moreover, the labor for the project work is always delivered by, and under the responsibility of, this project owner, and so these are external project teams for GlobalConstruct, but these teams do work under the direct supervision of GlobalConstruct's senior project management consultants. The consultants' day-to-day activities are often complex and vary depending on the needs of the client and the type of project. Their ability to work with large international teams across various sites undoubtedly has helped many clients deliver successful projects well ahead of their competitors.

While Jacob had been surrounded by an excellent team of people with different backgrounds and various alternative ideas, he was well aware that the future of GlobalConstruct was at stake. Supported by both the recent recruitment of some young talents who joined the board of directors and the increasing importance of data analytics as a tool to support major decisions, he thought the company was ready for a new step forward. As a result of his never-ending study of how much bad project management costs almost every company, he realized that GlobalConstruct was ready for a major change in its way of working. His ultimate goal was to install a data-oriented decision-making process at all layers of the company, and to make this data-driven project management approach the flagship of GlobalConstruct.

To reach this objective, he assigned Emily Reed as a permanent member to the board of directors. Only a few weeks after this assignment, she had not only become responsible for a prestigious tennis stadium construction project for clients in Australia and Singapore, but she had also gained full authority to apply a new data-driven project management approach to one of these projects. This new data-driven methodology should be developed in-house, in close collaboration with all members of GlobalConstruct's core project team, and the project data of the upcoming tennis stadium construction project should be used as a test case for the further development, and possible approval, of the new project management system.

Jacob was convinced that Emily was the right person for this challenging task. Not fully aware of the difficulties she could possibly face, Emily could only see the beauty of the challenge and the beneficial impact it could have on the future of GlobalConstruct. She had never been afraid of the impossible—and she had the ability to transform any impossible endeavor into an exciting challenge. And a challenge it turned out to be!

CHAPTER

2

Plan

"I still maintain that we should opt for Australia!" Mark Rogers, Chief Financial Officer (CFO) of GlobalConstruct, exclaimed. The meeting called by Chief Executive Officer (CEO) Jacob Mitchell still lacked consensus. Two options were on the table: GlobalConstruct could join the bidding process for a new and extremely prestigious tennis stadium construction project in either Singapore or Australia. Given the importance of these types of projects, their successful completion could easily lead to follow-up projects and propel GlobalConstruct's rise on the international playground. The Australian government was very keen on implementing the tennis stadium construction project with success, given the negative publicity it had suffered as a result of similar projects in the past. Announcing the timely delivery of such a well-publicized initiative might alter public opinion. And if this were the case, GlobalConstruct would become Australia's number one choice for additional tennis stadium construction projects.

Project Details

Jacob rubbed his eyes and said, "Let's go over this one more time. Emily, please give us an overview of the different phases involved in these projects." Emily Reed, the Chief Operations Officer (COO), had come up with the different work packages and activities that would be required in order to bring about the successful completion of either project.

"The technical requirements of these projects are very similar and can be deconstructed into five work packages." Emily had asked one of her team members to provide more details on each of the work packages. Furthermore, to obtain a detailed description of the dependencies between the work packages and the activities of the tennis stadium construction project, Jacob and Emily had conducted several interviews with Australian experts in these types of projects, which resulted in the design-structure matrix of Table 2-1.

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Table 2-1. Design-Structure Matrix of the Tennis Stadium Construction Project for Australia

		Activity ID (using x for succeeding activities)															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Preparation	Clearing the site (1)		x														
	Removing trees (2)			x			x										
Field work	Subsurface drainage (3)				x												
	Filling playing field/track (4)					x											
	Installing artificial playing turf (5)																
Ground work	Excavation (6)							x									
	Pouring concrete footings (7)								x			x					
Seating	Pouring supports seat galleries (8)									x							
	Erecting pre-cast galleries (9)										x						
	Pouring seats (10)																x
Construction	Steel structure (11)												x				
	Roof (12)													x	x	x	
	Dressing rooms (13)																x
	Painting (14)																x
	Lights (15)																x
	Scoreboard (16)																

Every member around the table was well aware of the different phases these types of projects needed to go through. Choosing between Australia and Singapore entailed several different considerations. While the work packages and activities were identical, Australian companies were backed by the government. Hence, the precedence logic of Table 2-1 for the Australian tennis stadium construction project could be slightly different for the Singaporean project. The main difference between the two countries' project implementations lay in the way the "construction" and "seating" work packages would have to be planned and executed. These work packages could be done in parallel for the Australian project, but for the Singaporean project, the "construction" work package (activities 11 to 16) could only begin when all of the "seating" work (activities 8 to 10) was finished. So, while the invested funds were at higher risk for the tennis stadium construction project in Australia, this could probably be countered by an earlier completion date compared to the planned finish of the Singaporean project. In order to compare both alternatives, Jacob wanted to get a clear overview of the completion dates of the Singaporean and Australian tennis stadium construction projects. Emily produced an overview of the activities and their durations in weeks as provided in Table 2-2.

Table 2-2. Overview of Activity-Duration Estimates (in Weeks)

Work Package	Activity	Singapore	Australia
Preparation	Clearing the site	6	6
	Removing trees	2	2
Field work	Subsurface drainage	8	8
	Filling playing field/track	14	14
	Installing artificial playing turf	12	12
Ground work	Excavation	4	4
	Pouring concrete footings	4	4
Seating	Pouring supports seat galleries	10	12
	Erecting pre-cast galleries	10	13
	Pouring seats	4	4
Construction	Steel structure	2	4
	Roof	4	8
	Dressing rooms	4	4
	Painting	3	5
	Lights	2	4
	Scoreboard	3	3

Mark tried to summarize the main differences between the two projects. "So, we see that the main difference lies in the sequence of the activities of the previously mentioned work packages. In Australia, some of the activities can take place at the same time, but the individual activities take longer. What is the reason for this?" Jacob argued that, since these activities were executed simultaneously, there was less information available. This could be one of the causes for the longer duration estimates. "Right," Jacob said. "We now have sufficient information to make a first comparison between the two projects."

"How long will it take to complete these projects?" he asked. "And which of the two alternatives is the most attractive?" he immediately added.

It was clear that Jacob was aiming at a quantitative analysis rather than a subjective judgement in order to analyze and compare the expected behavior of the two projects before expressing a preference for one of them—and he would certainly want such an analysis before he would be willing to make a definite decision.

"Hang on a second!" Mark, who was in charge of GlobalConstruct's finances, knew the pitfalls of working with estimates.

"These numbers are averages—or, most likely, rough estimates, right?" he interjected. "One thing we know is that estimates are always wrong. So, I would like to get some different views on these estimates." Jacob knew there was great merit to Mark's objection. He suggested they tap into GlobalConstruct's Knowledge Network and get the opinion of two other experts. Jacob proceeded by adjourning the meeting: "All right, let's meet again next week to go over the experts' opinions."

Next Meeting

A week goes by so fast for a project manager! While Mark and Emily had been mainly involved in getting to know both projects' potential features much better, Jacob had talked to the head of GlobalConstruct's Knowledge Network and come back with new estimates, seen from an outsider's point of view. Emily, in particular, believed that this additional data was the missing link for a deep and sound analysis of the two projects.

"Emily, Mark, thank you for coming. The goal of this second project meeting is to determine whether our previous preference for Australia still holds with the new data at our disposal. I've brought a memo that reflects the opinions of Victoria and Andrew, two of our experts. These numbers can be combined with the previous numbers, which are most likely estimates since they are based on historical data. It's worth noting that Victoria usually has an optimistic outlook on the projects we conduct, while the opposite is true of Andrew's point of view." A list of the estimates given by the two experts is given in Table 2-3.

Table 2-3. Additional Activity-Duration Estimates (in Weeks)

Activity	Singapore		Australia	
	Victoria	Andrew	Victoria	Andrew
Clearing the site	3	6	3	6
Removing trees	1	3	1	3
Subsurface drainage	4	12	4	12
Filling playing field/track	11	17	11	17
Installing artificial playing turf	11	13	11	13
Excavation	2	6	2	6
Pouring concrete footings	3	8	3	8
Pouring supports seat galleries	10	10	10	14
Erecting pre-cast galleries	9	11	11	15
Pouring seats	3	5	1	7
Steel structure	1	3	3	8
Roof	3	5	6	10
Dressing rooms	3	5	3	5
Painting	3	6	3	7
Lights	1	3	3	8
Scoreboard	2	4	2	4

In addition to an attachment with updated estimates, Jacob had received word that the governments of both Singapore and Australia were offering a significant milestone payment if the tennis stadium construction project were to be finished early—but significant penalties if the promised deadlines were exceeded were also part of the contract. In order to bring clarity to the clients of both projects, a tight—but nevertheless realistic—deadline for each project should be set. These deadlines should create a time-bound framework for management, providing working goals, benchmarks, and milestones. Despite preferring shorter time frames, the project owners should be prepared for the unexpected, and possible delays might endanger the predefined deadlines. So, Mark was eager to know what deadlines would be realistic for both projects, as well as the probability that GlobalConstruct would meet those deadlines. Just like Jacob, he realized that only a quantitative analysis could provide the necessary answers to the many questions they had, and both gentlemen knew that it was Emily who should come up with an approach for providing these answers.

Assignment

Despite the fact that both projects were in an early phase, Jacob reminded his core team members of the importance of making the right decisions from these early project phases onward.

"If we are to address the need for expanding our activities to an international level, we must now select one of these two projects based on a sound analysis," he said to the team.

He told his two colleagues that a quantitative and sound evaluation of the project proposal would be essential for choosing between Australia and Singapore and that it must be shared with all of the other members involved in the project. He briefly mentioned the *program evaluation and review technique* as a project methodology that is commonly used in conjunction with the *critical path method*. Because of their similarities, he explained to the team, they are usually referred to as an integrated project analysis tool, abbreviated as PERT/CPM.

Since people often need a gentle nudge to remind them to complete action items, he explained to his colleagues that he would distribute an email with an action list summary. By the next meeting, he expected his team members to check this list carefully to ensure that action was indeed taking place as agreed.

"I'll see you at the next meeting, on Monday, with your clear and easy-to-understand results," he said, and he immediately left the room on the run to another meeting. No doubt the company is doing well, Emily and Mark must have thought. Jacob had certainly looked incredibly busy during the last few weeks, and it was clear that something exciting was heading toward the project team!

ACTION LIST SUMMARY

Note from Jacob: There is no doubt that exciting times lie before us. I expect a sound data analysis as well as a strong project analysis for both the Australian project and the Singaporean project to support our decision, which we should make next Monday.

- The data analysis should include:
  - An analysis of the network logic.
  - The construction of the baseline schedule.
- The project analysis should include:
  - An analysis of the expected project durations.
  - A comparison of the averages and standard deviations for both project durations.
  - Key findings of the analyses and recommendations.

Times Change

Knowing that it was still early in the morning, and realizing that his two team members might still be in weekend mode on this sunny Monday, Jacob opened the meeting with strong coffee and breakfast, courtesy of the company. He talked about his first project ever—when he had just graduated from college—and spoke about the primitive computer technology that was amply available to analyze expected project behavior. Mark had never shown much interest in computers, and so he concentrated on the delicious breakfast, realizing that this morning's meeting would be a crucial one for the future of GlobalConstruct. For her part, Emily listened attentively to her employer's anecdotes while doing some preliminary calculations on her brand-new MacBook to be better prepared for the discussion scheduled for the meeting.

"Times have certainly changed a lot," Jacob said, "but some things will never change. Good preparation is—and will always be—key to project success!"

Jacob explained that time estimates for activities are crucial in the early phases of the project definition, since they give a rough estimate of the expected project duration and costs.

"The project owner often decides to hire us based on these rough promises," Jacob explained, "which is why we should make them as accurate as possible."

"I understand the importance of good time estimates," Mark replied, "but how can we provide reliable estimates in such a preliminary phase of the project? Isn't that simply impossible?"

"Exactly," Jacob replied, "which is why we have to use a stepwise methodology—and that's the reason I scheduled this meeting with two of my best and most enthusiastic employees."

Emily smiled proudly.

He continued to explain that, in the early days at the dawn of his career, projects were much easier than they were today. But that was also a time without many proven project management methodologies, and project data were very scarce or simply not available. He again referred to a project management methodology that existed years before he started his career, and he told the team that it was the foundation of every project management methodology created ever since.

Jacob had first heard about that methodology—called PERT—when he was an engineering student, and he recalled that it had originally been developed for the ambitious Polaris rocket project at the end of the 1950s. "I believe it was an abbreviation for Program Evaluation and Review Technique, although I have to admit that I can't exactly remember why it got such a strange name."

Jacob explained that he was obsessed with the old press articles of his youth about the U.S. government's race to finish this project as quickly as possible due to concerns about the Soviet Union's growing nuclear arsenal. "Essentially, PERT was the first project management planning and control tool available for managing projects," Jacob said, "and more than just a tool: it created awareness that projects don't just happen, they must be managed!"

"Do you really think that the tool, which is now more than half a century old, is still valuable today?" Emily asked critically. She was notorious for her critical look at everything suggested to her. However, her criticism had never been regarded as resistance to adopting new methodologies, but rather as an inspiring curiosity that questioned things before accepting and fully embracing them. In this particular case, everybody realized that Emily would be the one to defend the use of any data-driven methodology at GlobalConstruct long before others would even know of its existence.

So, Jacob replied: "As always, the answer here is *yes* and *no*." Jacob talked about PERT's relevance to projects in which uncertainty is relatively low and the availability of resources is relatively high. "I believe the technique is still relevant today. It certainly is for small-scale projects, but it can also be used as a first filter mechanism for analyzing the predicted behavior of larger projects."

Although Jacob couldn't remember exactly how the technique worked, he immediately added that "the basic idea is so easy that we have to give it a try."

"However novel the technique was in those early years, I now regard it more as an easy way to set up a stepwise data-driven approach to analyze our projects in a very early stage," he continued without hesitation, and he wrote the following three words on the whiteboard:

ACTIVITY → NETWORK → PROJECT

Jacob continued to explain the stepwise approach by giving a short summary of each of the three stages.

ACTIVITY. Jacob explained that a first step should include an analysis of the activity durations based on the three estimates they had received from Emily and the two experts, Victoria and Andrew. He warned the team that he believed that not all three estimates were of equal importance, but nevertheless he considered them to be more valuable than only one single-point estimate for each activity duration.

NETWORK. In a second stage, the project activities should be assembled into a network diagram to model the logical dependencies between these activities. He reminded the team that the logic was slightly different for the two projects, and care should be taken not to mix the design-structure matrices of the two project proposals.

PROJECT. In a final stage, the project behavior should be analyzed in terms of both the expected durations and their variability. Such an analysis should enable the team to compare the two projects with other possible alternatives and should facilitate their selection of one of the projects.

Despite Jacob's clear and convincing tone of voice and the simplicity of the three-phased approach he proposed, Mark quickly realized that Jacob had only a basic notion about the underlying principles of the PERT methodology. It quickly became clear that much work would have to be done to find out how PERT could be used for GlobalConstruct's projects. So, Mark was not surprised when Jacob suddenly said: "Mark and Emily, I know that you are much better than I am in exploring the quantitative details of methodologies—so I want you to explore the secrets of PERT and use it for our two potential projects."

"A task that fits me like a glove!" Emily replied.

"Let's explore its dark and hidden secrets and report results in tomorrow's breakfast meeting," Mark added.

"Passionate as always!" Jacob grinned. "Show me how and why it should work for our projects! Or, alternatively, tell me why it won't!"

Activity Analysis

Emily arrived late to the next morning's meeting, which was very unusual for her. She explained that she had been exploring the tiniest details of PERT, and while PERT had revealed its dark secrets slowly hour by hour, she began to fully appreciate the technique only as the sun was rising again. By the time she went to bed to catch some sleep, she was happy that she had learned the very basic foundation of what had been her job for years now: managing projects.

"It was a short but good night," she said when she entered the room, "but sorry for being late." Emily enthusiastically started her explanation of PERT by saying that statistical methods could be used to describe the extent of variability in the activity-duration estimates and to model the degree of uncertainty inherent to projects. She explained that computing the standard deviation of each path in a project network would provide a probabilistic estimate of the time required to complete the overall project. She said that PERT relied on a straightforward and easy-to-understand probabilistic approach in which managers have to provide three estimates for each activity duration: an optimistic or best-case estimate, a pessimistic or worst-case estimate, and finally a most likely estimate.

"I believe that the best-case estimates are given by Victoria, since she is known for her optimistic outlook on our projects," Emily said.

"I guess that Andrew's estimates can then be considered as worst-case estimates, since they have the highest values," Mark replied (Table 2-3).

"Indeed," she replied, "when combined with my realistic or most likely estimates (Table 2-2), we have everything for a good and sound PERT analysis." She opened the lid of her MacBook and showed a graph to her team members that she felt could be used to showcase the elegance and simplicity of the PERT technique (Figure 2-1). Despite her short but intensive night, it was clear she was eager to explain the tiniest details to her two team members.

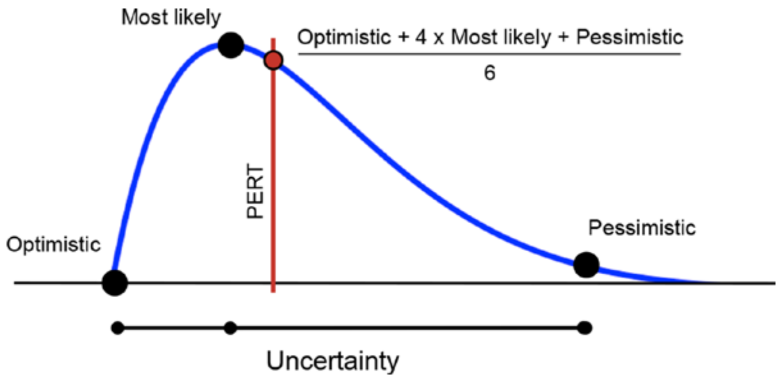


Figure 2-1. The PERT distribution used for activity durations

Emily explained that the shape of the graph reflected the probability distribution for an activity duration, which clearly indicated that real activity durations are stochastic and might be longer or shorter than initially expected. Moreover, she told the team that it was known from academic university research that real activity-duration distributions often follow beta distributions, or log-normal distributions, or triangular or even double triangular distributions. Before Jacob or Mark could interrupt her theoretical focus on statistics, she smiled and said, "But none of this statistical knowledge is really important to us. PERT is easy and cool. Simple statistics. No deep knowledge required."

She agreed with the team to refer to the distribution as the PERT distribution, and she explained that only three-point estimates for the activity durations must be used to model activity-duration variability. She reminded the team that these three-point estimates reflected the best, worst, and most likely duration of the activity, and then explained that their values could be used to calculate the average and standard deviations for each activity. Before she explained how this was done exactly, she reminded the team that one of the strengths of PERT was that it made statistics accessible to a wide audience. "No advanced calculations or overly complex statistical distributions," she said, "but rather some basic and straightforward calculations—and they all make sense!"

She took an electronic pen and added three dots to the graph on the screen of her computer to indicate the possible worst-case, best-case, and most likely values for a fictitious project activity. She said that, depending on the three values she had just provided, the PERT distribution could be drawn by connecting the three dots with a curved line.

"Let me show you how the average value and the standard deviation of the activity duration will be calculated by using these three estimates," she said, and she continued without any interruption or room for questions.

She started by saying that the PERT distribution emphasized the most likely value over the minimum (best case) and maximum (worst case) estimates to reflect that it is more likely to end up with a real activity duration that lies closer to the most likely value than to the two extreme cases. While she was drawing the formula for calculating the average activity duration on the whiteboard, she added that the most likely estimate would receive four times the weight of either the minimum or the maximum value, as follows:

AVERAGE = (BEST CASE + 4 x LIKELY CASE +
WORST CASE) / 6

Mark liked the idea of a weighted average to express that the likelihood of the real activity duration's lying close to the realistic estimate is larger than the likelihood of having extreme values.

"I believe it is an easy way to express that people are typically capable of providing a more confident guess for this most likely value than they are for the minimum or maximum," he said.

"Exactly," Emily continued. "The PERT distribution constructs a curve as shown in my graph, which places progressively more emphasis on values around the most likely value, instead of on values around the extreme values."

"In practice, this means that we trust our own estimate for the most likely value, and we believe that, even if it is not exactly accurate, the real activity duration will be close to that estimate."

"But since estimates are seldom very accurate, shouldn't we have an idea about their confidence or accuracy?" Mark asked.

"Correct, and that is why the standard deviation should also be calculated for each activity, as a measure of variability in the activity duration."

Emily told the team that this calculation could also be made using a straightforward formula, which she wrote on the whiteboard:

STANDARD DEVIATION = (WORST CASE - BEST CASE) / 6

Emily explained that this formula was based on the principles of a three-sigma interval that stated that almost all of the observations lie in that interval when the variable is normally distributed. She reminded her team members that a three-sigma interval refers to the observation that the percentage of values that lie within an interval around the average in a normal distribution with a width of three standard deviations is equal to 99.73 percent.

"Although the PERT distribution is not a normal distribution, the general idea behind this standard deviation formula is that it almost guarantees that the real activity duration will lie between the extreme minimum and maximum values," Emily said.

"Makes sense," Mark said. "Worst-case and best-case estimates are supposed to be very extreme values, so it is reasonable to expect that the real duration will not lie outside that interval."

Emily summarized her explanation by stating that the PERT distribution was based on three estimates, and that the two formulas were based on trust in these human inputs. While the calculation of the average value put more weight on the most likely value—as an indication of trust that this value was much more likely and accurate than the two extreme values—the standard deviation formula relied on the minimum and maximum values to express that the real activity duration would probably not exceed these two extreme values.

"PERT trusts the human input," Emily proudly summarized, as if she had invented PERT.

"Indeed: garbage-in, garbage-out. Wrong inputs, biased conclusions," Mark replied.

"As always," Jacob said.

Table 2-4. PERT Analysis for the Two Projects

		Singapore						Australia					
ID	Activity	BEST	ML	WORST	AVG	SD	CRIT	BEST	ML	WORST	AVG	SD	CRIT
1	Clearing the site	3	6	6	5.5	0.5	yes	3	6	6	5.5	0.5	yes
2	Removing trees	1	2	3	2	0.33	yes	1	2	3	2	0.33	yes
3	Subsurface drainage	4	8	12	8	-	no	4	8	12	8	-	no
4	Filling playing field/track	11	14	17	14	-	no	11	14	17	14	-	no
5	Installing artificial playing turf	11	12	13	12	-	no	11	12	13	12	-	no
6	Excavation	2	4	6	4	0.66	yes	2	4	6	4	0.66	yes
7	Pouring concrete footings	3	4	8	4.5	0.83	yes	3	4	8	4.5	0.83	yes
8	Pouring supports seat galleries	10	10	10	10	0	yes	10	12	14	12	0.66	yes
9	Erecting pre-cast galleries	9	10	11	10	0.33	yes	11	13	15	13	0.66	yes
10	Pouring seats	3	4	5	4	0.33	yes	1	4	7	4	1	yes
11	Steel structure	1	2	3	2	0.33	yes	3	4	8	4.5	-	no
12	Roof	3	4	5	4	0.33	yes	6	8	10	8	-	no
13	Dressing rooms	3	4	5	4	0.33	yes	3	4	5	4	-	no
14	Painting	3	3	6	3.5	-	no	3	5	7	5	-	no
15	Lights	1	2	3	2	-	no	3	4	8	4.5	-	no
16	Scoreboard	2	3	4	3	0.33	yes	2	3	4	3	0.33	yes

Network Analysis

Emily showed Table 2-4 on her computer screen and pointed to the averages and standard deviations of each activity for both the Australian and Singaporean projects based on the formulas she had just explained to her two team members. She explained that these activity estimates and PERT calculations should now be connected to the logical structure of the design-structure matrix for both projects. Even before Jacob got the chance to raise some questions about the table and some empty values in the standard-deviation column, Emily closed her computer screen and started talking about connecting these calculated values to the project network. She looked at Mark, who had expertise in network analysis and who had prepared something to show to Jacob. Jacob was impressed by the team spirit of his two colleagues and was curious about what they had in mind.

"Such a network analysis connects the activity estimates to the dependencies between the project activities and allows us to estimate the total expected project duration and its variability," Mark said.

He took a printed sheet from his briefcase, unrolled it, and explained that the design-structure matrix for the Australian project was graphically displayed in Figure 2-2. He told the team that a similar graph could be made for the Singaporean project, which would only be slightly different.

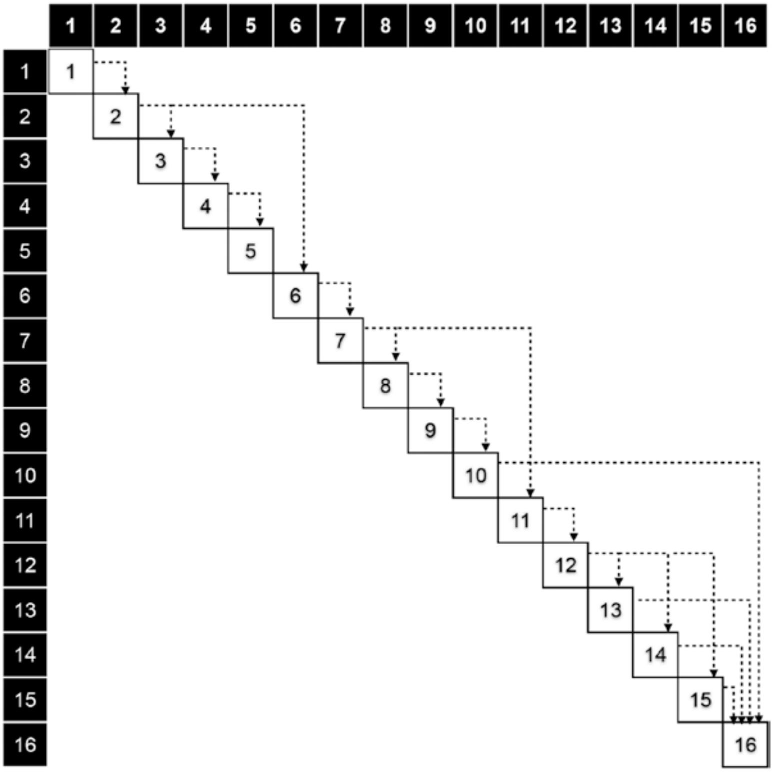


Figure 2-2. A graphical representation of the design-structure matrix of the tennis stadium construction project in Australia

Mark explained that the graph connected the project activities to each other using the information displayed in the design-structure matrix (Table 2-1). He showed that the activities were displayed on the diagonal of the graph and that succeeding activities were connected by arcs between them. The activity connections led to chains of activities, until an activity was found with no succeeding activity. In that case, the chain ended; such a chain was called an activity path, which plays a crucial role in PERT analysis.

Mark took a pen and wrote some numbers on the whiteboard, saying, "For the Australian project, this results in five different paths, each with a different total duration."

Activity path	→ Path duration
1 - 2 - 3 - 4 - 5	→ 42 weeks
1 - 2 - 6 - 7 - 8 - 9 - 10 - 16	→ 48 weeks → longest path (on average)
1 - 2 - 6 - 7 - 11 - 12 - 13 - 16	→ 35 weeks
1 - 2 - 6 - 7 - 11 - 12 - 14 - 16	→ 36 weeks
1 - 2 - 6 - 7 - 11 - 12 - 15 - 16	→ 35 weeks

Mark explained that the longest path determined the minimum duration of each project, and showed that it would equal 48 weeks for the Australian project.

"This longest path is known as the *critical path* and is nothing more than the sequence of project network activities that add up to the longest overall duration," Mark said. He continued to explain that a similar analysis for the Singaporean project should reveal a longest path equal to 53 weeks, which was slightly longer than the Australian project, but still within an acceptable time horizon for the Singaporean government.

Project Australia	Expected duration = 48
Project Singapore	Expected duration = 53

"The critical activities are indicated with a 'yes' in the criticality column (CRIT) of Table 2-4," Mark continued, "so the expected project duration is nothing more than the sum of these critical activities. For now, these values should be considered as expected durations, but it should be clear that, in reality, the real project durations might differ from these expectations."

"The crucial question," Jacob replied, "is how we define the accuracy of each expected duration."

"Exactly; it all depends on the variability in the activity durations," Mark answered.

"I believe that we should focus on the critical activities only, since variations in these activities have much more impact on the expected duration," Jacob replied.

"Yes. By definition, non-critical activities have slack in their timeline and are therefore less prone to have an impact on the expected project duration in case of delays," Mark answered.

"That's precisely the whole idea of the critical path," Jacob added.

"And that's why I haven't displayed the standard deviations for the non-critical activities in Table 2-4. We simply don't need those values," Mark said.

He explained that the total variability of the project should be calculated based on the values for the standard deviations of the critical-path activities, and thus the values of the non-critical activities could be ignored.

"Be careful with standard deviations," Emily added. "We should use their squared values (known as variances) instead." She told the team that there was a statistical formula that defined the variance of the sum of uncorrelated random variables as the sum of their variances, a property that did not hold for standard deviations.

"So, if the total project variability is equal to the sum of squared standard deviations, and only the values for the critical activities need to be taken into account, then I get the following values," Mark said, writing the following numbers on the whiteboard:

Project Australia	Variance = 3.5 → Standard deviation = 1.87
Project Singapore	Variance = 2.16 → Standard deviation = 1.47

"Nice work," Jacob said. "What can we conclude?"

"The Singaporean project has a longer expected duration than the Australian project, but its variability is smaller," Mark observed.

"So, could we now reasonably assume that the Australian project is more promising than the Singaporean project because of its lower expected duration, or should we conclude that the expected project duration of the Singaporean project, while somewhat longer, is more accurate due to its smaller standard deviation?" Jacob wondered immediately.

"We should analyze both the expected durations *and* the standard deviations in more detail," Mark replied, "and then make a final decision."

"I wish someone could help us better understand these numbers," Jacob said. "We should have a methodology to turn these numbers into better decisions," he added.

Both team members smiled at each other and then turned back to Jacob. There was no doubt that the two teammates were well prepared.

"Here is where the beauty of statistics comes in," Emily replied. She looked at Jacob to prepare him for a short but intensive training about the specific meaning and the statistical analysis of the averages and variances for the two projects.

"It's like a jigsaw puzzle falling into place, believe me," she said enthusiastically.

Statistics had been—and always would be—her favorite topic of discussion…

Project Analysis

Emily thanked Mark for the clear and easy presentation of how to calculate averages and standard deviations for both projects, and reminded Jacob that these numbers would now play a crucial role in a sound, but easy-to-follow, statistical analysis.

"It's super easy," she said, "since I assume everybody has heard about the normal distribution in statistics." Jacob immediately realized that the concept of *super-easy* had a very different meaning for Emily. He fastened his seatbelt for a lecture in advanced statistics.

"Have you ever wondered why this notorious normal distribution is so important?" she asked Jacob rhetorically.

While Jacob clearly demonstrated that he couldn't give a valid answer, Mark nodded affirmatively and said that the well-known normal distribution was so commonly used in management methodology that there must be a reason for that.

"The normal distribution—often referred to as the Gaussian distribution—is a symmetric, bell-shaped curve. Its beauty lies in its elegance and simplicity for math calculations," Emily replied.

"Can we please talk normal language," Jacob replied, giving Emily a wink. "Or can you at least tell me where you are going with all this praise for a statistical distribution?" he continued.

Emily grinned and wrote the following words on the whiteboard in her typical style, as if she were revealing a deeply hidden secret to the company:

THE CENTRAL LIMIT THEOREM

"The reason," she confided, "is that we all make use of the central limit theorem, although we often don't realize it."

Jacob was not as surprised as Emily had expected and said, "I remember that my statistics professor told us that the central limit theorem is the most powerful theorem in the world. But I can't remember what it is, let alone why and how we use it every day, as you say."

Emily explained that the main idea of the central limit theorem is that the average of a sample of observations drawn from a population with any distribution shape is approximately distributed as a normal distribution if certain conditions are met. The central limit theorem states that, given a distribution with an unknown mean and variance, the sampling distribution of the mean approaches a normal distribution with a known mean and variance.

"What she means is that the amazing and counter-intuitive thing about the central limit theorem is that, no matter what shape the original population distribution takes, the sampling distribution of the mean approaches a normal distribution when nothing too crazy happens," Mark added.

"I think I've got your point, and it explains the passion for your beloved normal distribution. But I honestly still don't see any link to the project analysis at hand," Jacob replied.

"If we know the statistical behavior of the Australian and Singaporean projects, we can better analyze and compare them, and thus make a decision based on numbers and facts," Emily said.

"And the central limit theorem provides us with a tool to calculate these statistics for both projects?" Jacob asked.

"Indeed," Emily replied. "The connection between the central limit theorem and the project is easy and unambiguous"—and she wrote the following words on the whiteboard:

Statistics	Project Management	Analysis
Population	→ Project	Use the normal distribution (with known
Sample	→ Critical path	values for average and standard deviations)

Emily explained that the population used in the central limit theorem could be represented by the project, and the sample would then be the longest path in the design-structure matrix of the project.

"It should be clear that, ultimately, we are interested in knowing the behavior of the population—in our case, the expectations of the two projects—but all we need is some data about the sample," she explained, "and since the sample typically is a smaller part of the population, the longest path can be used as a good representative sample."

Based on the known averages and standard deviations of this critical path sample, the central limit theorem could be used to draw conclusions concerning the project using the normal distribution.

"Now you probably see why I appreciate this normal distribution so much." Emily laughed warmly as she gave her two team members a printed illustration of two normal distributions (Figure 2-3).

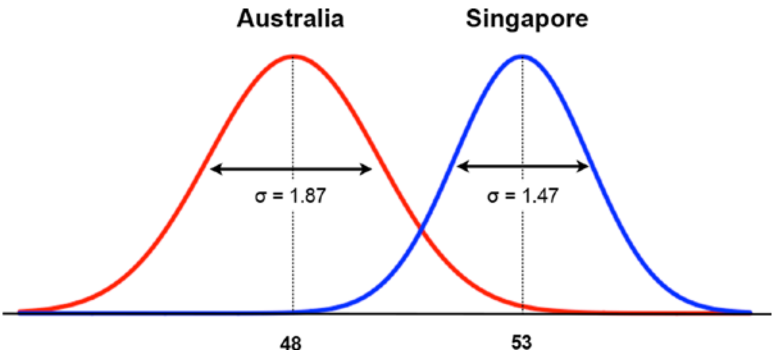


Figure 2-3. The comparison of the Australian and Singaporean projects

Jacob and Mark stared at the image for a moment and realized that Emily was right: the PERT analysis was not as hard as they had initially thought. The illustration clearly displayed the expected project durations of the two alternative projects—and the widths of the distributions, expressed by the standard deviations, showed the accuracy of these expectations. Once again, a graphical image was worth more than a thousand words…

"I believe the conclusion is straightforward! There's no doubt that we should opt for the project in Australia," Jacob said.

He told his team members that, simply by glancing at Figure 2-3, he could see that the chance that the Singaporean project would end at week 53 or earlier was exactly 50 percent, while this would be a guarantee for the Australian project.

"I wouldn't call it a guarantee," Emily replied, "although it is close to 100 percent."

To clarify her statement, Emily wrote a simple formula on the whiteboard and explained that normal calculations could be easily done in any spreadsheet tool. "In MS Excel," she continued as she pointed to her writings on the whiteboard, "a simple yet elegant formula will show you that the exact probability is equal to 99.62 percent!"

PROBABILITY (DURATION ≤ 53) = NORMDIST(53, 48, 1.87, 1) = 99.62%

"That's why I called it a guarantee," Jacob smiled.

"I understand your reasoning," Mark suddenly interrupted, "but I don't understand why you used the number 53 for the analysis of both projects. That just seems so arbitrary to me."

Mark said that the analysis didn't feel right to him, since it looked like it was judging the expected behavior of one project based on the expected duration (i.e., 53 weeks) of a second, alternative, project. "Could anyone tell me what the chances are that the Australian project's duration will exceed the Singaporean project's duration?" he asked, looking in Emily's direction.

"That is an easy question to answer if you've mastered some basic concepts of statistics," Emily replied. "But don't worry—I'll explain them in detail."

"Fasten your seatbelt," Jacob said to Mark. They all laughed and enjoyed the inspiring atmosphere.

Emily opened her MacBook and asked whether there was a printer available, since she had prepared some basic statistical calculations. Meanwhile, she explained that Mark's question could be reduced to calculating probabilities for a new normal distribution, which could be easily done based on the two normal distributions for the two projects. She told the team that, once they had figured out how to obtain this new distribution, the remaining calculations were straightforward and easy as pie.

"The new normal distribution should be nothing more than the difference between the two old distributions," she said, and she wrote the following equation on the whiteboard:

$$\text{PROBABILITY (Australia} \geq \text{Singapore)} = \\ \text{PROBABILITY (Australia} - \text{Singapore} \geq 0)$$

Emily explained that the trick was to consider the distribution of the difference of the duration of the two projects—and since, thanks to the central limit theorem, the original project durations followed a normal distribution, she told the team that the difference would also follow a normal distribution. For Emily, everything seemed to be trivial, but the two men were taking notes as if the exam were scheduled for early next week.

"You should know that the difference between two normally distributed random variables X and Y can be easily calculated when X and Y are independent by using the following straightforward formulas that I learned by heart when I was in high school."

She always gave her team members the impression that statistics is a science that everyone should master as a kid because of its simplicity and importance in everyday life.

"The following formulas should be used to answer the question," she continued, and she wrote these three equations on the whiteboard:

$$AVG(X - Y) = AVG(X) - AVG(Y)$$

$$VAR(X - Y) = VAR(X) + VAR(Y)$$

$$STDEV(X - Y) \neq STDEV(X) + STDEV(Y)$$

She then explained that, if the duration of both projects followed a normal distribution with known averages and variances, then the difference between these projects would also follow a normal distribution with an average equal to 48 – 53 = -5 and a variance equal to 3.5 + 2.16 = 5.66. To get the value of the standard deviation, the square root of the variance should be taken, which was equal to $\sqrt{5.66}$ = 2.38, a number that could be used to answer Mark's question:

$$\text{PROBABILITY (DIFFERENCE} \geq 0)$$

$$= 1 - \text{PROBABILITY (DIFFERENCE} < 0)$$

$$= 1 - \text{NORMDIST}(0, -5, 2.38, 1) = 1.78\%$$

"So, the chance that the Australian project's duration exceeds the Singaporean project's duration is only 1.78 percent, which is close to nothing," Jacob said, staring at the numbers on the whiteboard.

"I told you, statistics and PERT, it's all super-easy," Emily replied.

"I wouldn't call it super-easy, as you do, Emily," Mark said, "but I have to admit that PERT is an easy and elegant approach that goes beyond the use of subjective and often misleading arguments while making decisions."

"I agree—and, given this analysis, I believe it's clear that we should opt for the Australian project," Jacob concluded.

"Who am I to question your gut feeling!" Emily replied, smiling. She was extremely happy with the quantitative decision-making process they had followed. She was confident that this could be the beginning of a totally new data-driven management approach for GlobalConstruct.

Critical View

Now that it had been decided that the Australian project should be chosen, both Mark and Emily were eager to go further in their data-driven analysis. The two friends were talking about PERT's weaknesses and possible improvements to make the analysis even more realistic. Just before Jacob was going to close the meeting, Mark interrupted him and told both Jacob and Emily that they should be aware of some of the shortcomings of such a data-driven technique.

"We should at least understand why such an analysis might lead to biased results," he said.

Mark continued, saying that, by focusing on the variability of the activities on the critical path, they were assuming that non-critical activities would never have any impact on the project duration.

"That's, of course, not the case, since every non-critical path can become critical when changes in the durations occur," Mark said.

Emily confirmed this and told her team that any technique would suffer from simplifications. She mentioned some of the other weaknesses of the analysis—for example, the presence of multiple critical paths for some projects—and then explained that while the analysis normally treated multiple critical paths independently, this—according to Emily—was not always the case. She continued by saying that the variance of the sum was not equal to the sum of the variances, as they had calculated—and just before she was going to explain how the real statistical formulas should be used, Jacob intervened and abruptly stopped her never-ending enthusiasm: "Despite all of the weaknesses," he said, "I believe it's good for now."

He told Emily and Mark that they could spend more time and effort on a more detailed analysis once the proposal for the Australian project was approved by the client. He said that no further analysis was required for now, and a much closer collaboration with the project client would enable GlobalConstruct to define various country-specific estimates that were more accurate than their PERT estimates.

"I regard today's analysis as a first rough risk analysis for deciding in favor of the Australian project," he concluded, "but a more profound risk analysis will tell us much more so that we can more accurately predict the expected behavior of the project once it is in progress."

Jacob once again thanked his team members for the fruitful meeting, and then left the room. While Mark was feeling happy with the analytical approach they took to analyze the project's critical path, Emily stayed behind with a hunger for a more powerful analysis of the project data. After all, she was the one who knew that PERT could suffer from oversimplifications, and that much more powerful tools could be used to correct them. As always, she wanted to go much further and deeper into the details of mathematics. However, she knew that her day would come soon.

CHAPTER

3

Risk

A couple of weeks after the initial briefing, the team members gathered in the conference room. GlobalConstruct's CEO, Jacob Mitchell, had just announced his final decision to go for the tennis stadium construction project from the Australian government. "The Australian government is anxious to get started on the project. They want to make a statement regarding the quality of their projects, and they want to do it quickly," he said. Manpower to execute the various activities was not an issue, since Australia had access to an almost endless supply of workers. Additionally, many Australian subcontractors were eager to be involved in such a prestigious project.

Mark, the CFO, immediately got excited: "Let's not wait any longer; let's present our final planned status to the government by the end of this week," he said. "If we can quickly present a reasonable delivery date for the project, the government might consider a quick approval and a go/no-go decision, and then we can possibly start at the beginning of next year."

"Let's go back to the drawing board and review our initial time estimates and planned delivery date," Jacob replied enthusiastically, and he immediately looked in Emily's direction. Everybody knew that Emily had a thing for numbers.

M. Vanhoucke, *The Data-Driven Project Manager*,
https://doi.org/10.1007/978-1-4842-3498-3_3

Project Plan

From the beginning of the initial meetings, Emily had shown a contagious enthusiasm for the tennis stadium construction project, and everybody knew that she wouldn't be satisfied with a short and quick analysis. Given her deep passion for analytics and her conviction that a data-driven management approach would always outperform a decision-making process that was based solely on experience, she immediately started to talk about the importance of planning: "We should put effort into analyzing the project data in detail, not only to come up with a realistic plan, but also to put every little estimate of the plan in question."

Mark replied that planning was one of GlobalConstruct's strengths, and that they had proven in the past that a proper and realistic plan was beneficial for most stakeholders involved with the company's projects. With his years of experience in planning projects for the company, Mark was trained in structuring numerical data into easy-to-read graphs and summary statistics. "It took us a while before everybody agreed upon the right sequence of work packages and activities, but we finally agreed on timing and the logic between the different work packages and project activities." On the whiteboard, he displayed a graphical representation of the design-structure matrix (initially proposed in Table 2-1) and explained that such a network diagram was a good way for visualizing the network logic of the activities of the tennis stadium construction project (Figure 3-1). Moreover, Mark mentioned that the estimates for the activity durations had been a point of discussion among the different team members, but that the values displayed below each activity node in the network were the final values everybody had agreed upon.

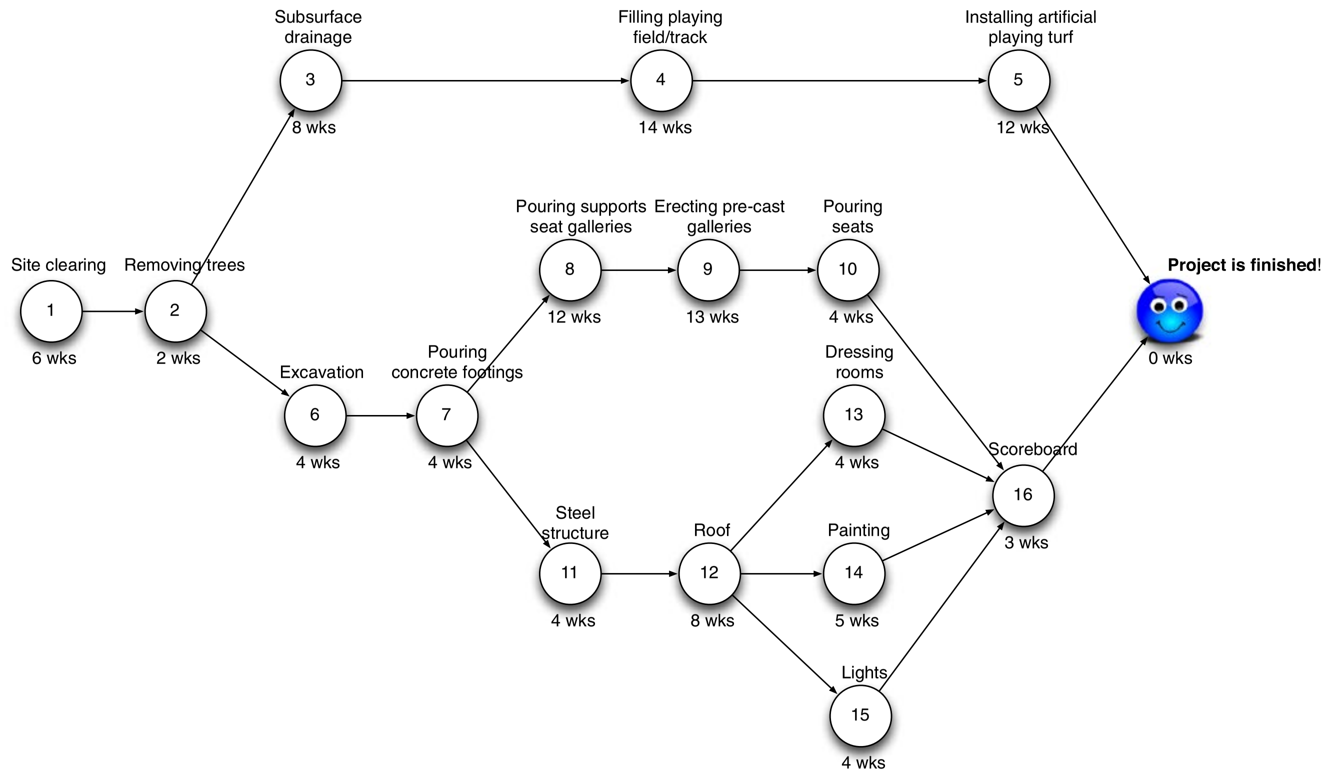


Figure 3-1. Network diagram of the tennis stadium construction project

"The picture says it all," Emily continued, and thanked Mark for his efforts in visualizing the project data in a tangible way. Mark explained that this graphical visualization could be easily used to construct a project plan to share with the Australian government. Emily immediately replied that the team should be cautious and that they should realize that plans were not always as realistic as they wished. "We shouldn't forget that this plan is merely a decision based on our own subjective estimates, and we should realize that things might go wrong that could possibly destroy the initial plan." In what seemed to be an agitated reaction, Mark replied that a sound analysis of the risk factors was obviously the next step in analyzing the plans, and he reminded everyone that this was exactly why they had convened this meeting in the first place.

Jacob noticed the tension between his two team members, and he decided to ask them some straightforward questions in an effort to keep things from escalating. He looked at Mark and said: "I understand that the logical sequence of activities as shown in the network diagram is more or less fixed and approved, and that it allows us to easily construct a plan for the project." Mark nodded in the affirmative without saying a word. "I also understand that this plan is based on time and cost estimates, which might be subject to small errors, or sometimes might even be completely wrong," Jacob continued.

"That's exactly what I meant by saying that plans are not always realistic," Emily interrupted.

"So then my simple question is," Jacob continued, "if estimates are almost certainly wrong, what is the purpose of such a plan?"

Mark and Emily looked at each other as if they felt that they had to explain the basic principles of planning to the most experienced team member. After some hesitation, Mark replied to Jacob's unexpected question in a skeptical voice: "I'm not saying that a plan should reflect the future progress completely, but it should at least be a pretty realistic forecast of how we could manage the project." He explained that the major risk now lay in the accuracy of the time and cost estimates, and that the impact of this lack of accuracy should be measured and assessed in order to take further action. "A plan is a snapshot, with many things that can potentially go wrong—but at least we can use it as a reference framework for further analysis."

"Exactly," Emily confirmed. "It's like a roadmap. You can use it for taking another road in case the traffic is stuck!"

"That makes sense," Jacob replied, happy that the tension between the two was only temporary. Jacob knew better than anyone else that tensions between his most precious team members would not be beneficial for the further course of the project. He sipped his coffee and said enthusiastically, "Let's make a plan, perform a risk analysis, and see where we can go from there! How about that?"

Risk Sheet

Emily presumed that Jacob's surprising intervention was intended to steer the meeting's topic into a risk-analysis direction. Having studied Mark's proposal, Emily was ready to bring some new information to light. Emily's previous job experience involved a short stint for a company in Australia. She had used her contacts to inquire about the accuracy of the time and cost estimates that were presented in Mark's network diagram. "Right, let's get to it," Emily said, matter-of-factly. "My contact has actually provided me with a detailed report on all the most important risks related to each of the individual activities," she continued while distributing the risk-analysis report displayed in Figure 3-2. "It appears that, while the average estimates were generally quite realistic, there are some major risk factors we had not foreseen. Especially in the initial phase of the project, it appears that several things might go wrong with the delivery of the equipment." Jacob and Mark were grateful for Emily's research, although this clearly meant that a more systematic analysis of the risk factors would have to be conducted in order to find the best risk strategy for the project.

"Right," Jacob confirmed. "It's crystal clear that we have some new work cut out for us, and that we need to run some simulations to get an accurate estimate of the risks and feasibility of the project."

Activity	External		Internal	Risk rating	Remarks
	Probability	Impact	Controllability		
Preparation					
1 Clearing the site	Medium	Medium	Low	Medium	The first step is to clear the site of all small items and debris so the construction effort can begin. Because the site is quite overgrown it is not 100% certain how much work this phase will require. However, it is clear that delays are more likely than not.
2 Removing trees	Negligible	Very high	None	Undefined	The ground contains a number of fairly large trees that have to be removed prior to the construction project. All the permits for this removal are in order, but there is a very small risk that environmental activists will try to prevent the removal of these trees. However, this generally happens in less than 0.1% of all construction projects. When it occurs, however, the consequences for the project are disastrous, with very long delays that endanger the successful completion of the complete project.
Field work					
3 Subsurface drainage	High	High	High	Medium	For this specific project the installation of the subsurface drainage poses a very real risk. The reason for this is the very rocky ground layer in which the drainage has to be installed. Fortunately, our company is highly experienced with this type of installation, and we are confident that the risks imposed by this environmental factor can be substantially lessened because of this. However, because the true nature of the underground cannot be predicted exactly, the precise duration of this activity is highly uncertain.
4 Filling playing field/track	High	Low	Low	Medium	The filling of the playing field depends on the timeliness of the supplier of the soil. These suppliers are all local partners, which we have never cooperated with. As such, problems with timeliness may occur. Fortunately, there are multiple suppliers available and the time to switch to another supplier should be minimal.
5 Installing artificial playing turf	None	None	None	Very low	The installation of the playing turf is a highly standardized operation executed by professionals whom we have worked with multiple times in the past. Hence, no delays are expected whatsoever.
Ground work					
6 Excavation	High	High	Low	Very high	Similar to the installation of the subsurface drainage, this activity can be highly influenced by the nature of the ground layers. Very rocky ground layers may require rock blasting using explosives. The precise impact all this will have is highly unpredictable; as such, the duration is only a rough estimate.
7 Pouring concrete footings	High	High	Medium	High	Construction errors in the foundations of a building are the number one reason for significant repairs in later years. Because of this, extensive tests of the concrete footings have been mandated. Should these tests uncover any defects, parts of the foundations may have to be recompleted. It is very hard to predict the impact of these tests in advance. However, our company does have substantial experience in working with the construction of foundations for large building projects, which significantly reduces the likelihood of construction errors.
Seating					
8 Pouring supports seat galleries	Low	Low	Medium	Very low	The concrete pouring for the superstructure is not a complex undertaking; no real issues are expected in this phase of the construction project.
9 Erecting pre-cast galleries	None	None	None	Very low	This is merely fixing a number of prefabricated pieces in the correct location; no issues are expected for this activity.
10 Pouring seats	High	High	Medium	High	Constructing the seats is a high-risk activity because the client expects a very high quality finished product. Tennis spectators are used to high-quality seating, and a tennis stadium has to be constructed to higher standards than a typical soccer stadium. Moreover, the construction procedure used is novel, and it is impossible to predict the specific issues that may arise.
Construction					
11 Steel structure	High	High	Low	Very high	The steel superstructure consists of very large steel beams. A major risk factor when installing these steel beams is strong winds, which may cause significant damage to the foundations and the steel structure itself. Unfortunately, the location of the stadium is known for sudden gusts of wind. When winds are too strong construction has to be halted. The current estimates are based on the average weather conditions, but the weather, and specifically the wind speed, is known to vary greatly and significantly more or fewer days of high wind than expected are possible.
12 Roof	Medium	Medium	Low	Medium	The installation of the roof materials can also be delayed because of the winds, but there is substantially less potential for damaging the structure. Moreover, this installation activity has a much higher wind threshold beyond which work has to be halted.
13 Dressing rooms	None	None	None	Very low	The installation of the dressing rooms does not use any special materials or expertise and is therefore a very low-risk activity.
14 Painting	High	High	High	Medium	The sheer size of the building poses a significant challenge for the painting. A large amount of scaffolding has to be constructed, and scissor-work platforms have to be used. The ad hoc nature of these operations makes them very hard to estimate accurately beforehand.
15 Lights	High	High	Medium	High	The installation of the lights is faced with the same challenges as the painting.
16 Scoreboard	Low	Medium	Low	Low	The scoreboard is installed by a specialized contractor who has a lot of large projects in his portfolio. Hence, no real issues are expected during this phase of the construction. Nevertheless, this is the first time we are working with this supplier so unexpected events can always occur.

Figure 3-2. Risk Report: Risk rating for activity durations using internal and external criteria

Emily explained that a prerequisite to fully exploiting the power of a project risk methodology is the classification of the risk sources into different dimensions, such as the *likelihood*, the *impact*, and the *controllability* of the risk. She took the risk report (Figure 3-2) and explained that the various activity risk classes were defined in collaboration with the Australian government, since the government had a much wider view of the potential risks in its country. "The input of the Australian government was crucial and serves as an outsider's view of the potential risks of the project," Emily said. "After all, they have more experience in these types of projects carried out in their home country and are probably well aware of the risks involved."

Emily indicated that the government's assessment of the accuracy of the activity estimates and their potential risk factors were displayed in the *external analysis* columns of the risk report. She explained that each potential source of activity risk had been split up into a likelihood of occurrence and a potential impact it might have on the expected timing of each activity. "Basically, this wasn't rocket science—we just split up risk as follows," she continued, and wrote a simple yet elegant formula on the meeting room whiteboard.

RISK = PROBABILITY x IMPACT

"Great work!" Jacob exclaimed. "This is valuable information that we can use for a project risk-assessment exercise to decide about future actions, and potentially to redefine or redesign the activities of the project."

"Exactly," Emily said. "But there is one more thing!" she continued in what seemed to be an imitation of Steve Jobs' voice.

Emily explained that she had submitted this likelihood/impact classification for an internal company review in order to identify most of the forms of controllable risk. "Given the external risk classification of the Australian government, which reflects the typical risks of the project, I believe that we, as a company, have a good idea of what our own strengths and weaknesses are," she explained. "I believe our own unique way of working can have a positive effect on how risk should be classified, and we should therefore add a third risk factor that expresses the degree of controllability we have for each risk factor."

Emily continued by explaining that she had had a team meeting with three colleagues who specialized in recognizing and controlling risks, and that they had decided collaboratively to turn the external risk rating into a new final value specific to the company. She explained that this controllability was shown in the *internal analysis* column of the risk report, and that it expressed the company's ability to cope with certain risk factors. "This fruitful meeting has resulted in this risk-rating metric, which expresses both the Australian government's view on risk as well as our own internal review of its controllability."

RISK-rating = PROBABILITY x IMPACT x (1 - CONTROLLABILITY)

Since controllability is an estimate of the ability of an appropriate company response, higher controllability should lead to a lower risk rating, and therefore the source of risk should be considered to be less important for the project. She told her team members that this final *risk rating* was shown in the next-to-last column of the risk report and illustrated this internal/external risk rating with an easy example. "Whereas the installation of the subsurface drainage was externally assessed as a high-risk and high-impact activity, our company's experience working in rocky soil significantly reduces the impact of any disruptions."

"I like that approach," Jacob replied. "Defining risk based on external expert knowledge, but adding an internal company-specific dimension to it—that's what I call combining the best of both worlds. What's the next step?"

"The risk rating should enable us to assess the accuracy of the activity estimates, and should put the black-and-white view of the critical-path schedule in the right perspective," Emily said.

"The problem with the critical-path analysis was that it implied that activity durations are deterministic," she continued, "but most activities have risk and should be modelled as stochastic variables."

Mark furrowed his brow, took out his calculator, and remarked: "Aha! Stochastic variables. That sounds like statistics!"

About Statistics

Emily explained that one of the core concepts of data-driven risk assessment is the ability to use ranges of possibilities for optimizing the best average outcome across all possible outcomes, rather than focusing on one specific outcome. "Once we acknowledge that the activity durations have distributions, rather than single-point values, it is easy to see that we can simulate artificial project progress using fast and efficient randomized algorithms that make use of the input distributions." She talked about the use of Monte Carlo simulations as a fast and easy way to imitate the expected project progress, and provided the team with a great introduction to how it could be used to create graphs about the activity sensitivity and total expected project durations and costs. "When we recognize that activity durations have distributions, then the total project duration and cost also have distributions!" she said magically, "so we should find out what that activity distribution is in order to set up an appropriate risk-mitigation strategy to protect our plan for things going awfully wrong."

"Although I like the idea of Monte Carlo simulation, I think that assigning different theoretical statistical distributions to each individual activity will lead us too far," Jacob commented. "Besides, can't we use the PERT distributions instead?"

Emily had an affinity with numbers, partly because of her background as an engineer, but also thanks to her true belief that a data-driven methodology must always be used to strengthen often subjective experience. So, the whole team was somewhat surprised when she agreed with Jacob that using an overload of theoretical statistical distributions is a bridge too far for many of the project management engineers working at GlobalConstruct.

"Exactly," she said, surprisingly. "We should keep the system simple and easy to use, and we should define some well-understood classes of risk and link them to statistical distributions."

She explained that a small number of clearly defined risk classes, without relying heavily on the correct statistical terminology, would simplify the risk analysis dramatically.

"All we need to do is agree on a limited set of possible risk classes," she said enthusiastically. She told the team that the PERT distributions couldn't be used since they only expressed the internal company view of the activity risk, but she promised that she would propose a similar—and maybe even easier—alternative. "Let's define some classes of activity risks now," she said.

No risk. First of all, there certainly existed activities for which the duration estimates were 100 percent accurate. One such activity was the erection of the galleries, where the use of prefabricated components guaranteed timely performance and thus posed no risk whatsoever. "These *risk-free* activities obviously should be incorporated in the analysis—but a single-point estimate is good enough for such an analysis; there's no need to use distributions," Emily said. "But I guess we don't have many of these activities, unfortunately."

Variation. "Indeed," Mark began, "although I believe that risk-free activities exist, most often there is still some doubt about the degree of accuracy in the activity estimates." Mark explained that the company had tried very hard to estimate many of the activity durations accurately, but that it was always wise to incorporate a certain margin of error. "As an example, no real issues are expected for the installation of the scoreboard, since this supplier has a solid reputation. Nevertheless, this is the first time we will be working with this contractor, which is always a reason to be slightly cautious." He looked at Emily and continued without hesitation, "That's why I prefer to use a small range of *variation* for most of these activities, rather than a single-point value. We often feel quite comfortable about some of our time estimates, but we are rarely 100 percent sure."

Foreseen uncertainty. Jacob was enjoying the animated discussion between the two colleagues, but interrupted them to make sure that they realized that activity estimates were seldom risk-free or subject to small variations. "During my career, I have noticed that often, if not always, you have situations that can be known to a certain degree in advance (or at least foreseen before they actually happen), but ultimately, we never have a clue whether or not these unexpected events will happen." He referred to the weather sensitivity of the roof installation and pointed out that this might cause significant delays. "These *foreseeable events* might result in huge delays compared to the initial estimates—with a huge impact on the project plan—but it's hard to predict how big exactly this impact will be."

Unforeseen uncertainty. "Yes," Emily said, "but things can even get worse! We should admit that, despite the experience we have in tennis stadium construction projects, there is also a minority of activities that are totally new to us." She told the team that, in these cases, everybody should realize that these activity estimates were no more than rough estimates, and many *unforeseeable events* might occur, making these estimates unreliable. "Let me give you a simple example," she continued. "There are new quality tests required for pouring the concrete footings, and this is the first time we will be subjected to these tests. So, it's very hard—if not impossible—to know what to expect from this."

Jacob was happy with the input of his two team members and decided that it was almost time to conclude the meeting and send them back to their offices with more work. "This animated discussion illustrates the willingness of our team to analyze the risk reports in a thorough way. It also shows that risk is a strange phenomenon—it's everywhere, it's unpredictable, it's sometimes dangerous." He looked at his two team members and then continued: "We're good at planning, and we work in a relatively certain environment, but something always comes up as a surprise! Let's do the calculations using the classification we just proposed."

Jacob rested a few seconds and then suddenly pointed at the risk classification report (Figure 3-2). "What do we do with these dark-colored activities with an undefined risk rating?" He explained that the removal of trees should not be an issue, but there was a very small chance that environmental activists would pose a problem. If that happened, delays could be so huge that they basically destroyed the whole planning of the project. However, the likelihood of such an event was estimated to be so small that it was almost negligible.

"I'm not sure we have to incorporate the rare events that are beyond the realm of normal expectations," Mark quickly reacted.

"I agree," Emily responded. "In statistics, we call that an outlier!"

"Yeah, statistics, or whatever!" Jacob said, faking irritation in his voice. "We'll see each other in tomorrow's meeting. I expect a simple, yet sound, risk analysis. But time flies—we have to move on!"

Assignment

As usual, Jacob told his team members that he would distribute an email with an action list summary. The results of these actions, which would be discussed in the next meeting, included the construction of an earliest baseline plan and a sound analysis of the risk table (Figure 3-2). The analysis of the data should result in risk classes for the activity durations and should be linked to the baseline plan to perform a schedule risk analysis. Before concluding the meeting, he told his colleagues that new people would join the next meeting, and that they would undoubtedly have their own way of looking at project management. "The challenge is to convince them that this risk approach is the best way to go forward," he told his core team members. "I'm counting on you!" he quickly added before he left the room.

ACTION LIST SUMMARY

- A critical-path analysis: An earliest start schedule with an indication of critical and non-critical activities.
- A risk-classification analysis: A classification of activities in risk classes and a choice of distributions for each class.
- A schedule risk analysis (SRA): Since a Monte Carlo simulation requires fast computers, this analysis could be restricted to an overview of how such a Monte Carlo simulation should work to perform a schedule risk analysis (a small artificial example of the simulation with a limited number of runs should clarify the obtained results and conclusions).
- A summary: An overview of the most important output metrics of the SRA study, as well as a discussion about their added value in comparison to the critical-path analysis.
- A comparison: An overview of, and a comparison between, the two alternative risk-analysis methods (SRA and PERT).

New People

Jacob, Emily, and Mark were gathered in a conference room one floor below the room where they usually held their weekly meetings. Jacob had scheduled the meeting for early in the morning in the biggest room the company had and decided to invite some other people from the company whom he believed could make a crucial contribution to this morning's meeting. His ambition was not only to discuss the risk sheets provided for the project, but also to lay the foundation of the risk-management approach that could be used for all of GlobalConstruct's future projects. He welcomed everybody with that mystical smile of his that he always had when exciting things were about to happen—and he asked everybody to give a quick introduction of how they thought they could add value to the project.

Ruth Bowman presented herself as a data scientist familiar with easy-to-use statistics for dummies, but also with the latest developments in artificial intelligence techniques, which she believed should be used in any project environment. As she was the head of GlobalConstruct's Accounting Department, she was an easy target to laugh at when the numbers did not match reality. Often, that was because the people outside her department did not understand the basic principles of reporting project progress. One of her strengths was her ability to help people without detailed knowledge of accounting methodologies understand what went on in her department. "I'm someone who is skilled at combining very specific and often complex methodologies into easy-to-understand principles that everybody can easily grasp," she said. It sometimes frustrated her that no one was really interested in what she considered to be the core of any company: reporting the numbers!

Mick Hudson presented himself in the typically short and to-the-point style that characterized many people with a computer background. He was the youngest computer scientist in the company and was known for his strange and often not-so-funny jokes, but with magic hands and an incredible affinity with novel software tools and IT methodologies. He was known in the company as the "Spreadsheet Guy" as he was a true believer that a spreadsheet allowed a business to keep a record of a huge amount of data in a single organized location. Besides that, everybody knew that he was the helping hand for people with little to no experience in computer technology, which made him the most charming guy of the IT department. In a previous life, he had been an IT teacher at the local school after graduating himself, but he had joined the company in search of new and bigger challenges after only two years there.

Mark and Emily didn't have to be introduced to the other members. Everybody knew that they had been involved in the project from the very beginning. Jacob knew that Mark and Emily would play an essential role in today's meeting, not only because of their expertise in projects like this, but also because of the inspiring nature of the previous meeting about the PERT comparison of the two alternative projects. Jacob's goal was to set up a similar data-driven meeting today on risk management, and he truly believed that the presence of both Ruth and Mick could be used as a facilitator for a more quantitative decision-making process for all projects in the company. On top of that, Jacob knew that years ago Ruth and Emily had shared an apartment at the engineering faculty of their home university, and their shared passion for number crunching made the two closer than anyone else in the company. Some people jokingly said that you should watch your words when talking to one of them, because they always tried to convert a conversation into hard data and numbers to be used by one or another software system. Jacob bluntly called them "quant-nerds" but loved them both for their prominent and quantitative look at the business. That was exactly the reason Jacob had strategically brought these two ladies together for today's meeting. A quantitative look and data-driven decision-making process was the way to go forward for GlobalConstruct. He was truly convinced of that!

Risk Definition

After a short introduction and a summary of the main take-aways of the previous meeting, Jacob quickly passed the floor to Emily, who agreed to give a general introduction of risk management for projects. Jacob asked her to hold the middle between a general introduction of risk-management concepts and the practical application of these concepts to the Australian project. "First, everybody should understand the basic concepts before we proceed with the practical (and maybe pragmatic) use of these concepts," he said. It was immediately clear that this project-risk exercise should be used as a pilot for the future projects of GlobalConstruct. Emily couldn't be happier with such a sound approach that started from the very basics—and so she accepted the challenge with great pleasure.

"If we want to analyze the risk of our projects," Emily promptly started, "then the first question that we should ask is how to define risk in a project." The statement was meant as an open question to her team members and a check as to whether they were ready to hold an interactive discussion. She therefore immediately stared at her team members, waiting for an answer.

"Risk refers to the presence of events that bring our project objectives into danger," Mick promptly answered.

"Not necessarily. I believe that it depends on how you look at risk," Ruth replied. "Risk can also be beneficial to the project. Unexpected events sometimes turn out to be better than expected, and they might add value to the project."

"Agreed. I would define risk as something that is different than expected! Either in a good or in a bad way," was Mark's reply.

Emily smiled at Jacob, as if the two colleagues shared some hidden secret, and she brought the group discussion exactly to the point she wanted it to be. "Exactly! We touch here on a very important aspect of risk management," Emily said. "You should first define what you expect before you can measure differences from your expectations."

"We have our plan," Mark interrupted. "It might not be a 100 percent realistic one, but at least we can reasonably assume that this is how we expect to run our project."

Emily pointed at Mark as if he had just given the final clue to what risk management was and explained that the real purpose of the project plan was indeed to act as a reference point for risk calculations. She told the team that the plan might not be as accurate as the company wished, but at least it was their best guess of how it could be. She continued to explain that risk, which she prefered to call *uncertainty*, might move their initial planning into unexpected directions, and therefore it was crucial to have a plan to measure the size of these unexpected directions *relative to the plan*. "You see, we have various definitions of risk! Maybe it would be better to refer to risk as *uncertainty* to express that it might change the initial planning in positive *and* negative directions."

"Now that we have defined risk as a degree of difference from the initial expectations, the next question is how to calculate risk," Emily continued. It was clear to everyone that she enjoyed the interactive style of the meeting.

"You showed us the formula in the previous meeting," Mark replied, and he wrote the following words on the whiteboard:

RISK = PROBABILITY x IMPACT

"Isn't this the way to calculate risk?" he asked.

"Yes," Emily replied, "but let me illustrate the beauty of this formula with an easy example from your daily life."

She asked the team members at what time they should leave their homes if they had to take an airplane from Brussels Airport next Saturday with a 10 a.m. departure time. She was convinced that using this easy example would allow her to illustrate the importance of this formula.

"It depends on the destination," Mick cleverly noticed.

"Let's assume you fly to my favorite city: Lisbon. Portugal's city of light!" she enthusiastically replied.

"I believe that I should leave at approximately 8 a.m., or 8:30 at the latest," Mick continued. "After a 15-minute drive, I should have enough time to park my car in the parking spot near the entrance, followed by a timely check-in to leave Brussels for a short stay in Lisbon."

"Same here," Ruth said. "The parking spots are pretty cheap, and leaving around 8 a.m. should be sufficient to catch the plane on time."

Emily replied with a follow-up question. "Would you change your mind if you knew that your flight was scheduled on a Monday instead of a Saturday?" she asked the team.

"I would leave earlier on Monday morning. 7 a.m. at the latest!" Ruth immediately responded. "Besides, I believe it's better to catch a train. Traffic jams are huge on Monday mornings!"

"Indeed," Mick added. "Although I prefer the luxury of driving my car, I would now take the train, even with the knowledge that it will be full of people with a Monday morning grimace on their face. It's much more certain, at that time of day, that you'll arrive at the airport on time."

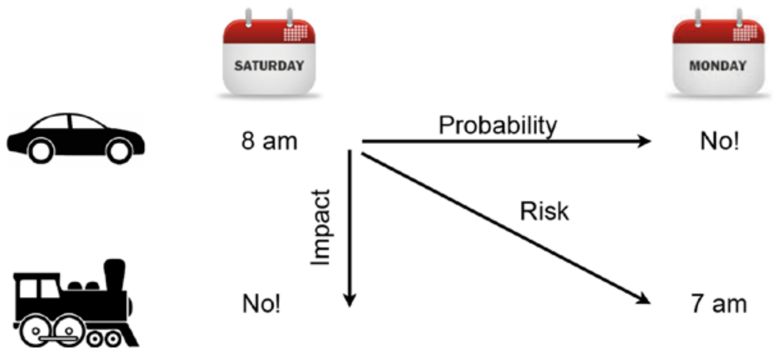


Figure 3-3. What is your departure time from your home when you have to take an airplane?

Emily smiled and said, "Great response! That's exactly why I wrote the formula on the whiteboard in the previous meeting!" She wrote a summary of the responses on the whiteboard (Figure 3-3), pretending she was the teacher of a risk-management class, and continued.

She explained that the choice of the vehicle clearly depended on the day of the week, and that this choice had both a *probability* dimension as well as an *impact* dimension. "The day of the week clearly influenced your departure time from home," Emily said, "since you were thinking in terms of probability calculations."

"The chance of having a traffic jam on Monday is indeed higher than on Saturday," Mick confirmed. "It is reasonable to switch to a safer mode of transportation in that case," he added.

"Exactly," Emily continued, "but the selection of your mode is clearly a decision based on impact rather than on probability."

"Both modes of transportation have a certain risk of delay, but you all believe that traffic jam delays are worse than delays in the train schedule," she continued, "so you all think the impact of a delay—if it occurs—is higher for cars than for trains."

Emily looked at the team and saw that the easy example had indeed illustrated well that everybody takes both dimensions, probability and impact, into account when making decisions regarding risk.

"Got it," Ruth replied. "Risk equals probability times impact. Always!"

"I couldn't say it better," Emily replied, and she looked at Mark, who was ready to take over the discussion. "The floor is now yours, Mark," she said.

Risk Classification

"Let me clarify how we used the formula from the previous discussion to classify each activity into a certain risk class in the risk reports of Figure 3-2," Mark started.

He explained that he had analyzed the risk reports that he had received from Emily in a previous meeting and concluded that the risk rating system of those reports was based on an easy classification of the risk dimensions.

"In order to make the system easy to use, both the probability and impact columns can have only one of three different values—*low*, *medium*, or *high*—for each activity," he explained to the team. "Since risk is the multiplication of these two dimensions, the activity risk can be expressed on a scale of five different values," he continued, and he wrote the following on the whiteboard:

LOW x LOW = VERY LOW

LOW x MEDIUM = LOW

LOW x HIGH = MEDIUM x MEDIUM = MEDIUM

MEDIUM x HIGH = HIGH

HIGH x HIGH = VERY HIGH

Mark explained that these five possible values for each project activity were shown in the risk rating column of the risk report in Figure 3-2, and he immediately showed a summary picture on his laptop screen to give an impression of the overall idea of the risk rating system (Figure 3-4).

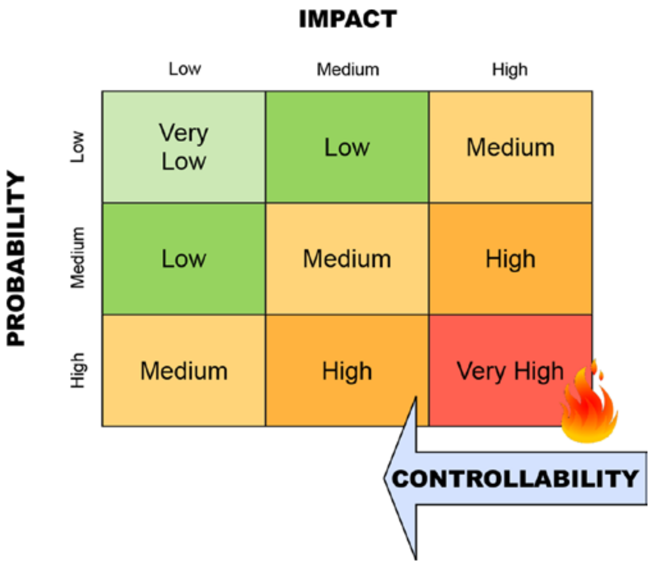


Figure 3-4. The probability/impact/controllability risk matrix

"This easy five-value risk rating system enabled the Australian government to assign a value for each project activity without much discussion," Mark said, and he pointed at one activity to illustrate how they came up with the risk rating. He referred to activity 1 (clearing the site) as an example of an activity with probability and impact values that ultimately received a medium risk rating.

"Since such a risk-class assignment should be done for all project activities," he said, "each activity can be classified into one of the nine areas of Figure 3-4, resulting in five different risk rating classes."

"An easy and elegant system, if you ask me," Mark added.

"I don't want to be rude," Mick replied, "but I think some mistakes have been made." He looked at activity 7 (pouring concrete footings), which should normally have been assigned a very high rating, but for which the risk report (Figure 3-2) showed just a high value. "That is contradictory to your easy classification method," he concluded.

"IT guys are sharp as a snake," Emily said, "but here is where the concept of *controllability* comes in."

Just like she did in the previous meeting with the core team of the project, Emily explained once again that the *risk* x *impact* classification could be considered as an external view of the risk of project activities, while controllability could be defined as a company-specific internal view of coping with those risks.

"You can consider the current activity risk rating as an objective outsider's view of risk," she continued, "but as a company, we might be able to reduce certain aspects of risk."

She explained that little to nothing could be done to reduce the probability of the risk occurrence, since probability was a concept that was beyond the company's control and defined the likelihood of occurrence. However, she stated that the impact, i.e., the result of the risk once it occurs, could be reduced by the company, and the degree of this possible reduction depended on the ability of the company to react to the unexpected event. "While we can rarely control the likelihood that something occurs, we can be good at reducing some of the potential impacts of certain unexpected events once they occur," she said, "so controllability is clearly the company's view of risk and its ability to reduce the impact of it."

"This potential reduction of the impact is shown by the left shift arc on my picture on the screen," Mark added, pointing at Figure 3-4 again, "and that is why activity 7 (pouring concrete footings) has received a *high* rather than *very high* label. Although the activity would be classified as very high from an external point of view, our company's ability to reduce its impact resets it to high."

"Controllability might reduce the impact of risk once it occurs, but it never has an effect on its likelihood of occurrence," Emily concluded, and wrote the following words on the whiteboard:

CONTROLLABILITY = REDUCTION OF IMPACT

"Each activity has a risk rating value that depends on not only probability and impact, which reflect the outsider's view," Jacob summarized, "but also on a third correction factor, known as controllability, which expresses how we as a company are able to cope with the impact of the risk."

"I like this idea," Mick replied, "but for me it's still a little bit fuzzy—certainly if I have to load this into a spreadsheet. Computers don't like words (very low, low, medium, high, or very high); they need data and numbers!"

"That is indeed the next step," Emily answered without hesitation.

"Time for a coffee break first," Jacob wisely decided.

Risk Analysis

Never underestimate the power of a good cup of black coffee.

While the team had discussions during the coffee break that went well beyond the risk-management theme, Emily didn't join her colleagues, instead working on her laptop like a lunatic while loudly sipping from her big cup of coffee. By the time everybody entered the room for the second part of the meeting, she was ready for the more quantitative statistical analysis Mick had asked for.

Emily immediately started talking about the necessity of understanding statistics and probability distributions, and also about the difficulty of using these concepts in a business context in which not everybody was as keen as she was about quantitative methods.

"In order to not overwhelm some of you with a long-forgotten statistical analysis, it is crucial that we develop a risk rating system that is comprehensible for everyone—and easy to use."

That sounded like music to the ears of most people in the room, except for Ruth. "I don't have a problem with simplifying things, but we should make sure that this is not a euphemism for being wrong. We should use a sound methodology, no matter what!" she said.

"I couldn't agree more," Emily replied.

Emily explained that the next step should consist of the translation of the probability/impact/controllability risk matrix (Figure 3-4) into well-defined and easy-to-understand statistical distributions to model the uncertainty in the activity durations. She looked at Mark and Jacob and told the rest of the team that the three core team members had already made an easy activity classification in the previous meeting to express different degrees of risk. She said that she would summarize this again in this meeting.

"The challenge is to define distributions and assign them to the nine areas of the risk matrix," she said. "Once we are able to allocate the project activities to these areas, we can connect the statistical distributions with project activities, which makes us ready to transfer this to Mick, who will let the computers run through the data."

She drew a picture on the whiteboard that contained four graphical distributions that she wanted to use for a statistical analysis (Figure 3-5). "The picture shows four statistical distributions for modeling uncertainty in the activity durations of GlobalConstruct," she said, "each of which has a clear and well-defined meaning." In her typical short and to-the-point style, she briefly discussed each of these distributions as follows:

Figure 3-5. Typical distributions to be used for schedule risk analysis

Variation. Some project activities have relatively accurate time estimates and can therefore be represented by a symmetrical triangular distribution. This distribution expresses that the activity estimates are more or less accurate, except for small unexpected variations that might occur due to randomness.

Foreseen uncertainty. For the set of activities belonging to the class of foreseen uncertainty, it is assumed that the possible causes for deviations between estimates and reality are well known. Despite this knowledge, it is of course not known whether these causes will actually happen. Therefore, it is assumed that the project team members have a certain degree of knowledge about whether these activities might end early (left) or late (right) once the causes for disruptions have taken place. For this reason, these activities should be modeled by an asymmetrical distribution, with a skewed tail to the left or right, depending on the expected impact of the disruptions.

Unforeseen uncertainty. Sometimes the team has no prior knowledge of the expected activity duration, and therefore the initial activity time estimates are only a rough best guess that might be prone to error or even completely wrong. In these cases, the best thing to do is to define a range of possible values and to define a uniform distribution that expresses this lack of knowledge about the activity estimates. "Although I hope that most of our activities do not belong to this class, sometimes we have little or no experience, and therefore don't have a clue about an accurate time estimate. If you don't know anything, then everything is equally likely, and this can be modeled best by a uniform distribution," Emily concluded her summary.

Emily paused for a moment and looked around the awkwardly silent meeting room in search of questions or reactions from her team members.

"I see that you have added two more fields to your picture that you exclude from the risk analysis curly bracket drawn below the picture," Ruth suddenly said in an attempt to break the silence.

"That is correct," Emily replied, and she referred to the first one as the *risk-free* class, which required no distribution at all.

No risk. For activities with no risk, it can be safely assumed that our duration estimate is correct. No statistical distribution is required, and the activity duration can be modeled as a single-point estimate.

"What are the black swans?" Ruth continued her sequence of questions.

"A black swan is a metaphor for an event that is very unlikely to happen," Emily replied, "but if it does happen, it might have a huge, damaging impact, more serious than any other event you can imagine."

Black swan. For some activities, it is assumed that the probability of disruptions are extremely low, but not non-existent. However, if such a disruption unexpectedly hits the project progress, its consequences (impact) cannot be overestimated, and it will bring the project into a totally new—and probably unpleasant—reality.

"We should not take these extreme events into account, because they can be regarded as beyond the normal," Mark noted.

"I agree," Emily answered. "That's why I removed them from the risk analysis curly bracket in my picture. They are beyond the normal!"

In order to avoid a new awkward silence, Emily decided to actively close this part of the conversation by summarizing what had been said, and she passed the floor to Mark, who agreed to explain how these distributions could be linked to the nine regions of the probability/impact/controllability risk matrix (Figure 3-4).

Mark took over and explained that the old risk matrix in Figure 3-4 should now be overwritten by an updated one, replacing the words (*very low*, *low*, *medium*, *high* and *very high*) with one of the four different types of distributions discussed by Emily. He briefly told the team that the specific use of each of these four possible distributions would depend on the *probability* and *impact* values (ranging from *low* to *medium* to *high*).

"We have previously explained that *controllability* can be considered a company view of risk, leading to a left shift to reduce the impact," Mark repeated, "and we will now use the *probability* and the *impact* to assign the previously discussed distributions to the risk matrix."

"Once that is done, we hand it over to Mick and his super-fast computers," Emily added. To Jacob, it was crystal clear that Emily and Mark had prepared this part of the meeting very well.

"I believe that we can fairly assume that our initial time estimates for all activities are more or less correct—otherwise, we wouldn't have set them at the current values," Mark started his explanation, "but there is a chance that deviations might occur, and a higher chance means that these deviations are more likely to occur."

"Sounds obvious, but what's your point?" Ruth replied.

"My point is that the *probability* dimension can be modeled by the type of statistical distribution that we use during the analysis," Mark answered. "By linking the distribution types to activities, each type of distribution can define a different degree of variation in the activity durations." He took a pen and wrote the following words on the whiteboard:

PROBABILITY = TYPE OF DISTRIBUTION

"If we want to keep the system easy, then my suggestion is to translate the low, medium, and high probability values into the three uncertainty probability distributions proposed by Emily (Figure 3-5): *variation*, *foreseen uncertainty* (left- or right-tailed), and *unforeseen uncertainty*," Mark said.

"That defines probability. What about impact of risk?" Ruth asked.

"The impact of the risk matrix should be treated somewhat differently," Mark continued.

He explained that the impact is used to express the consequences of unexpected events once they occur, rather than the probability of their occurrence. Once the type of distribution has been chosen based on the probability dimension, the impact would be best modeled by the size of the deviation from the initial estimates of activity durations. "The expected deviation from the initial estimates is defined by the length of the tails—that is, the range between the minimum and maximum values," he said as he wrote the following words on the whiteboard:

IMPACT = RANGE OF VALUES

"The small, medium, and large values of impact in the risk matrix can now be translated into small, medium, and large ranges for each of the probability distribution types discussed earlier," Mark continued. He opened his laptop and showed an updated version of the probability/impact/controllability risk matrix (Figure 3-4), in which he had replaced the words with the different distributions, clearly showing that the type of distribution was determined by the probability dimension and that the range of the different distributions became larger along the impact dimensions (the update is shown in Figure 3-6).

"All we need to do now is assign each project activity to this new picture, taking into account the risk rating of the original risk report of Figure 3-2," Mark said. "In doing so," he went on, "each activity can then be quantified by a statistical distribution with a known type and range."

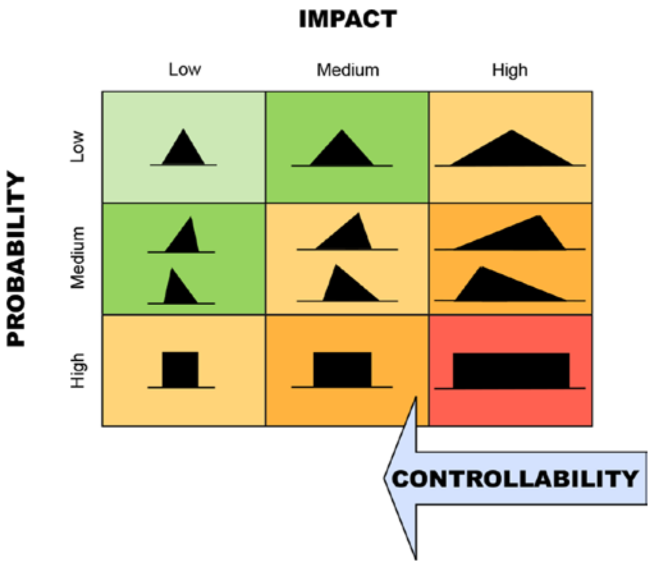


Figure 3-6. Risk distributions for GlobalConstruct's risk-classification method

Jacob observed his project team and saw that everyone seemed to be satisfied with the approach proposed during today's team meeting, convinced that this easy model might be another new step into a more data-driven project management approach for GlobalConstruct. He closed the meeting with a short wrap-up, thanking everyone for their contributions. He reminded the team that the theme of the next meeting would be the formalization of this new approach in an integrated software tool and looked in the direction of Mick, who was expected to play an essential role in this next step. "Looking forward to another inspiring meeting Thursday!" he concluded.

"Thursday is only the day after tomorrow," Emily whispered.

"Time flies when you're having fun," Mick replied wryly.

Time Machine

Mick opened the Thursday morning meeting by confessing that most of the concepts discussed previously were relatively new to him. He told the team that he had been inspired by the data-driven approach the company was taking in analyzing projects, and explained that this methodology fit perfectly into the company's strategy. He also told them that the approach proposed in the previous meeting was handed over to him so he could attempt to use the quantitative data to analyze the risk quickly and efficiently. He continued by explaining that the power of computers lies in the fast and easy processing of an overload of data, and that the previous meeting had clearly demonstrated that data was available at GlobalConstruct. "Since you guys are striving to analyze the risk of a tennis stadium construction project, which will only show its real face once it occurs, we talk about trying to predict the future."

"Exactly," Jacob replied. "We aim at being prepared for unexpected events once the project is in progress, given the data we have available today."

"You know, the good news is," Mick said enthusiastically, "that every computer contains an easy-to-use time machine to travel into the future."

"I understand you need fast computers to analyze data, but what does a time machine have to do with this?" Mark asked.

"A computer can imitate the expected future," Mick said. "All you need is data and some basic programming skills. And a good team!"

Jacob had always found IT people somewhat strange and aloof. Their childish enthusiasm about computer technology was contagious and often inspiring, but their well-known lack of interest in business relevance sometimes made them repulsive at company meetings. Mick was different. With a degree in computer science and a deep passion for every new gadget in the computer world, Mick's greatest asset lay in his ability to listen to people endlessly—which made him the perfect IT guy in Jacob's eyes. "Mick is not so involved in the business that he's biased like we all are," he once said to Mark, "but he has certainly enough affinity with the business to easily step out of his ivory IT tower to make the bits and bytes relevant to all of us." Everybody in the room was aware of Mick's business/IT integrative skills—he was highly appreciated by almost everyone in the company. Emily was undoubtedly the most enthusiastic person in the room. She was fond of numbers, calculations, and mathematics, but she had to admit that the latest developments in the ever-changing computer technology industry had become a mystery to her.

"A simple spreadsheet and some additional programming can do miracles!" Mick said.

Mick explained that computers were so powerful these days that it was extremely easy to generate an overload of data to be analyzed. He related that he had recently been responsible for a small IT project concerning the development and marketing of a mobile phone app, and he wrote down two simple project diagrams on the whiteboard (Figure 3-7).

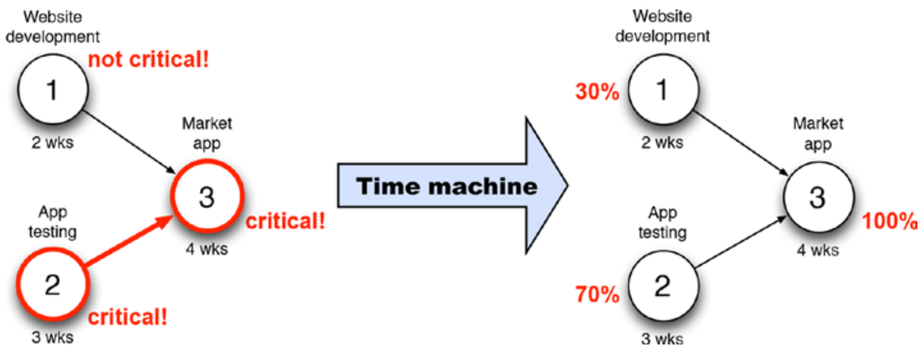


Figure 3-7. Mick's time machine project example

"The picture on the left displays the three major activities of my project," he continued, "and shows that the marketing of the app can only start once the app has been thoroughly tested and the website has been made publicly available."

"Is this the typical size of projects you are involved in?" Jacob jokingly asked. "You must have an easy life."

"I told you, IT is not complex—and besides, size doesn't matter," he replied animatedly, and then continued to explain that the traditional critical-path approach would only show a very black-or-white view of the project criticality, and that computers were able to bring more colors into the project manager's life.

"I guess you should call the sequence of activities two and three the critical path," he said, not sure he was using the right terminology.

"Exactly," Emily replied. "It's the longest path in the network, with a total duration of seven weeks."

"It's what we focus on," Mark added. "No delays are acceptable on this critical path."

"Suppose now that we use our computerized time machine," Mick continued with the enthusiasm of a child.

He explained that the distributions assigned to the nine areas of the risk matrix could now be used to generate numbers for each activity to predict the real activity durations.

"Each time, an activity gets another duration generated from the distributions, and consequently the project gets another total duration," he said.

"This might also result in another critical path," Mark noticed.

"Exactly; that's the whole point," Mick answered.

"But that's only one possible scenario for the future," Ruth added, "and we still don't know exactly how the real project's future will look."

"Indeed. But when we can repeat this time travel generation process multiple times—not once or twice, but, say, a thousand times," Mick continued, "then each time we might have a different critical path."

"Yes, I get it," Emily replied enthusiastically. "We can count how many times the activity lies on the critical path," Emily always looked up when she was thinking, "and the more often it lies on the critical path, the higher the degree of criticality."

"I told you that I would bring colors into your life," Mick said. "The so-called *criticality index* (CI) measures for each activity the number of times the activity was critical. If you divide this number by the total number of generations, it measures the *probability* that the activity lies on the critical path."

"What has the color to do with it?" Jacob asked.

Mick pointed to the right part of his picture and showed that the activities now had certain degrees of criticality, ranging between 0 percent (never critical) and 100 percent (always critical).

"While in your approach an activity is either critical or not, the time machine is searching for many possibilities in-between. No longer black or white, but instead a range of different colors. The added value of this approach is straightforward," he said. "The future will remain unknown, but our focus will be more future-oriented thanks to the more colorful view of activity criticality."

Mick explained that activity 1 (website development) was not labeled as a critical activity, but deserved at least some attention after the time machine travel, since it had a probability of no less than 30 percent of being critical. Likewise, activity 2 (app testing), which had been considered critical, had an updated criticality index of only 70 percent—which was much more than activity 1, but less than the third activity (market app), which would always be critical, no matter the future project progress. Mick took his pen and wrote the following on the whiteboard:

CRITICALITY INDEX = PROBABILITY THAT AN ACTIVITY IS CRITICAL

"I understand the logic," Ruth replied, "and I like the idea of having a more refined and colorful look at activity criticality, but I don't think I need a fast computer to do such an easy analysis." She took a pen and a sheet of paper and started to draw the distributions of both activities 1 and 2 on top of each other, explaining that the probability of each activity's being critical could be easily calculated. Emily, always in for some mathematical fun, joined her and stated that her calculations would only be correct when you could reasonably assume that both activities were not dependent on each other.

Mick looked at both women with an innocent smile, then abruptly stopped them by saying: "This is exactly where the beauty of the technique comes in! I know that my example is too easy for a super computer, but imagine what happens if you use the network diagram of the tennis stadium construction project." He referred to the network diagram of Figure 3-1 to show that the activities were highly connected to each other, and so the assumption that their risk was independent could hardly be maintained. "However, the power of this so-called Monte Carlo technique is that the computer can simulate data for any project network, as long as activity distributions are given as inputs for modeling the activity duration uncertainty."

"The complex relationship between the input data, the continuously changing critical path for each time travel simulation run, as well as the interplay between activities and their relations in the project network, is too complex for a human being, but it is not for a computer," Mick explained.

"No need for mathematical calculations," Mick continued. "You just need the type and range of the input distributions, and the computer will do the work."

"Sounds super easy!" Jacob said.

"As well as super fast!" Ruth added.

"You have to see it as a trip through time at the speed of a computer. A thousand or more different Gantt charts in a row, each time the same project, just other activity durations and different critical paths," Mick said, imagining this virtual time trip in his head (Figure 3-8).

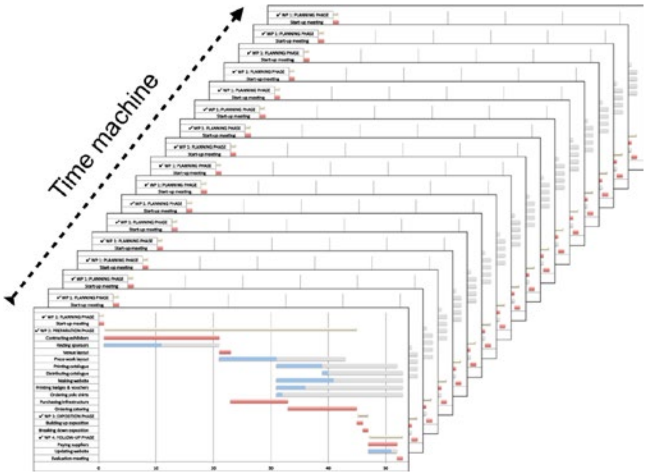


Figure 3-8. Risk analysis: The Monte Carlo time machine

"I knew IT people were strange," Jacob quietly whispered to Mark.

"I heard that," Mick spoke up, and started laughing.

“But, hey, wait a minute,” Emily suddenly said. “I don’t want to spoil the party, but the criticality index measures the probability, right?”

“Exactly,” Mick replied, “the probability that the activity lies on the critical path.”

“Then we aren’t measuring risk! Remember, risk is probability and impact!”

Emily looked toward Jacob with sudden disappointment in her eyes, as if she expected him to come up with a quick and easy solution to her valuable remark, but she quickly realized that Mick was well prepared for these types of questions.

“You have a point,” Mick said, “and that’s why I used the toy example. The real power of these computer time machines,” he continued, “lies in their ability to simulate thousands of runs, storing huge amounts of intermediate data before coming up with calculations such as the criticality index or anything else.”

“I have run some tests on the project with the statistical input data of the previous meeting,” Mick said, “and it could be shown that, in some cases, the criticality index seems to provide very strange results.”

“Think of an activity with a very high value for this index, close to 100 percent, but with a very short project duration, much shorter than the duration of all the other activities,” he said.

“In that case,” Emily continued, “the high CI value means that it almost always lies on the critical path, but due to its short duration, delays in this activity would hardly have any impact on the total project duration.”

“Exactly,” Jacob answered, “only probability, no impact.”

“As I said, while running through time, the computer will calculate alternative metrics, such as the significance index, a number between 0 percent and 100 percent, very similar to the criticality index, but with another meaning,” Mick said.

Mick explained that the *significance index* (SI) was defined as a partial answer to the criticism of the criticality index. Rather than expressing an activity’s criticality by the probability dimension, the significance index aimed at exposing the significance of individual activities, and hence this could be interpreted as a sort of measure of their impact on the total project duration. Mick wrote the following words on the whiteboard:

SIGNIFICANCE INDEX ≈ IMPACT OF ACTIVITY UNCERTAINTY ON PROJECT DURATION

Without any interruption, Mick continued explaining the power of computer calculations, convincing the team that the possibilities were endless. "Both the criticality index and the significance index report numbers for each individual project activity to highlight its expected performance under risk—but they only focus on one dimension of risk: probability or impact, but not both," he said.

"These two metrics should be combined," Emily replied, "in order to measure the real risk for each activity."

Mick agreed and said that the so-called *schedule sensitivity index* (SSI) combined both into an integrated metric that took both the probability and the impact into account, and he wrote the following words on the whiteboard:

SCHEDULE SENSITIVITY INDEX ≈ RISK OF ACTIVITY UNCERTAINTY

Mick told the team that the most straightforward way of calculating the SSI would be to multiply the CI by the SI but that the real formula was slightly more complex.

"I won't bother you with the mathematical details," Mick said, "but just consider the SSI as an integrated risk measure."

Mick told his team members that these three so-called sensitivity metrics (CI, SI, and SSI) all expressed how risky an activity was and how changes in the initial activity durations might affect the total project duration.

"The higher the values for each metric, the higher the risk of the activity and its effect on the total project," he added.

Mick promptly said that there were many other metrics available with similar interpretations, only using other slightly different underlying formulas, and he was proud to say that he had implemented a variety of others in this new spreadsheet tool.

Jacob thanked Mick for his important contribution and stated that there was no need for more metrics or detailed formulas. "I'm certain that you know much more, and that you've implemented the correct formulas in your software tool—but as long as we get the overall idea, we can go forward with this," he said.

"All right then," Mick replied, "let me show you the main results that my brand-new computer program has provided."

Evaluation

Mick distributed a printed sheet of the risk report originally used in the first meeting (Figure 3-2) and reminded everyone that the final risk rating could be regarded as a mix of probability, impact, and controllability.

He pointed to a picture displayed on the whiteboard (Figure 3-9) and explained that all project activities—except for the "no risk" and "black swan" activities—had been added to the two-dimensional risk matrix. Some of them had been shifted to lower-impact zones, as indicated by an arc to the left to visually display the effect of controllability.

"Based on the locations of each activity in the risk matrix, activity distributions and ranges can now be defined as proposed in Figure 3-6," he continued.

He referred to Table 3-1 and told the team that the table displayed the inputs (distributions and ranges) for each activity as well as the outputs of the time travel simulation runs. More precisely, he showed the team that the last three columns displayed the values for the criticality index, the significance index, and the schedule sensitivity index obtained after the computerized time-travel simulations, using the type and range of the distributions as indicated for each activity. Moreover, he proudly announced that such an analysis could be done in less than a second using a thousand simulation runs thanks to his quad-core computer processor.

Although Emily was not as impressed by the computer's speed as Mick was (she thought that computer speed was irrelevant for such an exercise), she immediately expressed her enthusiasm for the resulting values for the three risk metrics. "This analysis clearly shows that some of the critical activities are no longer as critical as we thought, and that the non-critical activities might become more critical than we sometimes expect," she said.

"Exactly," Mick replied. "Each activity now has a certain degree of criticality expressed by the three risk metrics." He showed that the activities on the critical path 1 - 2 - 6 - 7 - 8 - 9 - 10 - 16 did not always have the highest risk values, and that the risk values for some of the non-critical activities were not always equal to 0, or much lower than the values for the critical activities. "Although this might go against the philosophy of the critical path, it clearly shows that adding uncertainty into a risk analysis adds an extra colored dimension to the black-and-white view of the critical path." He was proud that he could illustrate his statement with the output of his software tool.

Jacob gave Mick a thumbs-up and asked the whole team: "What's the next step?"

"Although the results provide interesting insights," Mark answered, "the real value of this analysis will only become clear once we are right in the middle of the project progress."

"Indeed," Emily added. "For now, this analysis seems very static, since the project has not even begun. But once we are in the dynamic project phase, things will tend to run off schedule. Then, it will be crucial to take timely action to bring the project back on track, and we will be able to fall back on this risk analysis to take good and quick action by focusing on the activities with the highest values (percentages) for the risk metrics. These are the ones that should be carefully monitored, since they are expected to have the highest impact on the project duration," she said with the same enthusiasm she had at the beginning of the meeting.

"I got it," Ruth said. "Monitoring and controlling is key to project success!"

"You got the idea, Ruth," Jacob said. He thanked everyone for attending this productive meeting and encouraged them to contact Mick if they should have further questions after the meeting.

"We will certainly come back to this," he said in conclusion, "once we are right in the middle of the project progress, when action will be required. Although I never expect any delays in the activities, they always show up unexpectedly. At these times, we will have to be able to act quickly and effectively, and we'll be happy that we can fall back on today's analysis."

"To be continued . . ." he said as he left the room to go back to the real world.

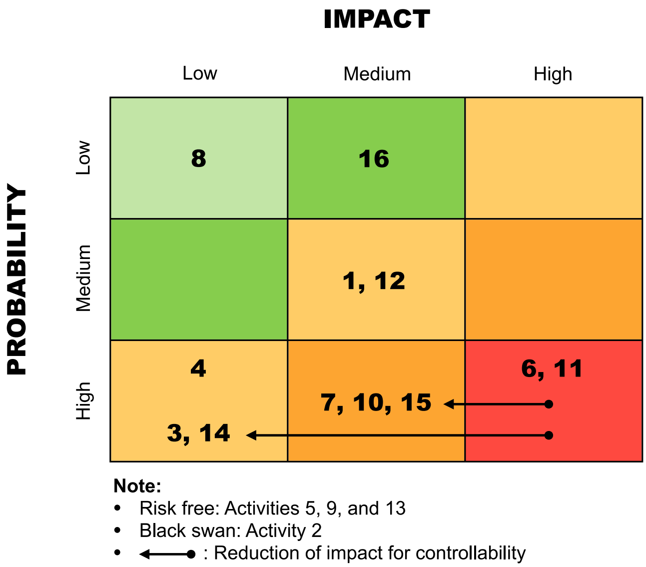


Figure 3-9. Activity assignments to probability/impact/controllability risk matrix

Table 3-1. Overview of Schedule Risk Calculations

Work package	Activity		Distribution	Range	CI	SI	SSI
Preparation	1	Clearing the site	Foreseen uncertainty	Medium	1.00	1.00	0.29
	2	Removing trees	Black swan	n.a.	1.00	1.00	0.00
Field work	3	Subsurface drainage	Unforeseen uncertainty	Small	0.03	0.59	0.01
	4	Filling playing field/track	Unforeseen uncertainty	Small	0.03	0.71	0.02
	5	Installing artificial playing turf	No risk	n.a.	0.03	0.68	0.00
Ground work	6	Excavation	Unforeseen uncertainty	Large	0.97	0.99	0.65
	7	Pouring concrete footings	Unforeseen uncertainty	Medium	0.97	0.99	0.41
Seating	8	Pouring supports seat galleries	Variation	Small	0.97	1.00	0.35
	9	Erecting pre-cast galleries	No risk	n.a.	0.97	1.00	0.00
	10	Pouring seats	Unforeseen uncertainty	Medium	0.97	0.99	0.41
Construction	11	Steel structure	Unforeseen uncertainty	Large	0.00	0.24	0.00
	12	Roof	Foreseen uncertainty	Medium	0.00	0.43	0.00
	13	Dressing rooms	No risk	n.a.	0.00	0.25	0.00
	14	Painting	Unforeseen uncertainty	Small	0.00	0.30	0.00
	15	Lights	Unforeseen uncertainty	Medium	0.00	0.24	0.00
	16	Scoreboard	Variation	Medium	0.97	0.99	0.21

CHAPTER

4

Buffer

The weekly Monday morning meeting with Jacob, Mark, and Emily was destined to be exciting but inherently different than the previous meetings about the tennis stadium construction project, not only because of Jacob's unusual late arrival, but certainly because of the presence of Joanna Barnes. In his weekly GlobalConstruct CEO's letter to all members of the company, Jacob had already stressed to the team members the importance of the timely delivery of the project, and he had introduced Joanna as a new member of the core team of this challenging project. No one really knew what to expect, but a new challenge was just around the corner. Some things never change.

"The project risk analysis has been unanimously approved by all members of the Australian government team," is how Jacob opened the meeting, with a shivering in his voice that balanced between excitement and despair. Mark and Emily knew that good news was always followed by decisions that should be made, and so they listened carefully to how Jacob continued his introduction. "While I previously said that manpower to execute the various activities was not an issue for the Australian government, thanks to the almost endless supply of workers, the situation is quite different for our own senior project management consultants, who will have to supervise all the work."

Jacob introduced Joanna as the head of GlobalConstruct's Human Resource Management Department. Joanna was not unknown to the other team members, but the fact that Jacob had invited her to their otherwise closed and intimate meetings was unprecedented and raised some suspicion. Joanna was well aware of this—so she immediately took over from Jacob and continued: "During the difficult negotiations with the Australian government, we agreed to deliver nine senior project management consultants from our company for the daily supervision of the project work." Joanna proceeded to say that

M. Vanhoucke, *The Data-Driven Project Manager*,
https://doi.org/10.1007/978-1-4842-3498-3_4

GlobalConstruct had to find a way to have access to nine project management consultants with enough expertise for this challenging project, and she argued that everything had to be done to guarantee their availability during the life of the project.

Jacob nodded affirmatively. "It might sound easy, but this resource-management task should be taken seriously—so it's worthwhile discussing in today's meeting," he said in concluding his introduction of the meeting.

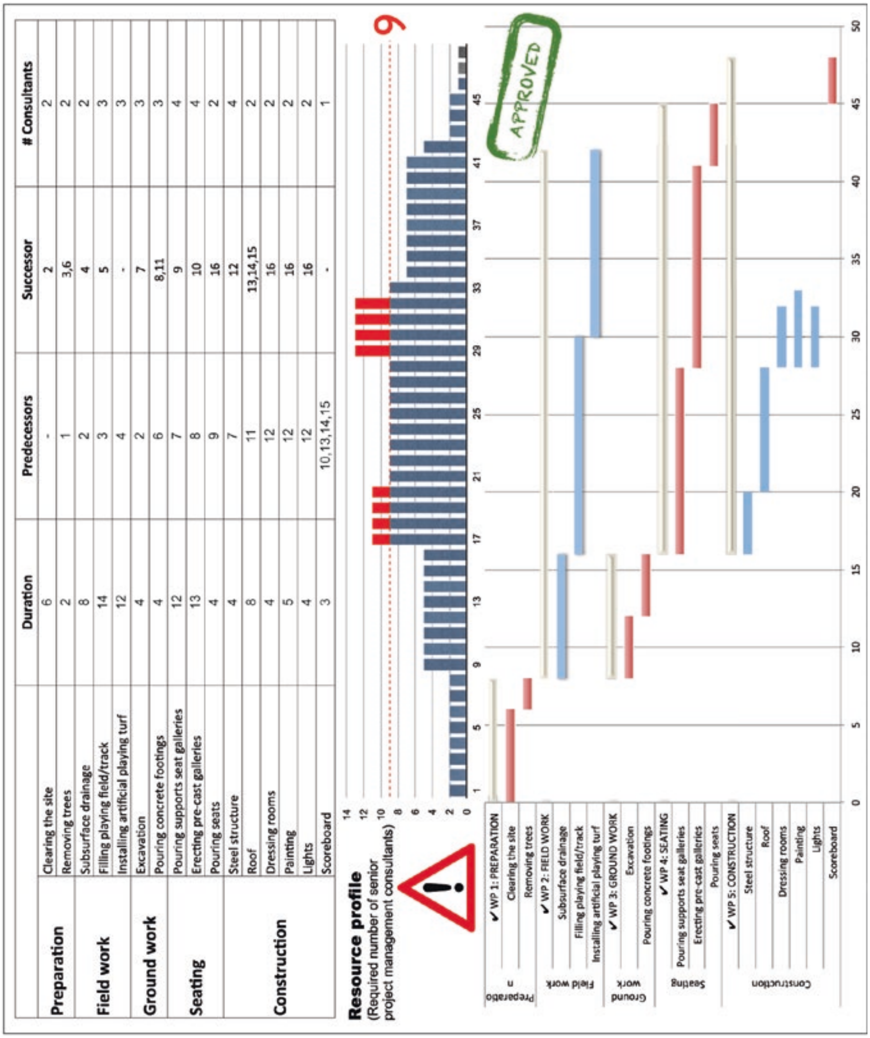
Resource Management

Mark hadn't heard about the project management consultants' availability problem prior to this morning's meeting, and so he had prepared an initial project plan that displayed the required number of project management consultants for each individual activity without taking Joanna's restriction into account. Unaware, until this morning, of the limited availability of nine consultants, he presented the proposed plan to the members of the team (as shown in Figure 4-1) and assured everyone that no significant actions were needed in order to cope with this unexpected limited availability. Although Joanna had little knowledge of project management topics, she knew how to read a Gantt chart—she immediately responded that these proposed plans were unrealistic and not good for the company's people. As head of the Human Resource Management Department, she immediately saw that the limited availability of the nine senior project management consultants was not always respected, and she drew the team's attention to the resource over-allocation in the resource profile of Mark's proposal.

With a voice that revealed the strength of a woman who would fight for the well-being of her people, she started a watertight monologue. "Plans should be realistic!" she said emphatically, and then immediately continued: "and an over-allocation of resources occurs when project managers have been encouraged to meet unreasonable expectations." She looked at Mark accusingly. "I believe we are right in the middle of such a situation. I do understand that you are pushing the senior project management consultants' allocation beyond obtainable limits in order to meet constrained schedules and budgets. But I hope you are well aware that an over-allocation puts unreasonable pressure on people and can be costly—not only in overtime money but also in decreasing performance, and possibly in loss of interest and burnout."

Jacob loved the way Joanna talked about the business and her people, and he appreciated the way she brought excitement, passion, energy, authentic meaning, and joy to her work. Nevertheless, this time he felt it was necessary to interrupt her fear of bad resource management. "Relax," he said. "I believe that we can easily cope with the resource pressure and solve the over-allocation without shifting the deadline further, which the client wouldn't accept anyway."

He pointed at the resource profile of Figure 4-1 and looked at Mark. "Can you do something without changing the plan dramatically?" he continued. "I mean . . . just a small update of the plan in order to cope with the limited project management consultants' availability problem?" An affirmative short nod was the only reply Jacob got. Mark had always been a person of few words—he believed his experience was on his side and that he would solve this issue easily without much disruption to the original plan.



		Duration	Predecessors	Successor	# Consultants
Preparation	Clearing the site	6	-	2	2
	Removing trees	2	1	3,6	2
Field work	Subsurface drainage	8	2	4	2
	Filling playing field/track	14	3	5	3
	Installing artificial playing turf	12	4	-	3
Ground work	Excavation	4	2	7	3
	Pouring concrete footings	4	6	8,11	3
Seating	Pouring supports seat galleries	12	7	9	4
	Erecting pre-cast galleries	13	8	10	4
	Pouring seats	4	9	16	2
Construction	Steel structure	4	7	12	4
	Roof	8	11	13,14,15	2
	Dressing rooms	4	12	16	2
	Painting	5	12	16	2
	Lights	4	12	16	2
	Scoreboard	3	10,13,14,15	-	1

Figure 4-1. The approved plan and the assigned resources (the senior project management consultants) for the tennis stadium construction project (note the over-allocation of the resources in the resource profile)

Buffer Management

While, in Mark's view, the resource over-allocation problem could be easily solved by a few minor changes to the plan, Emily kindly interrupted in her own unique, familiar, uncomplicated way: "I have a brilliant idea!" she exclaimed, "Superb and totally new!" Her never-ending search for new challenges, her distaste for the conventional path, and her ability to translate novel concepts into practical experience had often resulted in surprisingly unexpected outcomes, not always leading to better business results . . . but often considered important eye-openers to change direction and explore new paths. The audience could do nothing but listen.

On a recent business trip with her husband and son, Emily had attended a workshop where she had heard about a new upcoming project management technique, heavily inspired by the novel *Critical Chain* written by Eli Goldratt. Her experimental mentality was notorious, and everybody was aware that one day she would want to implement this often-heard-of technique on one of the company's projects. Everybody knew that that day had now arrived, and Mark realized that the minor changes to the original plan were surely the easy way to cope with Joanna's limited resource availability problem . . . but not Emily's way.

"I'm sure that everybody in this room agrees that the timely delivery of this tennis stadium construction project is essential for the company, and for the well-being of our people, for that matter," Emily said rhetorically. She didn't provide any room for a reply, continuing immediately to explain her idea. She explained that a *critical chain project plan* should provide the timing only for the start of activity chains, rather than for the individual activities. She showed that this meant that, for many activities, approximate start times and estimated durations were used, rather than the strict milestones that typified traditional project plans. Emily argued that the focus should not be on the timely completion of the activities, but rather on the project as a whole. "You shouldn't forget that the only thing that matters is the overall project performance, and not the performance of the individual activities," she added as a last undeniable fact, "so that's why you should give that novel approach a try!"

Having recruited Emily only three years ago, Jacob realized again why he never had any doubts about hiring this young but highly talented woman, and said: "So, why don't you explain the basic idea to us?"

Emily smiled with a mischievous innocence and said, "It's simple as tea!" while sipping her coffee and writing only three words on the whiteboard:

CUT - PLAN - BUFFER

CUT. Activity durations are often set as low-risk estimates to guarantee timely completion but should ideally be set more strictly to avoid unnecessary delays in activities and lack of focus. "Therefore," Emily argued, "activity durations should be cut to remove this unnecessary protection. I suggest we cut the activity durations in half (and round up to the nearest integer in case of fractional values)."

PLAN. A project plan must be constructed, similar to the one proposed by Mark, but activities should be scheduled as late as possible within the desired project deadline to postpone important cash outflows. "Obviously, when an over-allocation occurs, we must try everything to resolve it by shifting activities." She winked at Joanna, and continued, "We don't want our people to be overworked, do we?"

"That's not realistic!" Mark argued. "You first cut all activity durations in half, and then, in addition, you schedule them close to the deadline, leaving no slack at all. In my humble opinion, that simply guarantees that you'll miss the promised project deadline from the moment the slightest thing goes wrong." Emily smiled with that wiseacre face of hers, which people could only appreciate once they knew her better. "Wait a minute," she whispered, "because this is where the beauty of the critical chain concept comes in. You should buffer!"

BUFFER. The safety time removed from the activities should be aggregated and moved to strategic points in the project plan in the form of buffers to manage the impact of variation and uncertainty around projects. Emily explained that the sizing and placing of the buffers should be done in a unique way according to the critical chain concept, and she mentioned two types of buffers—project and feeding—as the mechanisms for protecting the project deadline from unexpected delays.

Despite her limited knowledge of project management, Joanna saw Jacob's approving look, and so she quickly agreed to consider this novel concept as a worthy alternative before further criticizing both Mark's and Emily's inability to respect the resource-availability limits. Rumors had been going around that Jacob and Joanna had had a relationship when they were young, but the truth was that they both had been, and still were, passionately engaged with their jobs, and were open to any idea that might satisfy their never-ending hunger for improvement. Backed by Jacob's affirmative reaction, Joanna said that she was open to analyzing the critical chain planning method as long as not more than nine senior project management consultants would be allocated to the project at all times.

Jacob suggested they explore the usefulness of Emily's method and compare it with the quick-and-easy solution proposed by Mark. "Convince me of the pros and cons of both approaches," he said to both Mark and Emily. "Keep me in the loop, and let's discuss the results in tomorrow's meeting. Same place. Same time," he added before he left the room with Joanna, leaving Mark and Emily alone with yet another exciting challenge.

"You would think there's something more going on between those two," Mark said. But Emily was already crunching numbers and changing plans. Her never-ending search for improvement made her unpleasant and aloof at times. Still, she knew that there was no time to waste. Tomorrow's meeting was less than 24 hours away.

Assignment

Given the two different approaches for allocating and planning resources, Jacob suggested that a comparison between Mark's traditional leveling approach and Emily's novel buffering approach should enable the company to make a final decision on how to respect the limited availability of the senior project management consultants. Before he left the meeting room, he had told the team that he would forward his action list summary to every member in the room, as he usually did. Much of the work for tomorrow's meeting now rested in the hands of Mark and Emily, and no intervention was currently required by the other team members, apart from familiarizing themselves with the basic concepts of project resource management and coming back to tomorrow's follow-up meeting with a critical mindset.

ACTION LIST SUMMARY

- Compare the two planning approaches to solve the resource over-allocation issue:
  - Mark's leveling approach: Analyze the easy solution to solve the resource over-allocation problem by shifting activities in time.
  - Emily's buffering approach: Analyze the more advanced critical chain solution using the *cut - plan - buffer* methodology.
- Analyze both plans as follows:
  - Identify the major flaws in each approach, and suggest improvements.
  - Calculate the total safety time in the plan for both approaches. Safety is expressed as the total amount of slack in the plan for Mark's approach, and as the total size of all buffers in Emily's approach.
  - Make a final decision that is acceptable to all team members and that can possibly be approved by the company's client.

Uncomfortable Entrance

When Mark entered the meeting room the next morning, he met Jacob and Joanna in a close conversation. Jacob leaned back and laughed loudly, while Joanna sat on the other side of the square table seemingly enjoying their early-morning intimacy. As Mark was not certain he had been noticed, he interrupted clumsily to announce that his colleague Emily had just called him to say that she would be five minutes late.

"No problem," Jacob replied, "we were just joking about her."

"Joking about what?" Mark asked, feeling uncomfortable by his unexpected interruption of what seemed to be an intimate conversation between his two colleagues.

"Well, my heart is already in my mouth knowing that Emily undoubtedly has prepared her novel resource planning approach down to the smallest detail." He laughed again, even more loudly than before. But Joanna noticed the uncomfortable hesitation in Mark's voice and so, in a friendly voice, asked him whether he had been able to alter the plan to resolve the resource over-allocation.

"I have indeed an alternative plan to discuss, but it might not be as exciting and novel as what Emily will propose," he answered. "I don't think it will be an easy meeting today."

Jacob replied that making difficult decisions was part of GlobalConstruct's DNA, and he told Joanna that the main reasons why he had chosen the job as CEO were to satisfy his desire to act as a facilitator and problem-solver and to feed his ambition to find solutions for complex problems in collaboration with a small but excellent team.

"No worries, a problem is just a solution in disguise," Jacob said enthusiastically. "We'll figure it out."

"That's right," Mark said, now feeling somewhat more relaxed.

"Ha, here you are, Emily!" Jacob said. "Let's start our meeting—there are tough decisions ahead," he joked.

Leveling (*Mark's approach*)

Mark quickly forgot his uncomfortable entrance and immediately put two plans on the table, printed on large sheets to reveal all the tiny little details. The first sheet was a copy of the approved plan presented yesterday (Figure 4-1), which, despite its approved status, clearly suffered from an over-allocation for the senior project management consultants. Based on the leveling approach he had proposed the day before to solve the over-allocation issue, he now brought an alternative plan that closely resembled the approved plan, but with some activities shifted further in time (to the right in the Gantt chart) to get rid of the resource problems (Figure 4-2).

"The basic idea of my new plan is easy," he said. "What can't be done in parallel should be done in sequence."

Mark reminded the team that the initial approved plan showed an over-allocation for the senior project management consultants, and pointed at the resource profile graph of Figure 4-1. He showed the team that the over-allocation started at week 17 with two extra project management consultants required for four weeks (above the limit of the nine consultants available), and a second period with an over-allocation occurred starting at week 29, where up to 13 senior project management consultants would be required (i.e., four more than currently available) for another four weeks.

		Duration	Predecessors	Successor	# Consultants
Preparation	Clearing the site	6	-	2	2
	Removing trees	2	1	3,6	2
Field work	Subsurface drainage	8	2	4	2
	Filling playing field/track	14	3	5	3
	Installing artificial playing turf	12	4	-	3
Ground work	Excavation	4	2	7	3
	Pouring concrete footings	4	6	8,11	3
Seating	Pouring supports seat	12	7	9	4
	Erecting pre-cast galleries	13	8	10	4
	Pouring seats	4	9	16	2
Construction	Steel structure	4	7	12	4
	Roof	8	11	13,14,15	2
	Dressing rooms	4	12	16	2
	Painting	5	12	16	2
	Lights	4	12	16	2
	Scoreboard	3	10,13,14,15	-	1

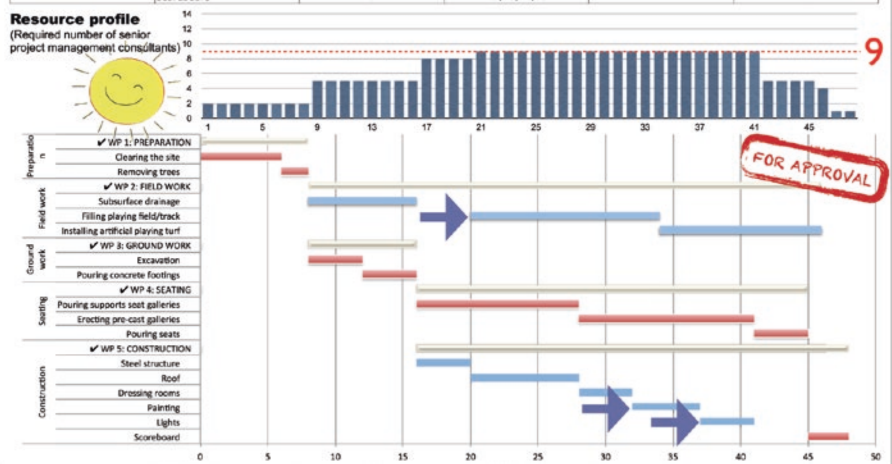


Figure 4-2. Mark's leveling approach: An alternative project proposal without any resource over-allocation

"We could simply accept the over-allocation, and let the project management consultants work overtime," Mark said, "but I know that Joanna is not very keen on accepting overtime during the planning phase."

"I don't have anything against overtime work," she replied, "but I don't think we should build it into our plans." Joanna told the team that planned overtime often had a negative impact on a project's health and on how project management consultant teams worked, and she reminded everyone that the project might simply stall, come to a halt, or even fail completely. "Working overtime is occasionally acceptable to solve acute project problems, but it should be avoided during planning as a work-around to solve a scarcity of resources."

"That's why I have the alternative plan ready for approval," Mark said. Mark showed that delaying activities 4 ("filling playing field/track"), 14 ("painting"), and 15 ("lights") would lead to a more leveled use of the project management consultants, thereby resolving all over-allocations and issues raised by Joanna. He pointed to the arcs in the Gantt chart and to the resource profile of the alternative plan and showed that, thanks to these activity shifts, the availability of nine senior project management consultants would never be exceeded during the project's life.

"An easy solution," Jacob responded, "but since this requires a change in the plan, it should be approved by our client."

"Exactly," Mark said, "but since the project deadline of 48 weeks remains intact, I don't see any reason why our client would object to this changed plan."

Jacob told the team that the client was probably well aware that they should accept some degree of change when working on any project, but he was not so sure it was wise to propose a change request so early in the project phase. Although he agreed with both Mark and Joanna that an over-allocation should be avoided during the planning phase, he nevertheless clearly stressed that a change in plan was not a desirable move in this early phase of the project. He looked at Mark and thanked him for the easy solution to cope with the over-allocation of the senior project management consultants.

"Since your alternative plan does not differ too much from the initial approved plan, I prefer that we stick to the approved version of the plan," Jacob said.

He agreed that building in overtime during planning was indeed not a very desirable approach, as Joanna had previously said, but Mark's alternative proposal clearly illustrated that the allocated overtime could be resolved easily. Therefore, he preferred to stick to the initial plan, despite its overtime, and to decide on some activity shifts to resolve the over-allocation during the project's progress.

"When we actually detect a real over-allocation during the progress of the project, we now know that simple activity shifts will solve these resource problems very easily," he said.

The team agreed with Jacob that making these small changes to the initial approved plan was probably not worth the effort, as it would lead to unnecessary discussions with the company client. However, before Jacob would make a final decision, he proposed taking a look at Emily's alternative approach, which could provide a completely new insight into how to cope with the over-allocation of resources.

"Food for thought," Jacob summarized to end the discussion. "Emily, you had an alternative view on this planning process, so why don't you tell us about it?"

Buffering (*Emily's approach*)

Emily hadn't said a word during the meeting, since she was eager to present the novel approach to the team. Although she realized that Mark's quick and easy solution was elegant in its simplicity, she preferred to present an alternative approach—a more complex one and hence, in her opinion, more promising. Emily reminded the team that she had explained the *cut - plan - buffer* approach in the previous meeting, and she now wanted to illustrate this three-step approach using the tennis stadium construction project data. She had prepared some calculations, and with a pen and cloth in her hands, she was ready for some drawings on the whiteboard. Everybody realized that, once again, this would be the starting shot for a teaching session beyond the normal practice of project management for GlobalConstruct.

"Are you ready for a new approach?" she asked to her team mates.

"We certainly are!" Everybody responded in choir. Was there any other choice?

Emily asked the team to take a quick look at Mark's alternative proposal and reminded them that this resource-leveling approach simply required delaying activities until resources were available. Although she praised this approach for its simplicity, she warned the team that it didn't leave much room for activity slack in the schedule. Moreover, she referred to Mark's new plan as a *milestone plan* to stress that the planned activity times typically marked specific points along a project timeline. She explained that a milestone planning approach gave little to no incentive to finish activities earlier than the planned finishing times and should therefore be handled with care.

"The problem with milestones," Emily continued, "is that they quickly become self-fulfilling prophecies."

Jacob, known for his passion for history and a notorious bookworm, quickly reacted by reminding the team that a former British naval historian named Cyril Northcote Parkinson had written a book about this phenomenon, which since then had been used in lectures on efficient time management. Emily smiled affirmatively and immediately wrote the following management law on the whiteboard:

> **Parkinson's law!**
>
> "Work expands to fill the time available for its completion."

"What's the problem?" Joanna reacted. "As long as correct time estimates for the project activities have been made?"

"That's exactly the problem," Emily replied. "Management laws always come in pairs."

Just below the first law, she wrote a second famous law on the whiteboard:

> **Murphy's law!**
>
> "Anything that can go wrong, will go wrong."

She explained that Parkinson's law, in combination with Murphy's law, would cause delays in the activity milestones, which undoubtedly would have an impact on other activities and the team working on the project, and eventually on the total project duration.

Emily explained that, when the activity finish times act as milestone targets, most people will not begin to work on the activities immediately, but will instead start at the last possible moment. This eliminates any potential safety margins and puts people under stress and pressure. She said that this phenomenon is known as the *student syndrome*—but she wondered whether this was only applicable to students. Everybody smiled, because they recognized this practice in their daily life. She told the team that Parkinson's law often occurred due to this student syndrome, and that the law consumed all safety time for each project activity, which eventually led to delays due to the inevitable intervention of Mr. Murphy.

"That's why the slightest problem will cause a delay and disrupt the milestone planning," Emily said.

"You should take that knowledge into account by allocating extra time for activities," Joanna replied.

"Your reaction goes right to the heart of the matter!" Emily replied thankfully. "You should *not*!"

Everybody saw that Emily was delighted by the surprised looks on her team member's faces, as she was well-known for her habit of explaining new matters that often went straight against normal business practice. She told the team that her amazingly counter-intuitive reaction lay at the core of the *cut - plan - buffer* approach, which she was now about to explain using the tennis stadium construction project data.

CUT. Emily introduced the concept of *aggressive time estimates*, which relied on the crucial insight that projects as a whole—rather than the individual project activities—should be protected against unexpected delays. Since activity estimates usually contained some degree of protection to anticipate the effect of the student syndrome and Parkinson's and Murphy's laws, people often recommended that you remove this safety time from these activity estimates. She looked at Joanna and told her that this was exactly why the allocation of extra time to activities was not the way to avoid these potential activity delays, while she wrote the following words on the whiteboard:

NEW! USE AGGRESSIVE TIME ESTIMATES

"The protection of activities against delays should not be a goal," she said. "We should protect the project!"

Joanna nodded silently, recognizing that Emily was a master at constructing logic from scratch—often starting with the wrong assumptions her team members had made and gradually guiding them into new, unexplored directions. Still, she was not entirely convinced that removing protection from activity time allocations was the right thing to do. Nevertheless, she decided to continue listening to Emily's reasoning before raising any objection.

"As an example, let's cut the activity duration in half to get rid of the unnecessary safety time, and round the duration to the nearest integer for simplicity's sake," Emily suggested.

Before giving her team the chance to react, Emily continued: "I know that this is a very aggressive (no pun intended) approach—having activities with much shorter durations and no protection at all—but let's look at the second phase of the new approach."

PLAN. Emily continued in a stepwise fashion, explaining that in a second phase the project should be planned with these aggressive time estimates while avoiding any over-allocation of resources similar to Mark's approach. Much against everyone's expectations, she advised the team to plan the work backward from the expected project completion date, so that each activity would start as late as possible. Emily carefully drew a Gantt chart on the whiteboard (Figure 4-3) and reminded the team that the activity time estimates had now been cut in half to obtain the aggressive estimates. She especially drew their attention to the fact that this plan, despite a much shorter activity duration, closely resembled the new plan for approval proposed in Figure 4-2 by Mark.

"Just as Mark did for his new alternative plan proposal, I have scheduled some activities in a sequence to avoid any resource over-allocation. Moreover, I have also left a gap between activities 3 and 4 for the very same reason."

"As far as I understand, the only difference with my approach is that the activity durations are much shorter, and that these activities are now scheduled as late as possible," Mark added.

"That's correct," Emily replied.

"Then I don't see any added value compared to my simple planning approach," Mark concluded, although he realized that Emily had not yet finished her explanation.

		Safe time estimates	Aggressive time estimates
1	Clearing the site	6	3
2	Removing trees	2	1
3	Subsurface drainage	8	4
4	Filling playing field/track	14	7
5	Installing artificial playing turf	12	6
6	Excavation	4	2
7	Pouring concrete footings	4	2
8	Pouring supports seat galleries	12	6
9	Erecting pre-cast galleries	13	7
10	Pouring seats	4	2
11	Steel structure	4	2
12	Roof	8	4
13	Dressing rooms	4	2
14	Painting	5	3
15	Lights	4	2
16	Scoreboard	3	2

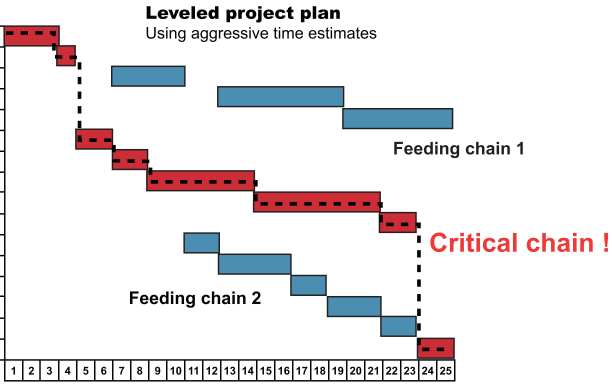


Figure 4-3. Latest start schedule with aggressive time estimates after leveling

Before she gave a reasonable answer to Mark's reservation, Emily started to add some notes on her drawing of Figure 4-3. She explained that the longest path in this resource-leveled network had to be equal to the total planned project duration, and she noted that this longest path was very much similar to the critical path, although there was one major difference. "While the critical path consists of a sequence of activities linked only by precedence relations between them, the longest path on the resource-leveled schedule can also consist of links due to limited resource availability," she said. She referred to this sequence of activities as chain 1 - 2 - 6 - 7 - 8 - 9 - 10 - 16 and called this path the *critical chain*. She told the team that this was a new name for the old "critical path" concept, but now extended to resolve resource over-allocations.

"In this case, the critical chain is identical to the critical path," Emily explained, "but they could have been totally different due to the fact that some activities have been shifted to resolve resource over-allocations."

Next to her Gantt chart, she wrote the following words on the whiteboard:

CRITICAL CHAIN: CRITICAL PATH AFTER RESOURCE LEVELING

"Since this critical chain is now the longest path in the project, it determines the planned project duration of 25 weeks," Emily said. "But obviously, since we rely on aggressive time estimates, this new plan contains no safety time whatsoever," she added as a comment.

Before going more deeply into this lack of safety time, she immediately continued by pointing to the other activities in the Gantt chart that were not part of this so-called critical chain. She told her team members that these activities could be considered as non-critical activities, and since they didn't lie on the critical chain, they should be part of another chain of activities that merged somewhere in the critical chain at one point or another. Then, without any hesitation, she wrote the following words on the whiteboard:

FEEDING CHAIN: ANY PATH FEEDING THE CRITICAL CHAIN

Apparently, the non-critical activities were part of so-called feeding chains, which entered (or fed) the critical chain at some point in the project. Emily explained that a first feeding chain consisted of activities 11 - 12 - 13 - 14 - 15, which connected activity 15 (end-activity of this feeding chain) with activity 16 (an activity on the critical chain). She drew special attention to a second feeding chain consisting of activities 3 - 4 - 5, which technically did not merge into the critical chain (since activity 5 was a project end activity), but merged into the final project completion date. Then, she returned to Mark, who had just claimed that this approach was very similar to his approach, apart from some tiny differences.

She admitted that her novel approach was not fundamentally different from Mark's approach, as it also aimed at resolving resource over-allocations by shifting activities in time—although now the shifts were made to the left in the Gantt chart (backward), while Mark's approach invoked activity shifts to the right. She reminded the team that the resulting schedule had a critical path, which was now called the critical chain, since it contained a sequence of activities with shifts in some of these activities to resolve the unavailability of resources. However, Emily immediately recognized that the major drawback of her approach so far was that the activity durations were set to very aggressive values—and therefore, the total project duration of 25 weeks could not be considered a realistic estimate, and could therefore not be compared with Mark's much more realistic project duration estimate of 48 weeks. Despite these weaknesses, she ended her explanation by stating that the critical/feeding chains concept was crucial for understanding the next phase of the *cut - plan - buffer* approach. She then suddenly fell silent to stimulate reaction from the team.

Still searching for a sound motivation for removing the activity protection (due to the reduction of activity durations to obtain aggressive activity times), Joanna reacted quickly: "What about Murphy's law now?" she asked with an irritated tone to her voice. "With these reduced activity times, I believe that the chance that we have activity delays is now even bigger than before," she almost shouted.

"That's what I told Emily in the previous meeting when she initially introduced the new idea," Mark replied, "but we know that Emily has a solution for every problem, don't we?"

"I understand your point, Joanna," Emily commented. "With aggressive time estimates, a latest start plan without any degree of slack, *and* Mr. Murphy's law, we'll end up with a perfect cocktail for project delays and unhappy clients!"

"That's why I said that we should add *more* safety time to the activities, instead of *reducing* the allocated time," Joanna said, but she was beginning to understand where Emily was heading to.

"Indeed," Emily replied. "We will now go to the third phase; we'll add buffers. We will indeed add safety time to catch up delays. But we won't add it to the activity estimates—we'll add it to other places in the project schedule instead."

It became clear that Emily wanted to use the previously mentioned weaknesses and flaws of her new planning approach to show the importance of buffering and to actually improve the overall project plan.

BUFFER. Obviously, Emily was well aware that the reduction of the activity time estimates to aggressive durations removed all protection and reduced the project plan to a schedule very prone to delays. Therefore, she introduced the general idea of project buffering as a way to re-introduce the removed activity safety time back into the project plan at certain predefined places in order to protect the project against delays.

"It's a matter of giving and taking," she said.

Mark and Joanna stared at Emily as if that last statement were Emily's way of pleading guilty to having ignored Joanna when she'd said that the aggressive time estimates approach was too prone to project delays. But Joanna was starting to appreciate the whole idea of project buffering, and so she said to Emily: "You took the safety time from the activities, and you will now put it back at other places in the project network, right?"

"Exactly." Emily replied. "And part of the removed activity time is added back into the schedule by using two types of buffers."

First came the so-called *project buffer* concept. Emily explained that a single project buffer should be added at the end of the critical chain to protect the project completion date from delays. Any delays in critical chain activities would be absorbed by this buffer without having an effect on the project completion date, and this protection would last until the project buffer was consumed. She continued by telling her team that a project buffer should protect the project completion date against changes in the activity durations along the critical chain, so it would not serve as a protection for delays in the other activities on the feeding chains. Meanwhile, she wrote the following words on the whiteboard:

PROJECT BUFFER.

A single buffer at the end of the critical chain to protect the project completion date

Then came the so-called *feeding buffer* concept. Once Emily got going, nobody could stop her. She continued by saying that the project buffer was inserted in the project schedule to protect the project deadline against changes in the critical chain, but she warned the team that the critical chain should also be protected against changes in any feeding chain. She explained the important difference between the single project buffer and multiple feeding buffers, and said that this was the beauty and elegance of the new planning approach.

"If delays occur in critical chain activities, the project buffer will be consumed," Emily argued. "However, if delays occur in activities on the feeding chains, the project buffer won't be consumed at all, but instead the feeding buffers will absorb these delays."

Consequently, feeding buffers at the end of any feeding chain should be added to the project baseline schedule as a way of protecting against delays in the feeding chains. She took her pen and wrote:

FEEDING BUFFERS.

Multiple buffers at the end of the feeding chains to protect the critical chain

It was clear to all team members that buffers would be used as a catch-up mechanism for activity duration variability by adding safety time to the various chains in the project plan. When activities suffered from delays, the other succeeding activities on the same chain would start later than expected, and this late start would be absorbed by part of the buffer. Emily told the team that activities no longer had strict starting times (as was the case in a traditional milestone plan), and so delays were now acceptable as long as the buffer was not completely consumed. However, to guarantee the timely completion of the project, these buffers should be sized according to the properties of the chains they protected, such that the buffers would not likely be consumed. Ideally, the size of these buffers would depend on the expected variability of the activities on the chain where the buffer was placed (which is the critical chain for the project buffer and the feeding chains for the feeding buffers). The impact that possible activity delays might have on the critical or feeding chains depended on many factors that were often well beyond the company's knowledge and awareness.

"I believe it is a general rule of thumb that the buffers for activities with high risk should be sized appropriately, while low-risk activities do not require a big buffer. For now, I suggest that we take, just for illustrative purposes, a buffer size equal to 50 percent of the length of the chain," Emily said, always seeking to simplify complex topics, as any good teacher should do.

She erased the text on the whiteboard and started drawing some Gantt charts to explain her idea.

"The basic idea of the project and feeding buffering approach is easy, but the way it is done is sometimes tricky and often requires pragmatic solutions," Emily said. Meanwhile, she continued drawing three different Gantt charts on the whiteboard as a foundation for three different proposals for sizing the buffers (as shown in Figure 4-4), which she wanted to discuss with her team members.

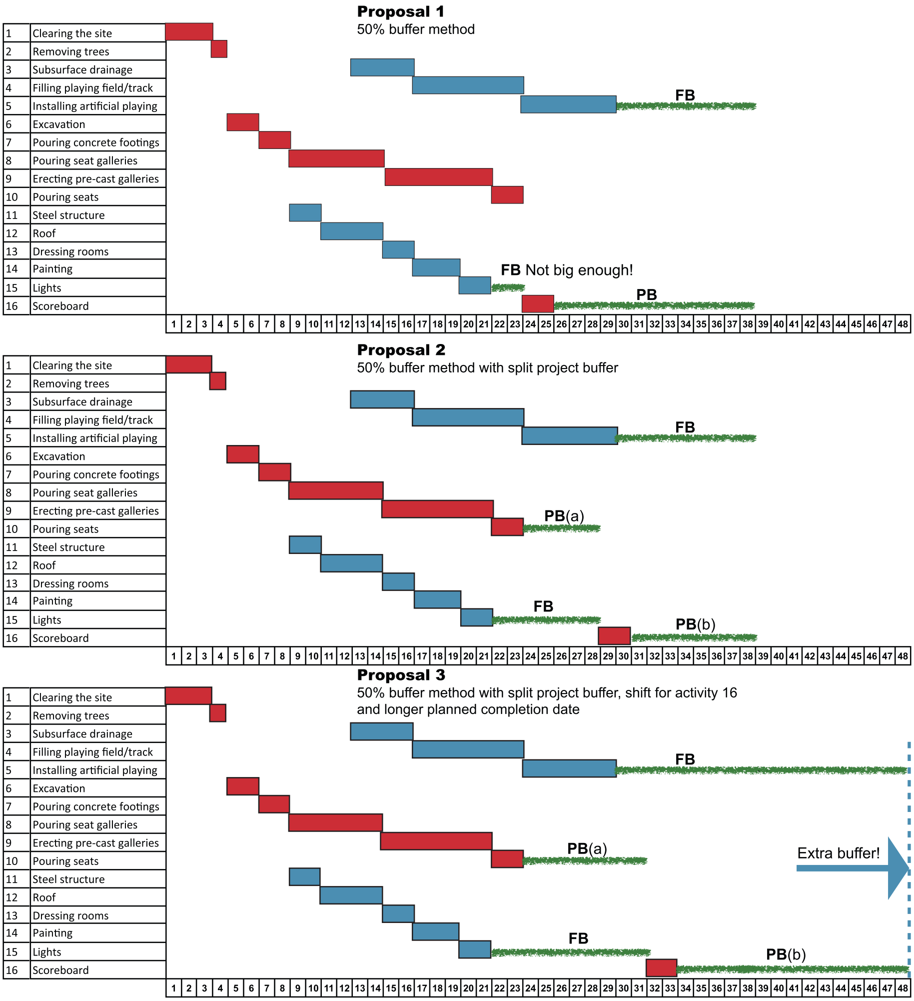


Figure 4-4. Emily's buffering approach: three alternative project proposals without any resource over-allocation

Proposal 1. 50% buffer. In her first proposal, Emily told the team that she worked backward, adding a project buffer at the end of the critical chain and feeding buffers at the end of each feeding chain, ensuring that their size was equal to 50 percent of the length of the chains (rounded up to the nearest whole week).

“It’s an easy and quick approach,” she said, “but one not free of problems.”

She had previously calculated the length of the critical chain to be 25 weeks, which meant that a buffer of 13 weeks should be enough to absorb all unexpected delays. Similarly, the feeding chain consisting of activities 3, 4, and 5 had a total length of 17 weeks, and so it received a buffer of 9 weeks. She referred to the top picture of Figure 4-4 and added the buffers to her drawings.

“The problem is the feeding chain with activities 11, 12, 13, 14, and 15,” Emily confessed.

“The buffer size should be 7 weeks, which is 50 percent of 13 weeks, rounded up,” Joanna said.

“Exactly,” Emily replied, “but I added a buffer of only two weeks.”

She told Joanna that inserting buffers forced the corresponding chain to move to the left of the Gantt chart, but since the feeding chain could not be shifted more than two weeks, the chain could not be buffered properly.

“The predecessor of activity 11 (the first activity of the feeding chain) is activity 7 of the critical chain, and therefore the shift to the left is restricted to a maximum of two weeks,” she explained.

“In that case, the second feeding buffer is not big enough to absorb the potential delays of the feeding chain,” Mark added.

“Exactly. This means that the feeding chain is not properly protected, and any delay in this feeding chain might consume the small buffer too quickly,” Emily said.

She explained that consuming this feeding buffer too quickly would lead to a delay in the activities on the critical chain, thus eating up the project buffer as well. Consequently, the project buffer would be consumed as a result of delays in the feeding chains!

“This is against the concept of buffering, since the project buffer is sized to capture delays only in the critical chain, and not in the feeding chains!”

“So, buffering is not a good idea after all?” Joanna asked, somewhat confused.

“There’s a solution,” Emily replied.

“There always is,” Jacob chimed in. Everybody was surprised that he was still listening, because it had seemed that he left the discussion a while ago to work on his laptop answering emails.

Proposal 2. Split project buffer. In a second proposal, Emily had split the project buffer into two parts, still guaranteeing that its total size of 13 weeks remained intact, as that was the right size for the expected delays in the critical chain. However, splitting the buffer into two parts allowed her to increase the size of the second feeding buffer from two weeks to the appropriate seven weeks, long enough to absorb possible feeding chain delays.

"The critical chain now includes two separate parts of the same project buffer (PB(a) and PB(b)) and is equal to the line 1 - 2 - 6 - 7 - 8 - 9 - 10 - PB(a) - 16 - PB(b) on the middle picture of Figure 4-4," Emily said.

She explained that the first part of the buffer (PB(a)) was set to five weeks by delaying the last activity on the critical chain, and this shift released exactly enough time to increase the feeding buffer from two weeks to the desired seven weeks for feeding chain 11 - 12 - 13 - 14 - 15.

"The feeding chain now has a seven-week buffer," Mark remarked.

"I get it; all buffers are now large enough to absorb possible delays, assuming that a 50 percent buffering approach is taken," Joanna confirmed.

"Indeed, and as you can see, the total project duration is now equal to 38 weeks, exactly the same as in my first proposal. This is still ten weeks less than Mark's proposal, but now with the appropriate buffer sizes."

"Is this your final proposal?" Jacob asked.

"Let me add one tiny little improvement," Emily said.

Proposal 3. Total buffer ≈ removed safety time. In a third proposal, Emily had made some minor adjustments to the previous Gantt chart by delaying the last project activity (16) even further, now starting at week 32 instead of 29, which enabled her to increase the buffer of the second feeding chain by three weeks, and led to an increase in the other buffers as well. This shift increased the planned project duration from 38 to 48 weeks, exactly the same as Mark's alternative proposal, to allow a fair comparison between the two schedules.

"Recall that I removed all safety from the activity durations to get aggressive time estimates," she said.

"Indeed, you reduced all activities by 50 percent," Joanna recalled.

"The total amount of time that you removed from the activities equaled 52 weeks. I did the math," Mark replied (this number is equal to the total difference between Mark's normal activity times and Emily's aggressive activity times).

Emily told the team that increasing the planned project completion time to 48 weeks, and the shift in only the last activity, resulted in a total (project + feeding) buffer size of exactly 52 weeks.

"You gave us back exactly what you previously took away," Joanna replied.

"I told you it's a matter of giving and taking!" Emily said.

It was typical of Emily to bring the discussion to a point where a fair comparison between two alternative approaches—Mark's traditional approach and her much more radical approach—could be made effortlessly.

"Time for an evaluation," Jacob said.

He closed his laptop and went straight to the whiteboard, asking the team to compare Emily's buffered proposals with Mark's proposal.

Review

Emily started the evaluation by admitting that the buffering approach was meant to be a proposal to discover other possible planning approaches different from the usual business practices, but she stressed that she had no intention of forcing a new approach on the company without spending time critically evaluating its merits and its pitfalls. She realized that implementing this approach would require a fundamental change in mind-set because it entailed convincing people to change their activity-estimating process to an aggressive approach.

"Honestly, I don't think we are ready for this today, but I believe it's worth exploring the idea for future projects," she said.

"I believe that the appropriate sizing of the buffers is crucial to the success or failure of the approach," Mark added.

"Exactly," Emily replied. "Sizing buffers at 50 percent of the chain length is a rule of thumb without any sound reasoning."

"We could easily take other factors into account that might cause delays when sizing the buffers," Mark added.

"Such as?" Jacob asked.

"The project network structure, the scarce resource availability, the accuracy of the time estimates, the project's inherent risk, and probably many more," Mark replied.

"The general idea is that buffer sizes should be enlarged as the potential delays in the chain become bigger," Emily summarized.

Everybody nodded.

With the promise that she wouldn't go into the details, Emily said that the previously calculated sensitivity metrics they had proposed in their risk management meeting (the criticality index, significance index, and schedule sensitivity index) could be used to predict the size of the potential delays in the critical chain and feeding chains. "It is my best guess that these sensitivity metrics can be used to size the buffers appropriately according to our knowledge of risk," she said.

"Food for thought," Jacob said, "but not for this project."

"I believe there is a second reason why we should not accept this new approach overnight," Joanna added. "Since Emily's proposed plan no longer relies on fixed activity milestones, but rather on flexible activity start times with extra buffers to absorb potential delays, it won't be very easy to communicate the plan to the client and potential sub-contractors working with our project management consultants."

"Indeed," Emily said, "how do you tell a sub-contractor that the starting time for his work is yet to be decided?"

Everybody laughed, recognizing that this would certainly not be the best way to build up a good relationship with GlobalConstruct's sub-contractors.

"It requires a certain degree of flexibility from everyone, or even a totally different mindset," Emily added.

"That's difficult, but not impossible," Jacob once again concluded, "but certainly not appropriate now at the start of such an important project as our tennis stadium construction project."

"If the time is not right for accepting this novel idea, despite its promising features, which of the two alternative plans should we select then as the most appropriate for moving ahead?" Joanna asked.

Everybody stared at Jacob. He was the one to make the final decision.

Decision Review

"Before we finish this meeting, let's briefly go over what we have discussed," Jacob said.

He praised the new buffering technique as an important eye-opener with promising features that should be further refined for future company projects, and he thanked Emily for her clear explanation of the general idea. Then, he expressed his concerns about changing the approved plan (Figure 4-1) to Mark's new proposal (Figure 4-2).

"Mark, I am well aware that your solution solves the resource over-allocation issue," Jacob said, "but a shortage of project management consultants is an internal issue that we should solve when the project is in progress."

"I understand," Mark replied. "It's not mandatory to change the plan, as long as we are aware of the over-allocation of resources."

"My suggestion is to keep the original plan as it is, despite some resource over-allocations," Jacob said. "Any objections?"

"It was a very interesting meeting with relevant new concepts that will have an impact on the way I look at project management," Joanna replied. "I wasn't a huge fan of allowing over-allocations in the plan, but I guess now that it's the best alternative and we can change it later as the project progresses . . . I have no objections."

The others confirmed by nodding to Jacob.

"No doubt we're an excellent team," Jacob said, "and it reminds me of a quote I once heard:

> *There are three solutions to every problem: accept it, change it, or leave it.*
>
> *If you can't accept it, change it.*
>
> *If you can't change it, leave it.*

Yes, we did consider alternatives. We even seriously thought about implementing a change in the plan, and we evaluated two different alternatives. One was easy, with small changes (Mark's approach), the other was totally new and implied a radical change (Emily's approach), but we didn't accept either of them. I call that courage! We didn't change, we left it as it was. But at least we thought about it!"

"That's the power of innovation: think outside of the box, then think twice, but don't rush and change things too fast," Emily said.

"I think we all agree that we should leave the plan as it is, and start this challenging project!" Mark said proudly.

"Thank you all for coming today—and we'll see each other in a few weeks time," Jacob said, concluding the meeting.

CHAPTER

5

Monitor

It has been exciting times since the initial approval of the project by the Australian government! While the first few days of the start-up of the project were hectic as usual, the work gradually returned to a normal day-to-day rhythm. As from the beginning, Jacob, Mark, and Emily were feeling quite confident that the project was going to be a success. To make sure that they would be able to deal with unexpected events, it was agreed that there would be a ten-weekly reporting cycle: every ten weeks, both the progress and the costs for each of the work packages were to be reported. This information, combined with their approved project plan and risk analyses, should be enough for informed actions if the project looked like it was running into the danger zone.

Jacob opened the first progress meeting with a positive note about the initial start-up of the project, praising the way the GlobalConstruct project management consultants had dealt with the new challenge. After this short but motivating introduction, he quickly turned the meeting over to Emily. He knew that a detailed look at the project's progress was beyond his knowledge because of his recent involvement with other matters and his having had almost no contact with the project management consultants the last few weeks. But he knew that he could rely on Emily 100 percent—he trusted her as if she were his own daughter!

M. Vanhoucke, *The Data-Driven Project Manager*,
https://doi.org/10.1007/978-1-4842-3498-3_5

Emily had printed the project management plan as approved by the Australian government and GlobalConstruct's board of directors (Figure 5-1). The plan included an overview of the expected timing of the project activities, as well as a graph showing the expected increase in the total cost of staffing (which consisted only of senior project management consultants assigned to the project to supervise the progress of the activities). After distributing this project plan on large sheets of paper to Jacob and Mark, she immediately continued by summarizing the main statistics of the project. "The total budgeted cost consists solely of the cost of the senior project management consultants working on the project, since all other costs for material and the like have been pre-financed by the Australian government. Since we know that the staff cost is €1,500 per week, the total budget at completion comes to slightly over €450,000." The estimates of the staffing requirements were set in collaboration with the project team and are shown in Table 5-1.

Project Status

Jacob highlighted the importance of the approved project plan for internal project monitoring and reminded the team that the cumulative planned increase in costs was the company's cost for the project management consultants assigned to the project. He told the team that not all of the senior project management consultants were fully used during certain periods, in which case the cost of their idle time was obviously not taken into account when accumulating the project cost. "The cost of the project managers is only allocated to the project budget when they are actively working on one of the project activities," he said. He continued to explain that, at other periods, more senior project managers were needed than were available, in which case the company assumed that they could be hired without much effort. "Since we have previously agreed to hire extra consultants only in circumstances when we really need them, the restriction of their limited availability has not been taken into account in the plan." Everybody knew that hiring extra consultants would not be as easy as Jacob proposed, but the team realized that he only said this to stress the importance of monitoring the cost of these precious company resources. "Therefore," he continued in a loud voice, "I consider strict control of the project management consultancy cost to be extremely important for GlobalConstruct!" He explained, still with a loud and clear voice, that monitoring the consultancy cost was not only crucial for taking timely action in case of excessive overspending, but also for correct communication with the outside world. Everybody knew that, in spite of his gentle character and notorious empathy, when Jacob raised his voice it meant that the successful delivery of the tennis stadium construction project would be crucial for the future of GlobalConstruct.

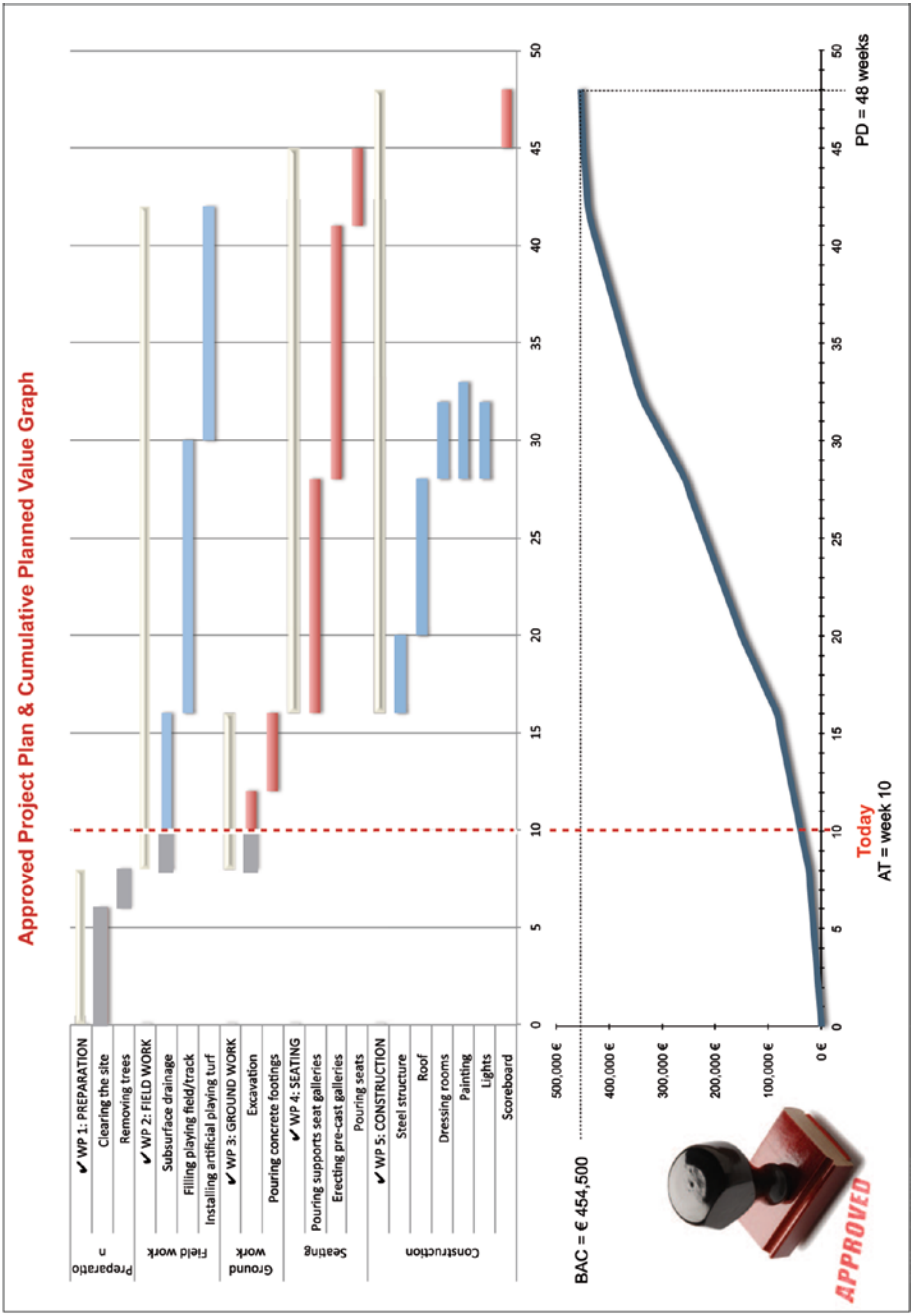


Figure 5-1. The approved project plan with the planned value graph (the cumulative cost for the assigned senior project management consultants) for the tennis stadium construction project

Table 5-1. Staffing Requirements for the Tennis Stadium Construction Project

		Time (weeks)	Staff (persons)	Planned Effort (person weeks)
Preparation	Clearing the site (1)	6	2	12
	Removing trees (2)	2	2	4
Field work	Subsurface drainage (3)	8	2	16
	Filling playing field/track (4)	14	3	42
	Installing artificial playing turf (5)	12	3	36
Ground work	Excavation (6)	4	3	12
	Pouring concrete footings (7)	4	3	12
Seating	Pouring supports seat galleries (8)	12	4	48
	Erecting pre-cast galleries (9)	13	4	52
	Pouring seats (10)	4	2	8
Construction	Steel structure (11)	4	4	16
	Roof (12)	8	2	16
	Dressing rooms (13)	4	2	8
	Painting (14)	5	2	10
	Lights (15)	4	2	8
	Scoreboard (16)	3	1	3

Mark understood better than anyone else that Jacob's call for detailed project monitoring meant that a formal procedure should be put in place to avoid miscommunication and late actions that might prevent timely project recovery in case of problems. He explained that the work packages should be used as management control points at which the timing, budgets, and actual costs were accumulated and compared to the value earned in each reporting period. "Although we have spent a lot of effort in planning and budgeting the project details for each individual project activity," he explained enthusiastically, "I believe that we should focus our attention on the level of the work packages (containing a set of activities), and only when action is deemed to be necessary will we shift our focus to the detailed activity level to find solutions to the problems."

Joanna, who had joined the team meeting just after Jacob's introduction, interrupted Mark, eager to learn more about the way this team was monitoring the project's progress. "I see that there is no detailed data available about the progress of the work of each individual senior project management consultant working on each individual activity. How can someone know that things are going wrong if you don't measure this?" As she was in charge of GlobalConstruct's Human Resource Management Department, it was not surprising that Joanna wanted to put the project staff in a central position.

Mark replied that drawing up individual time sheets for the project management consultants, with detailed monitoring of every single project activity that they supervised, would simply take too much effort. "The work-package control approach," he explained, "allows us to have a helicopter view of the performance of the tennis stadium construction project—and further action is needed only in the cases where work-package problems are detected, which then requires a detailed look at the underlying activities of the work package in trouble."

"Fair enough," Joanna replied, satisfied that her consultants were not being ignored during these monitoring meetings.

Table 5-2. Project Status at Week 10 for the Tennis Stadium Construction Project

Work Package	Planned Value (€)	Effort to date (person weeks)	Outstanding effort (person weeks)	Activities in progress
Preparation	€24,000	18	0	All 100% finished
Field work	€6,000	6	114	"subsurface drainage"
Ground work	€9,000	6	18	"excavation"
Seating	€0	0	108	None
Construction	€0	0	61	None

Mark distributed a brief summary of the current status of the project's work packages at week 10, as shown in Table 5-2, and insisted on walking through the data for each work package during the meeting. He started with a brief explanation of the meaning of the different columns in the table, as follows:

- Planned Value: The planned value at current week 10 for each work package is equal to the cumulative cost of the assigned senior project management consultants planned up to week 10. The total planned value (€39,000) is equal to the value of the bottom graph of Figure 5-1 at week 10.
- Effort to date: The work done up to today is expressed in person weeks for all the work packages that are finished or in progress. This estimate of the work done to date is given by the senior project management consultants and therefore expresses the estimated progress of the project for each individual work package.
- Outstanding effort: The estimated remaining work to be done to complete the activities for each of the work packages is also expressed in person weeks. This outstanding effort includes the estimated remaining work for all activities in progress as well as for the activities yet to be started for each work package, and these estimates are based on the expert knowledge of the senior project management consultants and made in collaboration with their workforce team.

He pointed to the values in the table and started with positive news. "The team has worked hard on the work package "Preparation" and completed it by the specified deadline." It was easy to see that, despite the timely delivery, the costs were exceeded since the total effort to date exceeded the effort as stipulated in the project plan. Mark continued: "We shouldn't worry yet about work packages "Seating" and "Construction," since they have yet to be started, but work packages "Field Work" and "Ground Work" are now in progress and deserve some closer attention." A detailed look at the individual activities of these work packages seemed to be necessary to find out what had gone wrong the last few weeks. Mark continued by explaining that breaking down the current status of both work packages into the different activities to closely monitor their performance and to enable timely action on this detailed activity level had revealed that only activities "Subsurface drainage" and "Excavation" were currently in progress, while the other activities had not even been started yet.

Jacob thanked Mark for his status overview, secretly winked at Emily, and then said in summary: "OK, everybody, that was a short overview of the project status up to today! Although it's interesting to understand the past, the question is: how to proceed from here into a promising future?" His statement seemed like an open question to the team members as a sign to digest Mark's clear and unambiguous status overview, but Emily knew that an immediate answer was required. Clearly, this was her time to speak up and introduce a new project control system.

Reporting Progress

Emily replied to Jacob's open question by stating that "the work package control approach proposed by Mark is a quick and easy method to detect project problems, which should enable the team to drill down to the activities to find causes for these problems." Emily explained that such a drill-down to project activities lay at the heart of a well-known project monitoring system, then introduced the team to a concept known as *Earned Value Management* (EVM). She explained how this project control system could improve the analysis of the overall project performance and could be used for positive predictors of project success. "The advanced use of the EVM system includes many features that will take us too far away from our scope, but the most basic requirement of such a system can be easily expressed in three keywords," she said enthusiastically—and she wrote three words on the whiteboard:

COLLECT - MEASURE - PREDICT

Emily explained that project cost and schedule management had to be defined properly before any benefits from using this project control system could be achieved. "We have the estimated cost for the senior project management consultants, and we have the approved project plan from Mark, so we have everything to implement this system!"

She explained that all the effort they had previously spent on the construction of a proper project plan was more than worth it. She referred to the use of the project network and the discussion they'd had about resource management several weeks ago, and she noted that, despite the hard work and fruitful discussions they'd had, it had often seemed that they were wasting their time on unnecessary project details. "Planning is spending time on preparing the project," she said, "while, often, we just want to start with the real work, and forget about the plan!"

"I think we learned a lot about the project and its features thanks to our planning discussions," Mark replied.

"That's correct, but apart from the excellent learning experience, we now also have a solid foundation for monitoring and controlling the project progress," she immediately added to Mark's positive response.

Emily explained that all the planned data could now be used and compared with the periodic actual time and cost data they should collect at regular time intervals. When a project status data table, such as the one in Table 5-2, is collected every now and then, problems will be detected in early stages, and immediate corrections can then be taken to bring the tennis stadium construction project back on track. "Let me explain how the *collect - measure - predict* approach really works," she said.

COLLECT. An Earned Value Management system is a methodology that can easily monitor the project plan, the actual spending, and the value of the work completed to find out whether the project is still on track. "The beauty of the system is that it relies on only three key metrics! Yes, you heard me, only three!" Enthusiasm had never been a problem for Emily, and she explained that a valuation of planned work (*planned value* [PV]) and the actual spending (*actual cost* [AC]) were to be compared with an estimated valuation of the work done up to today. This valuation was known as the *earned value* (EV) key metric and showed how much of the budget and time should have been spent, considering the amount of work done so far. "All these metrics are expressed in monetary units," she eagerly continued, "but some of them can be easily translated into time units, which makes the system an easy-to-use and highly accessible methodology to integrate planned progress with reality in order to monitor both time and costs."

Mark acknowledged that he had heard about the methodology, but had never used it for one of his own projects. "The planned value of the work is known from the plan, and the actual costs can be easily derived from the actual cost of staffing, so I don't think it will require much work to use your brilliant system," he remarked sceptically.

"Exactly," Emily said, unperturbed. "All the data is available to measure the performance of the project. Let me explain how."

MEASURE. The three key metrics (PV, AC, and EV) provide enough data to calculate the schedule and cost performance of the project, which should be monitored and reviewed at regular time intervals. The schedule performance measures the degree of completion of the work on time, while the cost performance assesses the deviations between spending and earned work. These performance indicators should be used to assess the project's current status, and they are a useful source of information for predicting the performance of the project's future with the remaining work yet to be done.

PREDICT. An EVM system is able to provide accurate forecasts of project performance problems in the future based on the current performance up to today. The measured performance of the work done can be used as a learning mechanism to correct the expected future performance of the work to be done, and when these expectations predict unacceptable time or cost deviations from the initial plan, action should be taken to minimize the damage. "This is an important contribution from EVM to project management—by providing a dynamic tool based on past performance, it gives us an idea about the necessity of actions."

Before the start of this progress meeting, Jacob had talked to Emily about a possible intervention during the meeting to present the basic principles of EVM. Although Jacob had first heard about the EVM method only in last week's meeting with the Australian government, he was convinced that a data-driven, easy-to-implement, and formal method should provide the project team with an objective way of measuring performance and predicting future outcomes. Jacob knew that no one better than Emily could introduce this new data-driven methodology to the team. In order to emphasize his support for the newly presented EVM system, Jacob said, "We can use the system to report progress with greater confidence and highlight any time or cost overrun earlier than ever." He was convinced that this new project control system would allow the management team to speak a standard language concerning project performance, and that it would enable them to make cost and time allocation decisions sooner than would be the case without such a unified integrated measurement system. He concluded the meeting with: "I see no reason why we shouldn't explore this novel idea!" Everybody knew that a green light had just been given to extend the current monitoring system with the EVM control methodology. As always, he suggested that, due to the urgency of a closer study of the potential use of EVM for the tennis stadium construction project, the next meeting would be held in the same room by the end of the week. "By then, we should have all these EVM miracles tested on the progress of week 10," he finally finished.

Assignment

In his action list summary email, Jacob highlighted the importance of analyzing the progress of the project and calculating the earned value management metrics for week 10. Since, for most of the company members, this was the first time they had heard of EVM, the key metrics should be calculated in detail and be used to assess the overall health of the project. It should be made clear how these three EVM key metrics could be used to assess the current time and cost performance and how they could and should trigger action in case of problems. Obviously, general recommendations regarding expected future progress should also be made in the next meeting, and Jacob was fully aware that today's action list summary probably involved quite a bit of work for the team members.

ACTION LIST SUMMARY

Note from Jacob: I am fully aware that not all the terminology described below has been explicitly mentioned by Emily, but she implicitly used much of what is written below when she explained her *collect - measure - predict* approach. Details will be discussed in next Friday's meeting, but just remember that good preparation is half the work!

- Project budget:
  - Clarify the total budgeted cost of the project management plan based on the expected cost for staffing.
  - Show the one-to-one link between the planned value (€) and the timing of the baseline schedule.
- Calculate the following earned value management metrics for week 10:
  - The three key metrics: The planned value (PV), actual cost (AC), and earned value (EV) (note that there is also a fourth key metric available, not discussed by Emily, known as the earned schedule [ES] metric).
  - The performance metrics: The schedule performance indices (SPI and SPI(t)) and the cost performance index (CPI).
  - The predictions: Expected values at completion for time (EAC(t)) and cost (EAC(€)) (if multiple versions are available, choose the most appropriate one).
- Summarize the key findings and give recommendations and suggestions for future actions, if necessary.

Expanding Knowledge

Jacob, Emily, and Mark were the first to arrive at Friday's early morning meeting. Jacob asked them to be half an hour early, since they had to agree on the specific purpose of the meeting. In the previous meeting, Emily had launched the idea of using a standard methodology and talked briefly about *earned value management* (EVM) as an easy tool for measuring project progress. The next day, Jacob had run into her office and, after his loud and enthusiastic "Excellent! We should go for it!", Emily had known he'd read about the project progress system and loved the idea. She hadn't expected anything else from him. Jacob proposed to use today's meeting as a sort of training on the system, which was exactly why he had invited three other members of the company.

"We all know how this EVM system works, but most of our company members have no clue what it is," he said as if he were already an expert in EVM after a one-evening exploration of the most relevant sites on the internet.

"I have to admit that I've heard about the system—but I've never used it, let alone know all the details," Mark replied honestly.

"Sure, I have used it in previous projects. It's easy as pie, believe me," Emily replied.

"Well, that's exactly the reason we're having this meeting," Jacob answered. He explained that he had invited Mick, Ruth, and Joanna for various reasons.

The IT wonder-boy Mick was attending the meeting since he would be in charge of setting up a simple and easy-to-use spreadsheet system to measure the future progress of the project using this EVM methodology. "I don't want to postpone the use of EVM to the next project," Jacob said. "The project has just started, so if we quickly come up with a simple tool, we can try to test it now!" Yes, no one doubted that Jacob was positive about the system!

Human Resource Manager Joanna was attending the meeting to have accurate estimates about the workload of the project management consultants and their current progress and expected work. "As the head of the Human Resource Management Department, she is the main contact between us and the project management consultants assigned to the tennis stadium construction project," Jacob said.

Upon Emily's advice, Jacob had also invited Ruth from the Accounting Department. Emily knew that accountants often had a different view on cost tracking than project managers. "She's the one to convince that EVM has merit for our projects," Emily said.

Mick was the first to arrive, some minutes before the start of the meeting, with his laptop in his hands as if he had plans to implement the new project control system on the fly. He knew he had not just been invited to learn how the new EVM system worked. He had heard the rumors about a possible implementation of the new project control methodology in a simple spreadsheet, and he was eager to take on this challenging task. As far as he was concerned, the approval for implementation had already been given.

Ruth arrived exactly on time, a typical characteristic of accountants, Jacob always said. He knew that she would play a crucial role in this morning's meeting. The success of the new methodology, and the adoption rate by the company, would depend on her approval. "Accounting rules the company!" she often joked. Most people disagreed, despite the grain of truth in her words.

Joanna arrived five minutes late, just enough time for Jacob to have another cup of coffee. She came from a short and early phone meeting with her senior project management consultants, since she wanted to confirm that the estimates for the outstanding remaining work (Table 5-2) were made in the most accurate way. She knew that when the implementation of the EVM system was approved, she would be the one responsible for collecting the weekly estimates about the outstanding effort to measure the periodic time and cost performance of the tennis stadium construction project.

Jacob welcomed everybody to the first joint progress meeting of the tennis stadium construction project and looked excited. "As you all know, the reason we're having a progress meeting with all of you is to introduce the EVM approach as a formal system to the company as of today," he proudly announced. "In a world where data is readily available and their analysis can be used to support decisions, we can no longer rely on our experience alone," he continued. "I will not bother you too much with my homily about the importance of innovation, and I'll give the floor to Emily, who will introduce you to this new system. Emily, the floor is yours."

Emily explained that a large part of successful project delivery was in keeping risks and changes under control. Highly successful project managers stimulated a risk-awareness culture in their company, continuously asking what could potentially go wrong. Successful project managers also monitored changes and assessed the impact of these changes on the project objectives, such as time, cost, and quality.

"In order to monitor these changes and their impact, we need planned data, real progress data, and a methodology," Emily said.

"The plan of the project is available and has been discussed in previous meetings," Mark told his three new team members.

"I have previously described the methodology as a *collect - measure - predict* approach," Emily continued with that well-known drive in her face, "which I will now explain to you in detail."

She told her team members that she would explain the three-phased methodology by showing that collecting planned data *and* progress data was crucial for the other two phases. These data would be used to measure the project performance at every review meeting as long as the project was in progress—and, each time, a prediction of the expected future project behavior would be made based on the assessment of the current performance known to date.

"Isn't this something we always do for our company projects," Ruth replied, "but in a far less formalized way?"

"Exactly," Emily replied. "There's not much new under the sun—it's a matter of convention and using the right terminology."

"And since I am in charge of implementing this method in a spreadsheet by the next project progress meeting, some details would be welcome," Mick said sarcastically, realizing that he certainly was the dummy in the group when it came to project performance measurement.

Collecting Data

Planned Data

"The core of an EVM system is pretty easy," Emily said, "since it all starts with a good plan as the foundation for everything."

She explained that the earned value management methodology tracks how much time and money have been spent on a project in relation to how much project work has been accomplished, and therefore relies on the approved plan as the central point of reference.

Knowing that Mick would be in charge of implementing this EVM methodology in a spreadsheet tool, Emily directed her attention to him.

"All we need to do is extract monetary numbers from the plan and the progress reports," she said, "and enter them into a spreadsheet tool for some basic calculations."

"Let's start with the planned data," she immediately added, clearly ready to give a high-speed lecture on the basic concepts of project planning to Mick, a project management rookie.

Emily reminded Mick that the timing of the activities had been subject to debate among the core members of this team, but it had finally been approved by the Australian government. The planned duration of the project was nothing more than the longest path in the project network, which was known as the critical path, or sometimes referred to as the critical chain. She showed him the plan displayed by the Gantt chart of Figure 5-1 with an agreed total duration of 48 weeks, and she wrote the following words on the whiteboard:

PD = PLANNED DURATION

critical path or critical chain length

She continued talking to Mick, explaining that—like the planned time—the total planned cost could also be easily derived from the planned data, and she showed him Table 5-1, which displayed a list of the staffing requirements and planned effort for the senior project management consultants required to work on all the activities. She told him that the planned effort for each project activity was equal to its planned duration (in weeks) multiplied by the staffing requirements (# persons) and was therefore expressed in "person weeks." Hence, in order to calculate the total planned cost of the project, the planned effort for each activity should be multiplied by the personnel cost per week for each project management consultant, which was equal to €1,500 The total planned cost was then equal to €454,500 and was known as the *budget at completion*. Again, she wrote this on the whiteboard, just below the previous notations:

BAC = BUDGET AT COMPLETION

planned duration x required staff x personnel cost per week per person

While Mick was taking notes on the new terminology, Emily said that a curved line could now be drawn that connected two extreme points of the project life cycle, as shown at the bottom of Figure 5-1.

"The line starts at point (0, 0) and ends at point (PD, BAC) of the (X = time, Y = cost) axes," she said, "and the slope of the curved line depends on the cumulative planned increase of the cost for the planned activities shown in the Gantt chart."

Emily explained that this so-called *planned value* (PV) line showed the cumulative increase in the total budgeted activity cost given the start and finish times of the activities in the baseline plan. For this reason, the slope of this line could differ from week to week and was equal to the sum of the planned cost of the activities scheduled during each week.

"The planned cost should be calculated for each activity individually, and for each week, by taking the *planned percentage completion* into account," Emily said, and she wrote the following words on the whiteboard:

PV = PLANNED VALUE

planned % completion x BAC

"This line is sometimes called the *budgeted cost of work scheduled* (BCWS)," Mark added in an attempt to show that the EVM methodology was not as new to him as Emily might have thought.

"Can you repeat that; I didn't get that one," Mick replied.

"Not necessary," Emily answered. "I prefer to call it the planned value. Much simpler."

Before she explained the progress data, Emily remarked that she would refer to the planned duration (PD) and planned cost (or budget at completion [BAC]) as planned time and cost values, respectively, used at different levels of the project. "Sometimes, the BAC is used to refer to the total cost of the whole project, but at other times, it denotes the planned cost of a single activity," she said. She explained that similar reasoning held for the planned duration (PD) and added: "As long as you realize that these two metrics refer to time and cost values extracted from the plan."

As a way to test his understanding, Mick said that the sum of the budget at completion for each activity was always equal to the BAC of the project. After Emily's confirmation, he continued by stating that the total planned duration of the project was obviously not equal to the sum of the PD values for each activity, but rather was equal to the longest path in the Gantt chart given the PD values for each activity.

"I couldn't say it better," Emily replied. She recalled that any intermediate value for the PD and BAC of the project could then be easily calculated, and was shown in what she had just called the planned value graph.

"It's all nothing more than planned data," Mick said.

Building on Mick's short intervention, Emily drew the team's attention once again to the fact that the planned value line was known from the moment the plan was approved, and argued that this planned value line should never be changed along the project progress.

"Never change the plan as long as the project scope doesn't change," she said.

With these words, she was warning the team that all planned calculations had been made as a good and solid preparation for controlling the project's progress. She reminded the team that they had spent weeks in discussions and negotiations before the plan was finally approved. They had spent days collecting time and cost estimates, figuring out the best possible network structure, and finding ways to split the project into manageable work packages. She continued that all that work had resulted in a Gantt chart and a planned value line, and therefore in time and cost values (PD and BAC) for the project. She was proud, she even said, that GlobalConstruct had allowed them to spend so much time in these preparation phases, without any pressure to move faster than they could.

"I don't know where you are going with this," Jacob said impatiently.

"My point is that such a heavy and time-consuming task for each project activity was worth the effort, but it cannot be repeated for every single reporting period once the project is in progress," Emily answered.

She explained that the collection of progress data for each review period should not be done for every single activity as had been done for the plan, since it would be too time consuming. Instead, the progress data collection should be done at a higher level of the project.

"Let's now discuss how to gather high-level progress data and connect them to the data of the plan," she said.

Progress Data

Emily advised that progress data should be collected at least a few days before every progress meeting, but preferably much more often at regular moments along the project's progress. She again told Mick that the repetitive character of this progress data collection process rendered a detailed activity data collection inefficient, and sometimes completely impossible, due to the lack of information about the status of each individual activity.

"Collecting progress data for each activity might look like the ideal approach, but it would lead us too far afield," she said.

She referred to Mark's project status report in Table 5-2, which displayed the progress data at week 10 for each work package rather than for each activity. The effort to date (person weeks) expressed the work done so far for each work package, while estimates about the outstanding effort (person weeks) revealed how much longer it would probably take to finish them.

"Based on this report, two types of calculations can be made for each work package," she explained, looking again in Mick's direction.

"First, we should calculate the actual cost for each work package," she said.

She reminded the team that the only relevant cost for control was the cost of personnel (project management consultants), and told the team that the total *actual cost* was equal to the money spent at a given status date (in this case, at week 10) as the sum of the actual spending for all work packages. She wrote the following words on the whiteboard, which should be applied to each individual work package:

AC = ACTUAL COST

effort to date x personnel cost per week per person

"The next step is the calculation of a new concept that takes a central place in an EVM system," she said.

She almost jumped from her chair to the whiteboard, as she was always enthusiastic when she had something new to show her team members. She defined the *earned value* as a metric that represented the planned value of the actual work performed at a given status date (week 10). She explained that the calculation of the earned value required an estimate of the *actual percentage completion*, which could easily be done using the progress data of Table 5-2, as follows:

ACTUAL % COMPLETION

effort to date / (effort to date + outstanding effort)

Based on the estimate of the actual progress for each work package, the earned value metric could now be calculated as the connection between the actual progress and its value in the plan. She warned her team that this concept was often subject to misinterpretations, and told them that this earned value measured the planned value of the real work done at a certain moment in time.

"But, unlike the AC metric, EV doesn't measure real costs but rather planned costs," she said.

"Unlike the PV metric, EV doesn't measure the planned progress but real progress," she immediately added, and she wrote the following on the whiteboard:

EV = EARNED VALUE

actual % completion x BAC

Table 5-3. EVM Key Metrics at Week 10 for the Tennis Stadium Construction Project

	Key values at week 10			
	BAC	PV (plan)	AC (reality)	EV (plan x reality)
Preparation	€24,000	€24,000	€27,000	€24,000
Field work	€141,000	€6,000	€9,000	€7,050
Ground work	€36,000	€9,000	€9,000	€9,000
Seating	€162,000	€0	€0	€0
Construction	€91,500	€0	€0	€0
Total	€454,500	€39,000	€45,000	€40,050

Emily suddenly stopped her EVM lecture for a few seconds and told the team that there wasn't much more to tell.

"That is earned value management! No more. No less," she concluded.

She looked in Mick's direction and told him that, with the input of these three key metrics, anything else could be automatically calculated in an automated spreadsheet. She opened her notebook and showed Table 5-3, which calculated each of the three previously discussed EVM key metrics (PV, AC ,and EV) for each work package, and she pointed at the total values for the project in the bottom row.

"That's the only input Mick needs from us at each progress period," Emily said, "and the rest will be done automatically in Mick's spreadsheet."

Before she started to explain how these three key inputs could be used to assess the current project performance and to predict the future performance of the project in progress, Emily wanted to add a fourth key metric that could easily be calculated based on the current data they already had.

"The earned value measures the planned value of the current project progress, expressed in a monetary unit (in euros)," she repeated once again, "but sometimes we prefer to express EV in a time dimension (in weeks)."

She said that the EV metric could be easily transferred into a time dimension (in weeks) and called this new metric the *earned schedule* (ES) metric, as follows:

ES = EARNED SCHEDULE

earned value expressed in weeks

"There's nothing new about this ES metric, since it merely expresses the EV metric in a time dimension," she said.

She reminded her team that the earned value of the project at week 10 was equal to EV = €40,050 and stipulated that the real work done so far at week 10 was therefore valued a little bit higher than expected, since EV had slightly exceeded its planned value of PV = €39,000.

"I don't want to jump to conclusions, but this means that we are slightly ahead of schedule," Emily said.

She continued explaining that the earned schedule at week 10 was equal to ES = 10.14 weeks, which could easily be obtained by detecting at what precise time point the current value of EV = €40,050 was planned.

"The current value of EV is equal to €40,050. However, the PV line in the Gantt chart of Figure 5-1 only reaches that value somewhat later than the current week 10—more precisely, at week 10.14, so that means we are slightly ahead of schedule compared to the plan."

"The ES value is interesting, and its calculation requires no extra input for the team," Mick said, "since it can be calculated automatically by the spreadsheet once the EV and PV metrics are known."

"Exactly," Emily replied, "and your spreadsheet should be able to calculate much more. Let's discuss the project performance indicators now."

"Only after a short but well-deserved coffee break," Jacob chimed in.

Measuring Performance

There was good news and bad news to report, Emily told her colleagues during the break. The good news was that the project was slightly ahead of schedule. Of course, the bad news was cost.

During the break, Jacob stood somewhat to the side in order to observe the animated group discussion between his employees, and he noticed that Emily and Mick got closer and closer, something he had been observing at earlier meetings too. To his pleasant surprise, both Ruth and Joanna were also relatively enthusiastic about the new control methodology, something that was not trivial considering their backgrounds. Mark, as always, was trying to figure out how these formulas could be easily implemented in his own spreadsheet, but he was realizing that, despite their simplicity, he'd better outsource this job to Mick.

Despite the bad news on the project cost, Emily was happy to announce that Mick had just promised not only to implement this new EVM methodology in an easy-to-use spreadsheet by the next meeting, but that he also would take the time to run some scripts on the central company database to analyze the behavior of past projects to shed some light on how the EVM methodology should have been performed for those projects.

"The project is clearly running over budget," Emily immediately stated at the start of the second part of the meeting.

She told the team that EVM would never compare actual spending (AC) with budgets (PV), which she called a typical mistake made by accountants. As she looked in the direction of Ruth, she stressed that the earned value metric played a central role in the EVM methodology, and that every calculation would contain the EV metric as one of the key metrics.

"The cost overrun is therefore not equal to €6,000," she said.

She told the team that the €6,000 was equal to the difference between the AC (€45,000) and PV (€39,000), but that this difference was totally irrelevant, and should never be calculated. "I heard you during the coffee break when you told me I should step out of my accounting comfort zone," Ruth said. "Never compare planned budgets with actual spendings, right?" she added.

Emily said that the real cost performance was measured by a so-called *cost variance* of €40,050 - €45,000 = €-4,950, and she wrote the following on the whiteboard:

CV = COST VARIANCE

EV - AC

Meanwhile, she looked at Mick, who was taking notes of almost everything written on the whiteboard, but she told him that there was no need to write down these formulas as there was only one rule to memorize:

"Everything should be compared against the EV, not only for cost but also for time."

Meanwhile, she wrote the formula for the *schedule variance* on the whiteboard, which, according to Emily, was a measure for assessing the project's time performance:

SV = SCHEDULE VARIANCE

EV - PV

She explained that the schedule variance of €40,050 - €39,000 = €1,050 showed that the project was slightly ahead of schedule thanks to its positive value, but admitted that a time delay expressed in euros was not as satisfactory as assessing the timing of the project. "It's much easier to express the project progress in a time dimension," Emily said. "Just like the earned schedule replaces the earned value, the SV(t) replaces the SV," she added, "but they basically measure the same thing."

She told the team that she would use the abbreviation AD for *actual duration*, which was always equal to the current status date of the project (currently week 10), and wrote the following formula on the whiteboard as an alternative version of the schedule variance (SV), now expressed in a time dimension:

SV(t) = SCHEDULE VARIANCE

ES - AD

Therefore, the SV(t) of 10.14 - 10 = 0.14 is identical to the SV of €1,050. Their positive values both express that the project is slightly ahead of schedule, as they had previously discussed. Emily made a quick summary draft on the whiteboard and showed Figure 5-2 to display the easy logic of performance measurement in earned value management.

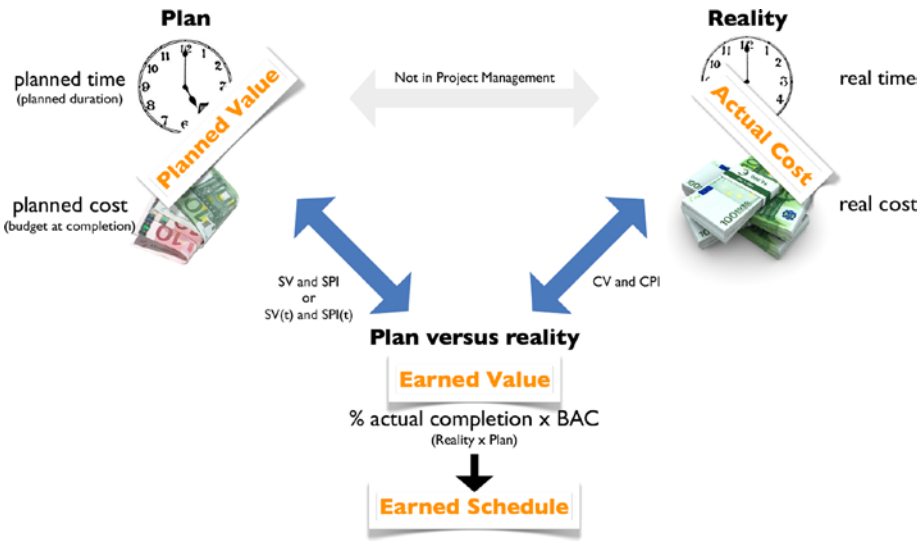


Figure 5-2. The easy logic of performance measurement in earned value management

Emily saw that the team was easily following the conversation, and no one was having real difficulty understanding the relevance of these standardized performance measures. She liked the idea that Mick would soon develop his own spreadsheet for all of the project members, and while she was staring at him, she decided to continue explaining how these performance metrics (CV, SV, and SV(t)) should be implemented as percentages.

"Rather than using absolute time and cost performance values, we should use percentages," she suddenly said, writing two alternative formulas on the whiteboard:

CPI = COST PERFORMANCE INDEX

EV / AC

SPI = SCHEDULE PERFORMANCE INDEX

EV / PV

She told the team that expressing the previous performance measures as percentages by simply dividing the formulas rather than using subtraction would enable them to draw the same conclusions, regardless of the size of the project. She told the team that a 100-percent value would indicate the expected planned (time or cost) performance, while values higher or lower would indicate that good or bad things had happened in the project. She calculated the value for the CPI = 40,050 / 45,000 = 89.00% and explained that it expressed a cost performance lower than initially expected, which was in line with the previously found negative value for the cost variance CV. Likewise, SPI could be calculated as 40,050 / 39,000 = 102.69%, and its value confirms that the project is slightly ahead of schedule.

Emily paused for a moment, allowing her team members to digest the seemingly simple formulas, and then suddenly asked the simple question: "Can you tell me what the maximum value of the EV metric can possibly be?"

"At the end of the project, all value will be earned, and EV will be equal to BAC," Mark proudly replied as fast as he could.

"Exactly," she replied, "but think what that means for the SPI."

Everybody quickly realized that, in these cases, the SPI would be equal to 1, which was an indication that the final project performance was equal to the planned performance, even for projects that finished late.

"There's no doubt that this could lead to wrong conclusions," Emily said, and she wrote the following sentences on the whiteboard:

At the end of a late project

EV = BAC and PV = BAC $\rightarrow$ SPI = 100%

(false indication that the project finished on time)

She explained that, of course, the wrong SPI value of 100 percent for a late project was not a real problem for a project manager once the project was finished. Instead, the real issue lay in wrong values during intermediate project stages when action should be taken in the event of problems. Therefore, the SPI should indicate values reflective of the real performance of the project, without flaws and unreliable values. She told her team members that this strange unreliable performance of 100 percent at the project finish also meant that the SPI would start going to 100 percent at a certain moment of the project progress, regardless of what the current real performance of that project was at that time.

"It is known that this unreliable trend to 100 percent starts somewhere in the middle stages of the project," she said, "and therefore the SPI cannot be trusted from those moments on."

"I'm afraid that the middle project stages often are the most crucial moments for taking action in the project," Mark replied.

"If we can't have reliable information, then what's the value of an SPI?" Ruth replied.

"The schedule performance indicator SPI should not be used," Emily replied, and she proposed a new, corrected version of the schedule performance index, as follows:

SPI(t) = SCHEDULE PERFORMANCE INDEX

ES / AD

Emily introduced the alternative SPI(t) as a time performance measure that was identical to the original SPI, but without the major flaw that it goes to 100 percent toward the end of the project. She reminded the team that the earned schedule metric ES was identical to the earned value metric, but expressed progress in time rather than in a monetary unit, and said that the actual duration AD expressed the current time of the project. She told the team that, similar to the previous conclusion, an SPI of 102.69 percent was now translated into an SPI(t) value of 101.40 percent, and both reported values higher than the planned 100 percent performance, indicating that project progress was slightly ahead of schedule.

"The two values are relatively close to each other, but that's because we are only in the early stages of the project," Emily said.

"At the middle and late stages of the project, when the SPI turns out to be highly unreliable for measuring the project's time performance, the SPI(t) will still provide reliable values," she added, while she wrote the following on the whiteboard:

At the end of a late project

ES = PD but when AD $\neq$ PD $\rightarrow$ SPI(t) $\neq$ 100%

(correct indication that the project finished early or late)

She referred to her notations on the board by saying that the maximum value of ES was equal to PD, similar to the maximum value of EV's being equal to BAC at the end of the project. However, the denominators of the SPI and SPI(t) formulas made the difference. It was because PV was equal to BAC that the SPI = 1 at the project end, but the actual duration (AD) could be shorter (early project finish), equal (on-time project finish), or higher (late project finish) than the planned duration (PD), which might result in SPI(t) values equal to 1 (for projects finishing on time), but also other than 1 (for early or late projects). She used a simple example to illustrate that the SPI(t) did not suffer from this unreliable trend to 100 percent to show that SPI should never be used, but rather replaced by the SPI(t) instead. She referred to an artificial project with a planned duration of 48 weeks, similar to the current tennis stadium construction project, and assumed that the project ended two weeks too late. She quickly convinced her team members that the SPI(t) would give a value of 48 / 50 = 96%, which was clearly an indication of late project delivery, while the SPI would always be equal to 1.

"The SPI(t)'s meaning is identical to that of the SPI, but it has no flawed behavior toward the late project stages, and is therefore reliable from the project start to its finish," Emily added.

"Let's just use this one to predict the future," Jacob added.

Predicting the Future

After a short break, Emily began by saying that the CPI and SPI(t) measurements only provided knowledge about the current performance of the project, while the central and most relevant question was whether the project's current performance should trigger project recovery actions. Since the EVM methodology was merely a tool set of measurements to trigger corrective actions to bring projects back on track, its performance metrics could only act as warning signals for actions and not as an automatic project recovery system.

"The EVM system provides the warning signals, but we have to decide when it's time for action," she said.

"Should we take action now to try to recover the cost?" Jacob asked.

"I certainly would, as it's only week ten," Mark said.

"I see it differently. Why would you overreact? It's only week ten!" Ruth replied.

"Both answers might be correct," Emily happily responded.

She agreed with both Mark and Ruth, because the central question—to react or not?—should obviously depend on the impact the current performance might have on the project's expected final status. She said that it was more important to focus on the expected time/cost performance at the project's end than on today's current project performance.

"We should predict the future performance using the information we have today," she said.

Emily explained that predicting the expected final time and cost performance of the project was super-easy, and she told her team that it was basically nothing more than adding the past knowledge to the expected future estimates, as follows:

FORECAST = KNOWN PAST + EXPECTED FUTURE

No one disagreed that the beauty of this formula lay in its simplicity. The current actual cost of €45,000 (i.e., the known past) added to the expected estimated cost for the work yet to be done should equal the total expected project cost. Likewise, the current actual duration of ten weeks added to the expected estimated remaining time for finishing the work should be equal to the expected total project duration. There's beauty in simplicity!

"I understand that the time and cost performance of the past is a known fact, but how can we accurately predict the expected future values?" Mark asked.

"As always, the answer lies in the data," Emily replied.

She told the team that the project's expected future behavior should be equal to the difference between a targeted value and the value of the work so far, as she wrote on the whiteboard:

EXPECTED FUTURE = (PLANNED TARGET - CURRENT STATE)

She explained that the targeted values were stipulated in the project plan, which was obviously equal to the planned duration (PD) for time predictions, and equal to the budget at completion (BAC) for cost predictions. Additionally, as she had explained earlier, the current value of the work done so far was measured by the earned value (EV), expressed in a monetary unit, or alternatively by the earned schedule (ES) metric, expressed in a time dimension.

Everybody noted that she explained this with a certain degree of pride, as if her previous explanation about the similarity between the earned value and earned schedule metrics now suddenly made sense.

"The expected future for the remaining work is therefore equal to PD - ES (in weeks) for time and equal to BAC - EV (in €) for cost," she concluded.

She continued by saying that the time and cost predictions then easily followed from the formulas and were referred to as *estimates at completion* and were abbreviated by EAC(t) for time predictions and EAC(€) for cost predictions.

Time forecast (in weeks)	**Cost forecast** (in €)
EAC(t) = AD + (PD - ES)	EAC(€) = AC + (BAC - EV)
47.86 = 10 + (48 - 10.14)	459,450 = 45,000 + (454,500 - 40,050)

Mark stared for a few seconds at these numbers and remarked that the predictions differed from the expected planned values by exactly the values of SV(t) for time and CV for cost.

"We expect a final project cost overrun of exactly the CV value of week 10, and the expected time the project will end ahead of schedule equals exactly the current SV(t) value," he said.

"Cleverly noticed! That means that the current past performance is a fact, but the future work will be done at the expected planned performance," Emily answered. She explained that the EAC(t) and EAC(€) predictions as they were presented now implicitly assumed that the remaining work would be done as expected, i.e., at a 100 percent performance, thereby not taking the current performance as an indicator for the expected future performance.

"Why would we assume something like this?" Mark asked.

"That's for us to find out," she said jokingly, "but the answer depends on the nature of the current project progress and the measured deviations from the plan."

She said to her team that it was good practice to find out why the current project was suffering from some cost overruns so early in the project. It might be a very specific reason like start-up problems or excessive costs due to the use of temporary overwork, which in this case could mean that the cost overruns would probably not be repeated in the future of the project.

"In this case, using the previous EAC(€) formula makes sense," Mark said.

"But the cost overrun is more likely a structural problem—we underestimated the real cost during the planning phase," Emily continued.

She explained that in such a case, both the information about the current cost performance as well as the knowledge that the cost overruns were inherent to the project and probably could not be avoided in the future should be taken into account. So, she proposed a corrected version for predicting the expected future performance, which not only held for cost predictions, but also for time predictions, and she wrote the following words on the whiteboard:

$$\textbf{CORRECTED EXPECTED FUTURE} = \frac{\text{PLANNED TARGET} - \text{CURRENT STATE}}{\text{CURRENT PERFORMANCE}}$$

Emily explained that the correction factor, expressed by the current performance in the denominator, should be equal to CPI for cost predictions and equal to SPI(t) for time predictions.

"In doing so, current low project performance will penalize the predictions, while current high project performance will have a beneficial impact on future predictions," Mark said.

"Exactly! That's why we'd better use the following general formula," she answered, writing the general equation on the whiteboard:

$$\textbf{FORECAST} = \text{KNOWN PAST} + \frac{\text{PLANNED TARGET} - \text{CURRENT STATE}}{\text{CURRENT PERFORMANCE}}$$

She showed that this general formula contained all previous formulas. The current performance could be added in the denominator of the new formula to correct the assumption that the expected future would be in line with the project performance obtained so far. Likewise, the current performance could also simply be ignored and set to an artificial 100 percent value in the denominator, which then meant that the expected future would be according to the planned progress, similar to the uncorrected formula. "Given this new corrected prediction, the final time and cost forecasts will take the current SPI and CPI into account, which will result in new values," Emily said, as follows:

Time forecast (in weeks)	**Cost forecast** (in €)
EAC(t) = ES + (PD - ES) / SPI(t)	EAC(€) = AC + (BAC - EV) / CPI
47.34 = 10 + (48 - 10.14) / 1.014	€510,674 = 45,000 + (454,500 - 40,050) / 0.89

"The bad cost performance gets worse, and the good time performance is expected to improve even further," Emily said.

"If we don't take action now, the cost overrun will further expand to an astonishing €510,674," Mark concluded, "which is well above our initial budget estimate."

"While the small current positive effect of time will only have some minor positive effect on the total expected duration," Emily added.

"Interesting information," Ruth said. "It indeed all lies in the data."

Emily told Mick that there existed many alternative versions for the general forecasting formula to predict the expected time and cost project performance in a slightly different way, but apart from some minor details they all followed the same general idea. She promised to share these extensions in a private meeting with him in case he wanted to implement these extensions in the spreadsheet, but they would add no overall value to the discussion here today.

"That's indeed fine for now," Jacob added, expressing his gratitude for the exciting and interesting meeting.

Evaluation

"I think we should implement this EVM control system as soon as possible and use it for the tennis stadium construction project," Jacob said to the team. "The time progress of the project is excellent, and I'm confident we still have time enough to recover from the small cost overrun," he added.

While not everyone was convinced of this, they all agreed that the crucial moments for action would lie ahead of them, and that the next reporting meetings should bring clarity about the severity of the cost overruns. Moreover, everybody agreed that this new methodology was easy enough to be implemented for use in the remainder of the project—and they all gazed in Mick's direction with a "the sooner, the better" look in their eyes.

Mick told Emily that he had exactly what he needed to start implementing the methodology in a software tool.

"It won't be very complex," he said, an expression common among IT people when they start with an implementation.

"Keep it as simple as possible," Jacob reacted.

While Emily did not always agree with the oversimplification of new tools in the company, she understood well that its future use would depend heavily on how easily the gathered data could be loaded into the software tool. She was always enthusiastic about new software tools and advanced techniques, but she realized that most people were not. She therefore agreed that the use of a simple data-protected spreadsheet that required a minimum of input and could easily generate automatic calculations and reports would be the best way forward. "A simple methodology in a simple tool," she added.

Emily then reminded Mick that he had promised to write a script to extract data from previous projects from the central database, such that the new EVM methodology, as well as the previously discussed risk techniques, could be applied ex-post to learn how these methods could be used effectively not only for the current project, but also for the company's future projects. "I think that such an ex-post analysis of the previous project data will reveal a lot of insights," she said.

Emily suggested that they present the information of the script runs at one of the next progress meetings. Together with the progress data for the tennis stadium construction project, the company would then be able to rely on the EVM methodology to make sound decisions for the project's future, and they would share these new insights with the Australian government.

"If we understand the advantages and disadvantages of the new project control system, I think we'll quickly learn how to better communicate our project decisions to the client," she added.

"Of course, we are—and always will be—a learning, evolving organization," Jacob concluded, and he closed the meeting.

CHAPTER

6

Control

Thirty weeks and multiple meetings had passed for the project now, and Jacob knew that today's third project progress meeting would be a crucial one. While the previous meetings were often cordial and explorative, this meeting was supposed to be the one where a final decision about the new project management and control approach would be made. For this reason, he had brought the right people together from across the organization in order to get things done quickly.

His colleagues Emily and Mark had been on the core team for this prestigious tennis stadium construction project from the very beginning, and had taken a leading role in fulfilling Jacob's desire to implement a more data-oriented project management approach. A few weeks ago, Mick had joined the team as a key player for the development of the new project control software tool, an easy-to-use spreadsheet that would be presented as a demo tool in today's meeting. Although not experienced in project management, his close collaboration with Emily had given him a good idea of how the current best practices at GlobalConstruct had evolved from a very intuitive project management approach to a strictly data-driven methodology with enough room for experience-based decisions. Jacob had also invited Ruth from the Accounting Department and Joanna from the Human Resource Management Department. Although these two board members had not been involved in the project from the very beginning, they had been crucial in some of the project decisions. Everybody knew that the two had a highly collaborative intelligence and that they would make an effort to understand the views and needs of the people in their departments. They would undoubtedly play a vital role in the general acceptance of the use of the new methodology and its software tool throughout all layers of the company.

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Jacob opened the meeting by stating that he had scheduled only a very short get-together with his key team members. He told them that the focus of today's meeting would be on a short introduction of the main data collected so far for the last three progress periods, displayed in the brand-new progress sheet developed by Mick and Emily. "With knowledge of the earned value management methodology, everybody should be able to draw some general conclusions," he said. He explained that Emily or Mick would briefly explain the basic features of the new progress sheet, which would enable everyone in the room to draw a general conclusion about the current project status. Furthermore, he stressed that the ultimate goal of today's short meeting was to give every single person in the room a brief assignment that would force them to think about the strengths and weaknesses of the control approach and allow them to define suggestions and improvements by tomorrow's meeting. It became clear to everyone that today's meeting was simply a preparatory rendez-vous for tomorrow's ultimate confrontation, in which Emily would present the new integrated project management and control system using all the methodologies they had been discussing up to now.

Progress Spreadsheet

At the third control moment, 30 weeks after the project had started, it became clear that, in spite of their best efforts to predict risk, they were facing some unexpected delays and more costs than they would have liked. After looking intently at Mick's new progress report, which displayed the progress data for three consecutive project periods (weeks 10, 20, and 30 in Figure 6-2), Emily immediately said: "I feel that it is now time to think about a strategy and possibilities to take immediate action if we want to finish the project successfully. We cannot just sit idly by, because if this progress continues as it is observed now, we are not going to make a dime on this project."

Mark was not entirely sure of this. "I've seen this on nearly every project I have worked on. Things are sure to stabilize. It is completely normal that things go awry in the first months of a project."

Before a full-blown argument could arise, Jacob interrupted: "I understand your point, Mark, but we are no longer in the project start-up phase, and time is running out fast. I'm not saying that panic is a good strategy, but it is also true that nearly half of our projects finish behind schedule and over budget. Nevertheless, you could be right, and this could be a fluke. Hence, I suggest we do as we always do when faced with difficult choices—we run the numbers, analyze the data, and think about the possible positive impact of certain actions."

The tension in the room had been lifted, and Emily made a final suggestion: "At any rate, I think it would be wise to repeat a meeting like this every five weeks, instead of every ten weeks, to see how the project has evolved, regardless of the decisions we will make today."

Jacob was looking at the report's project progression and concluded that it contained everything that they needed to take appropriate action. As agreed several weeks ago, the progress shown in the report had been analyzed by the standardized earned value management methodology, which had the ability to combine measurements of the project management triangle—time, cost, and scope—into a single integrated monitoring and control system. The report consisted of progress estimates collected by the senior project management consultants under the guidance of Joanna, who had been responsible for the work done up to today. Moreover, the report displayed all EVM key metrics, performance measures, and several time and cost forecasting values, and its general structure was divided into four main parts:

- Status week: The actual week of the project progress at which the current performance is being measured. The status reporting cycle is in its third round (week 30), and the project is over halfway to project delivery.
- Performance measures:
  - Baseline data: The data retrieved from the baseline schedule (Figure 6-1) are now displayed as the *planned percentage completion* (Planned %C) and *planned value* (PV) of the current status week in Figure 6-2. These metrics are no longer displayed on the activity level, but rather are summarized on the work-package level.
  - Progress data: The estimates about the project progress collected by the workers and reported to Joanna. These progress estimates are expressed on the work-package level and consist of the *actual percentage completion* (Actual %C) as well as the *actual cost* (AC) paid up to today for the current progress. Proud as he was, Mick told his team members that the status week, the Actual %C, and the AC were the only manual inputs required, while all other metrics were calculated automatically using the EVM formulas discussed in previous meetings.
  - Earned data: The periodic project progress input data are connected to the baseline data, and the *earned value* is calculated automatically. This metric takes a central place in this monitoring system and connects the manual progress inputs to the automatic planned value calculations and provides the summary statistics to assess the current time and cost performance of the project.

- Summary statistics: Based on the previously discussed input data, the aggregated time and cost performance metrics (SPI, SPI(t), and CPI) as well as time/cost predictions (EAC(t) and EAC(€)) are displayed automatically in the progress sheet. Mick remarked that they had implemented various versions of the forecasting methods, but Emily quickly noted that they showed no fundamental difference from the general formulas discussed earlier, and a detailed discussion was beyond the scope of the meeting.
- Event discussion: At the bottom of each progress period, a list of events that took place during each ten-week period is shown. These events contain remarks made by the senior project management consultants and clarify why delays or cost overruns have taken place. This qualitative information is considered to be an add-on to the quantitative EVM progress numbers and can be used to take better corrective actions, if necessary.

Jacob murmured and then suddenly decisively said: "Dear colleagues, we are no longer in the beginning of the project, and there is not much room for spending unnecessary money to take corrective action. Given the tight budget constraints, I suggest we think twice before we act, and also talk to the senior project management consultants and ask their advice." Jacob was known for his excellent communication skills and his preference for teambuilding ideas. "But the most important thing," he continued, "is that we now use this data to draw conclusions about the current project status and formulate suggestions about the future course of the project." He added that today's meeting was meant to be a short one to present the new progress sheet—and, while it was allowed to restrict today's focus to blindly staring at the progress numbers, he expected that tomorrow some advice would be given for how to use this wealth of data to set up a proper project control methodology!

Mark and Emily understood the message. A murmuring Jacob mostly meant that some clear and to-the-point status reports must be made, which should include not only the raw numbers, but also interpretations and solutions. After weeks of discussions about new data-driven methodologies, including new risk metrics (see chapter 3. RISK), a comparison between different resource management concepts (see chapter 4. BUFFER), and a novel project control methodology (see chapter 5. MONITOR), the time was right to unite these new project management approaches in an integrated framework. Without such an integrated view, data-driven project management would remain an empty black box with little or no added value for the company or its clients. Jacob wanted to present proposed actions to the team and the client by the end of the week. Clearly, there was no time to waste!

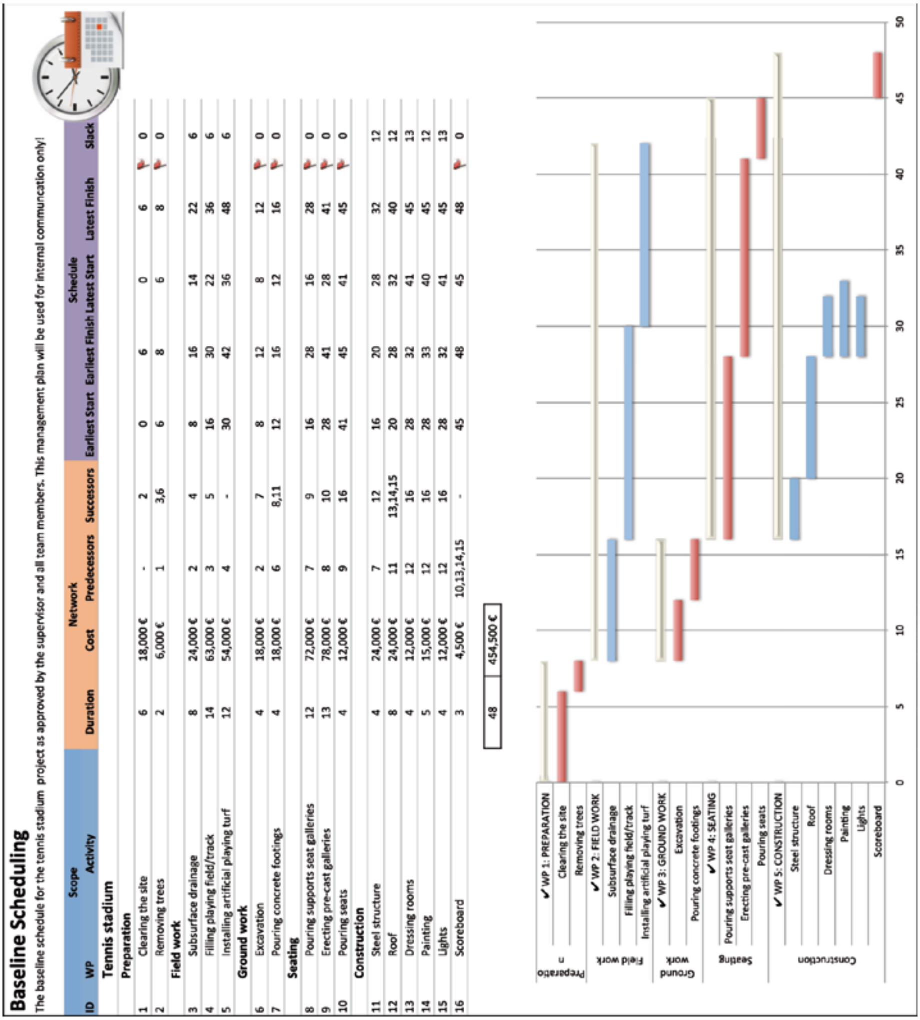
Assignment

In his action list summary email, Jacob highlighted the importance of having the project report progress data of GlobalConstruct's tennis stadium construction project (Figure 6-2) be analyzed with care to allow them to take timely action to bring the project back on track. The analysis should therefore contain a summary of the progress data, including budget data and summary statistics, with general recommendations for control and action. In his action list summary, Jacob made clear that the project team's ambition should now move beyond the discussion of new methodologies and the restricted focus on merely the calculations. Instead, he expressed his desire to combine the new concepts discussed at the previous meetings in a united project management approach. Although this assignment and his call for suggestions and conclusions were sent to all project core team members, he knew that it would be Emily who would take a leading role in assembling the new knowledge into an integrated project management and control approach.

ACTION LIST SUMMARY

Note from Jacob: Since we have decided to implement the new EVM methodology company-wide to be used to control all of GlobalConstruct's projects, I do not expect any detailed calculations for the EVM metrics. We did that before, and since they can now be automatically (and I assume correctly) calculated in Mick's progress sheet, I don't see any reason why we should repeat this process. Instead, I expect that each one of you, as a core member of the project team, will reflect on how we should use this wealth of data for monitoring the progress of our projects. I expect interpretations of numbers, highlighting strengths and weaknesses, but above all I expect suggestions for how we could use the richness of EVM data to monitor and control the tennis stadium construction project and to take better corrective action.

- Progress report: Identify the most appropriate summary statistics of Mick's progress sheet, give interpretations of their meaning for the project's progress, and formulate suggestions.
- Corrective action: Think about a way to integrate the risk metrics of the schedule risk analysis carried out several weeks ago (see chapter 3. RISK) and the EVM metrics in Mick's sheet and find out how they might support a corrective-action decision-making process to solve project problems.
- General recommendations: Provide an update of the current project status, expectations about the future project progress, and general recommendations for future actions.
- Your input: Highlight strengths and weaknesses and give general remarks for improvements. If you have any doubts or difficulties in understanding, prepare your questions for Mick (about the new spreadsheet tool) or Emily (about the use of EVM for the project).



Baseline Scheduling

The baseline schedule for the tennis stadium project as approved by the supervisor and all team members. This management plan will be used for internal communcation only!

Scope			Network				Schedule				
ID	WP	Activity	Duration	Cost	Predecessors	Successors	Earliest Start	Earliest Finish	Latest Start	Latest Finish	Slack
	Tennis stadium										
	Preparation										
1		Clearing the site	6	18,000 €	-	2	0	6	0	6	0
2		Removing trees	2	6,000 €	1	3,6	6	8	6	8	0
	Field work										
3		Subsurface drainage	8	24,000 €	2	4	8	16	14	22	6
4		Filling playing field/track	14	63,000 €	3	5	16	30	22	36	6
5		Installing artificial playing turf	12	54,000 €	4	-	30	42	36	48	6
	Ground work										
6		Excavation	4	18,000 €	2	7	8	12	8	12	0
7		Pouring concrete footings	4	18,000 €	6	8,11	12	16	12	16	0
	Seating										
8		Pouring supports seat galleries	12	72,000 €	7	9	16	28	16	28	0
9		Erecting pre-cast galleries	13	78,000 €	8	10	28	41	28	41	0
10		Pouring seats	4	12,000 €	9	16	41	45	41	45	0
	Construction										
11		Steel structure	4	24,000 €	7	12	16	20	28	32	12
12		Roof	8	24,000 €	11	13,14,15	20	28	32	40	12
13		Dressing rooms	4	12,000 €	12	16	28	32	41	45	13
14		Painting	5	15,000 €	12	16	28	33	40	45	12
15		Lights	4	12,000 €	12	16	28	32	41	45	13
16		Scoreboard	3	4,500 €	10,13,14,15	-	45	48	45	48	0
			48	454,500 €							

Figure 6-1. Project baseline plan of the tennis stadium construction project

Figure 6-2. Project progress report of the tennis stadium construction project

Project Control

Unlike yesterday's short meeting, today's gathering was not destined to be quick and easy. Instead, its focus was specifically on the presentation of a unified framework for project management and control, one that relied on the methodologies the team had discussed over the last few months. Everybody was well prepared and reviewed the analyses they had done with the team. More than anyone else, Jacob was the one who had gone through all the details of the concepts presented by his core team. He knew that today's meeting could be a new step forward in the direction of a new data-driven project management approach for GlobalConstruct .

He had given Emily full authority to lead this meeting to present the new tool to the team. Jacob knew that everybody would listen honestly, thoughtfully, and objectively and would make the right decision. After all these meetings, Jacob and Mark were well aware of Emily's teaching skills and knew that today's session would be another lesson in the simplicity and relevance of a unified project control methodology. However, Mick, Ruth, and Joanna were relatively new to the project management team and had carefully reviewed all of the previous meeting summaries of the project, even the summaries of the meetings where they had not been present. They realized that Emily had taken a leading role in presenting new ideas and concepts, and they saw that her often easy and stepwise approach (as she, for example, used for her *cut - plan - buffer* approach for resource management) was more of a general framework for explaining novel topics rather than an exact solution to the problems under discussion. When Emily wrote the following three words on the whiteboard, the others began staring at each other with a hidden smile and an "Oh my God, here we go again!" expression. Jacob loved this—he knew that Emily had grabbed their attention when she read her three words out loud:

ALARM - FOCUS - SHOOT

"I am very proud to present a new tool in a simple spreadsheet," Emily started. "And I'm even more proud that it's a 100 percent in-house development by Mick," she added.

Everybody was curious what the three words had to do with the newly developed software tool, and Jacob recognized once again that this was probably one of Emily's strengths. Triggering an audience while not giving all the details in advance made everybody curious and was therefore the ideal recipe for an exciting business meeting. After a short moment of silence, Emily told the team that the new software tool was an integration of the three keywords in a simple and easy-to-use way.

ALARM. Emily told the team that the previously discussed earned value management methodology had now been implemented to be used as a *warning signal* system. She said that she would explain how it could act as an alarm when a project is moving into the danger zone, and how it could provide triggers to search for the reasons for these problems in order to solve them before it is too late.

FOCUS. Once the alarm has gone off, the EVM clearly having given an indication that something has gone wrong in the project, the search for the reasons for these project problems should start immediately, aiming at finding the underlying reasons for the problems in order to find and propose solutions. The Focus principle prescribes that one should restrict the search to the most dangerous activities of the project, since they would most likely have the highest impact on the project objectives. Emily referred to the risk analysis methodology that they had discussed some weeks ago and told the team that the use of the various risk metrics would now allow the team to *define a focus* for solving the problems. She explained that the target was to mainly focus on the activities that might harm the project objectives and to spend less attention (or none at all) on the remaining activities, which wouldn't have a huge impact. "The most sensitive activities are the ones that deserve our attention every time an alarm signal is given," she said.

SHOOT. Once the problems are detected in some of the activities, in a final stage, the team members should determine when and how to react to the project problems. "With the right focus on the problematic activities, it's now up to all members of the team to decide whether they should take corrective action," she said. Emily told her team members that she explicitly referred to so-called *corrective action* since they should correct project problems and ideally bring the project back on track. "Once you aim (the *focus* phase), make sure you shoot well. One single shot, and the problems should be solved," she jokingly said, referring to why she called her last step the *shooting* phase.

While explaining the three words, Emily opened her MacBook and proudly showed the project control dashboard developed by Mick in a spreadsheet (Figure 6-3). She praised Mick for the excellent work he had done the last few weeks, and told the other team members that the dashboard perfectly fit within the three phases of the *alarm - focus - shoot* approach.

"This is the main dashboard of the new integrated project control tool, and I will explain, one step at a time, how this dashboard fits perfectly in the *alarm - focus - shoot* approach," she said enthusiastically.

"Mick, are you ready to explain how your beautiful piece of work works?" she added.

"You bet I am," he quickly replied, as enthusiastic as Emily was. "As long as you do the talking, and I just have to showcase my software."

You could almost hear Jacob thinking: "What a beautiful way to build team harmony!"

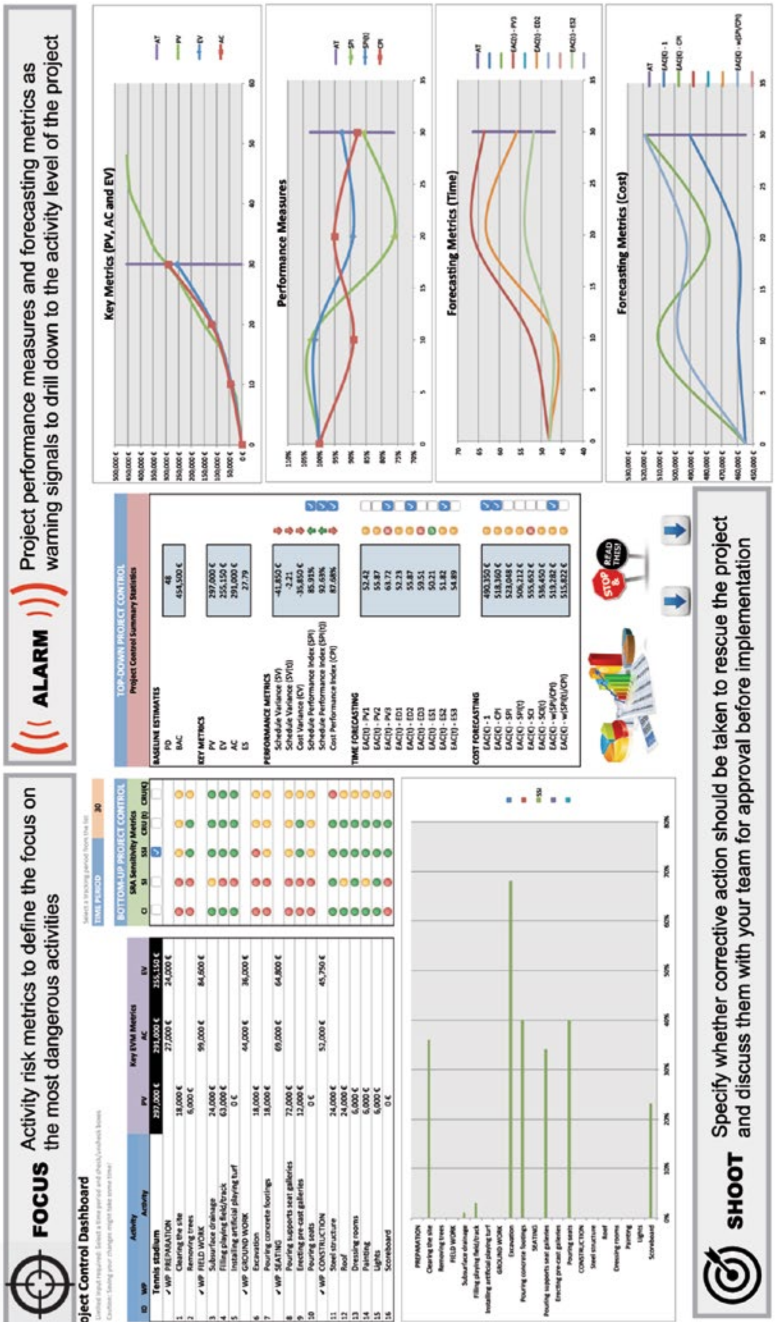


Figure 6-3. The alarm - focus - shoot project control dashboard

Warning Signals (*Alarm*)

Emily reminded the team of the excellent meeting they'd had 20 weeks ago when the earned value methodology was first introduced as a formal project performance measurement system. She briefly reviewed the use of the performance measures for time and cost (SPI and CPI) and reminded the team of the alternative time performance measure SPI(t) as the only reliable one to use for time performance assessment. When she was about to summarize the main contributions of the EVM system and its use for forecasting, Jacob abruptly interrupted her to prevent an repetition of what everybody already knew.

"I don't think we should go over the details of the EVM methodology again," he said, "as everybody is still convinced of the relevance of a strict control methodology for GlobalConstruct."

It first looked like Emily hadn't paid attention to Jacob's remark, and she continued for a while giving everybody's memory a jog of the main features of an EVM system. Suddenly, she looked in Jacob's direction and became aware of the repetitive character of her introduction.

"The time and cost performance measures act as sanity checks of the current project progress," she suddenly said to switch to the essence of today's meeting.

Mick smiled since he realized that she had borrowed the words *sanity check* from the software development jargon he had frequently used when developing the new software tool in close collaboration with her.

"It's a quick and simple method to discover many possible errors in the project," she continued, without any hesitation.

"The advantage of a sanity test, over performing a complete or rigorous test, is speed," Mick replied.

"Exactly, no focus on details, but rather a general view of the project progress," she added immediately.

"Quick and easy means less attention to details and therefore not free of errors," Mark added as a critical comment.

"Indeed, to every advantage there is a disadvantage," Emily replied.

Emily knew exactly what she was doing by referring to a potential disadvantage of a quick and easy sanity check, as she wanted to use this opportunity to link the use of the EVM metrics to the work breakdown structure (WBS) of the project.

"The performance measures serve only as warning signals at the highest level of the WBS," she said.

"They warn us of potential project problems, but do not give a specific reason why and how," Mick added with a confidence that had typified him since the development of the software tool.

"It's an alarm that acts as a trigger to drill down to lower and more detailed activity levels in the work breakdown structure," Emily said, "to search for the real project problems, if they exist, or, in the case of false warning signals, to search for problems but find nothing at all."

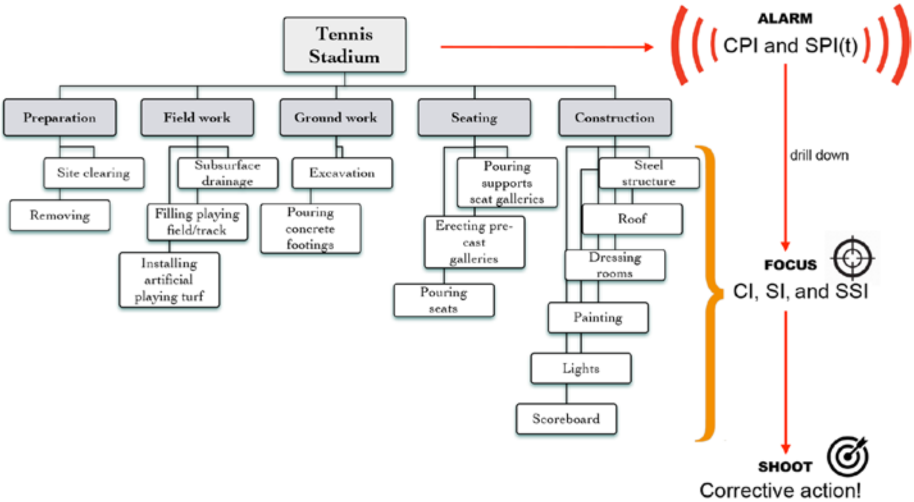


Figure 6-4. Linking the alarm - focus - shoot control approach to the work breakdown structure

Emily switched on the multimedia projector to show the work breakdown structure of the tennis stadium construction project on the whiteboard, which allowed her to add some notes to it (Figure 6-4).

"The work breakdown structure of the project graphically displays the different levels of the project network," she said, and she added the *alarm - focus - shoot* approach to the right of the picture.

She pointed at the top root node of the tree to indicate that she really was talking about the tennis stadium construction project, and reminded the team that the work-package level had been used previously to collect progress data. She also reminded her team that the lowest detailed activity level was the level of the project network, and the level on which the risk metrics had been calculated quite some time ago (see chapter 3. RISK).

"The time and cost performance measures CPI and SPI(t) report values on the highest level of the WBS," she said, while pointing at the root node, "but do not provide any information about the specific set of activities that caused the troubles."

She emphasized that these performance measures gave an indication of the time and cost performance of a project at the current status date, relative to the baseline schedule. Therefore, any deviation from 100 percent did not necessarily mean a good (above 100 percent) or poor (below 100 percent) project performance, but rather a difference from the initially expected performance as stipulated in the plan. For this reason, small deviations from the baseline plan should be tolerated and did not always require immediate action, while huge deviations might give an indication that the project was running out of control, in which case immediate action might be required.

"We need to define what an unacceptable point of performance is," Emily said, "and exceeding this point should lead to a drill-down in the work breakdown structure to search for problems on the activity level."

She took her pen and wrote the following on the whiteboard:

THRESHOLD 1. POINT OF DRILL-DOWN

More precisely, when the CPI and the SPI(t) values dropped below predefined acceptable threshold levels, it might be an indication of real project problems, and then further investigation would be necessary to find out whether the problems were real, and if they were, where they had actually occurred at the lowest levels of the WBS.

"If we don't know whether the problems are real, how do we search for them effectively?" Mark asked.

"I wouldn't say problems are not real," Emily replied, "but rather wonder whether they are relevant for the project."

Emily explained that the biggest problem with the easy sanity check (i.e., the alarm signal at the top level of the WBS) was that it only *reported* project problems, but did not provide an indication of the potential impact of these problems on the final project objectives. In some cases, the drill-down to the lowest activity levels could therefore be a search for problems that were not really relevant for the total project duration or time. In these cases, the problems occurred at activities that hardly had any impact on the total project duration or cost, and then the drill-down could be regarded as an overreaction and a waste of time and effort. But in other cases, the drill-down might lead to problems in activities that could potentially have a huge impact on the project objectives. In those cases, it was necessary to act quickly and effectively, since it was known that the impact would be dramatically huge if these problems were not quickly solved.

Emily gave the example of a project in progress with a rather low schedule performance index of SPI(t) = 60%, which really indicated that the project suffered from delays. She continued telling the team that a drill-down to the activities might reveal that the delays only occurred at activities that were not lying on the critical path, and concluded that in this case the activity delays would probably have no impact on the final project duration as long as the activity delays did not exceed their slack.

"It's an extreme example," she said, "but that's the idea! Some delays have more impact than others."

Emily looked at Mark and said: "That's the potential weakness of the quick-and-easy sanity check, it is—as you indicated earlier—not free of flaws."

Mark nodded to Emily proudly—he knew he understood the new approach.

"So, if delays occur, why don't we focus only on the critical-path activities of the baseline plan?" Ruth chimed in.

"That idea would make sense," Emily replied, "but we know that the critical path is dynamic and continuously changes over time once the project is in progress. All we need is a way to know where to focus," she added, "preferably on the activities with the most likely and highest impact on the project objectives in case problems occur."

With these words, she reminded the team of the risk meeting they had had some months ago, at which three risk metrics (the *criticality index*, the *significance index*, and the *schedule sensitivity index*) had been proposed to refine the static black-and-white approach of the critical path. The ability to fall back on these risk metrics now became crucial. It allowed them to focus on the most dangerous activities in order to take good and quick action when necessary—and to take no action at all when the warning signals were not really relevant.

"Once we decide to drill down to search for problems because the alarm went off (i.e., threshold 1 has been exceeded), the message is to focus on a search for activity problems that might have the biggest impact on the project objectives," Emily concluded, which was the second step in her approach.

Detect Problems (*Focus*)

"Once the first threshold is exceeded, and we have made the decision to search for problems, we clearly need to focus on activities that could do the most harm to the overall project objectives," Emily repeated. In order to clarify her point and illustrate this on Mick's project control dashboard (Figure 6-3), she pointed to the EVM graphs displayed on the right part of the dashboard. The performance graphs showed the periodic performance of the project, and the first threshold should be set on these graphs to determine the drill-down point. Once the decision for a drill-down is made, the attention should shift to the left part of the control dashboard, which provides reliable information about the sensitivity of each project activity. These schedule risk analysis metrics should then be used to optimize the focus on the most dangerous activities, the ones with the highest potential impact on the project objectives.

"After a drill-down, we should start searching for the reasons for the project problems," Emily said.

Emily explained that the search for problems should be done in order to find out where action must be taken. She told her team that knowing how problems could be solved was more important than knowing why things went wrong.

"The reasons for the past problems might be interesting, but knowing how to solve them effectively, with the least possible effort, is what really matters for the project," she immediately added.

Emily continued explaining that the search for solutions to the project problems implied that the project manager had an idea about the expected impact the solution would have on the project objectives.

Jacob interrupted the discussion and told her that the schedule risk analysis metrics discussed months ago might provide this knowledge, since they predicted the impact of activity delays and cost overruns on the final project duration and cost. He looked at Emily and, although everybody could tell that the two had prepared this as a bridge to the previous schedule risk analyses discussion, no one really minded that they had set up their seemingly fluent dialogue in a well-prepared scene.

"We should prioritize the activities according to their potential impact on the project objectives," Jacob said, "and our focus should be turned to the activities with the highest possible impact. If things go wrong with these activities, they will cause the greatest damage," he said.

"And, likewise, if we change some specific settings for these activities to solve problems, it will probably lead to major project improvements," Emily added.

"No doubt that our focus should be directed to them," Jacob answered in clear agreement.

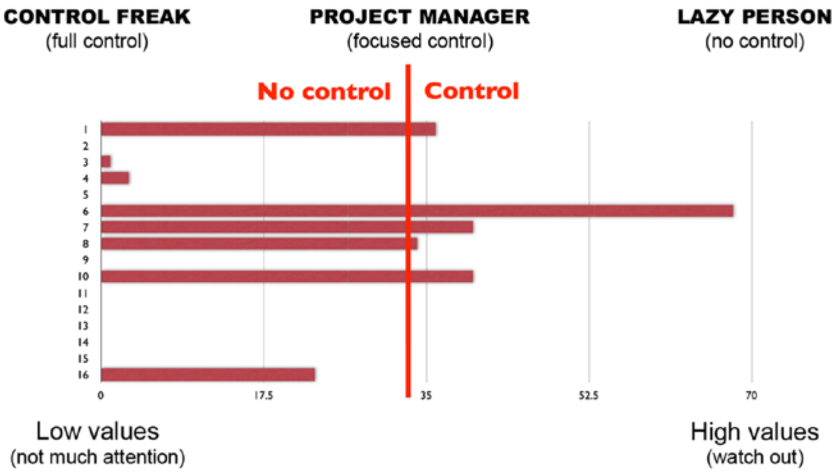


Figure 6-5. Focusing on what really is important depends on the type of manager

Emily referred to the activity sensitivity metrics of Table 3-1, discussed during the schedule risk analysis meeting (see chapter 3. RISK), and reminded the team that they had decided that the so-called *schedule sensitivity index* (SSI) was the most reliable metric.

"The SSI is more complete than the other metrics since it combines *impact* with *probability*," Mark said to his team members, reminding them that he had made a significant contribution during that risk analysis discussion.

Emily confirmed this statement and turned the team's attention back to the video projector, which this time was showing a graph with the SSI values for each activity of the tennis stadium construction project (Figure 6-5). She said that each horizontal bar displayed the value of the SSI—with longer bars denoting higher values—and clearly explained that high values reflected more risky activities. These activities deserved much more attention, while activities with lower values would probably have little or no impact on the project objectives, and therefore did not deserve much attention when solving problems.

"We should focus on the high SSI values and determine from which point we should define our focus," she said.

She drew an arbitrary horizontal line on the bar chart and told the team that everything to the left of the line was assumed to be too low to be worth considering.

"We shouldn't spend too much time on these activities, since any change won't have a large impact," she said.

She continued by saying that all activities to the right of the horizontal line were assumed to be very sensitive activities, and any change would likely have a bigger impact on the project objectives, and therefore would need the project's team attention. "These are the ones to focus on," she said, and she wrote the following words on the whiteboard:

THRESHOLD 2. POINT OF FOCUS

"The point where one normally draws the threshold (i.e., the horizontal line) depends on the type of manager," she continued jokingly. She wrote three management types above the graph and explained them in the following way:

CONTROL FREAK. People who believe that they need full control over every little aspect of the project take no risk at all. So, these perfectionists spend all their precious time on the tiniest details to find out the problem and the best possible solution. Control freaks completely ignore the valuable information of a schedule risk analysis by drawing the horizontal line completely to the left of the graph. For them, there is no need to focus, as they trust only their own judgement based on a full analysis of potential problems for all of the project activities.

LAZY PERSON. Lazy persons are not prepared to create and thrive in a little panic. They often leave the creation of panic for when things are going really badly for the project. Whether it is because they have a lack of desire to expend effort or a lack of discipline is not relevant, but their inability—or lack of willingness—to spend time on control often results in project problems that cannot be solved in a timely manner. These people draw the point-of-focus line very close to the right of the graph and define every activity as unimportant and safe, and even when the alarm for drilling down has gone off, they still think that none of the activities is responsible for the problems.

PROJECT MANAGER. Holding the middle ground between two extremes always pays off, and that's true for project control too. Project managers wish to spend their precious time on control as long as it doesn't outweigh the benefits, and they believe that with focused control they can reach the same results as the control freaks, but by spending less effort than the control freaks, an effort that is much closer to that of the lazy persons. Having no respect for laziness, the time freed up will obviously be used for other important aspects of managing projects, and so the project managers draw the horizontal line somewhere in the middle of the graph. In doing so, efficient project managers aim at focusing on only a part of the set of activities, without being too lazy and risking overlooking the most important problems.

The way Emily presented the different management types to her team members caused a lively discussion, full of vivacity and spirit. You couldn't accuse her of a dry, humorless teaching style.

"My daughter would call the lazy person a *you only live once* person," Ruth jokingly said.

"Tell me about it," Joanna replied. "If my son ever becomes responsible for a project, I foresee huge disasters!"

They all laughed loudly, sharing their experiences about their kids. Emily, however, told them that observations were quite the contrary. In her experience, young people more closely resembled control freaks, pinpointing every little detail every hour of the day, not taking the risk to overlook problems. She told the team that, later in their careers, people got more relaxed and, with a growing feeling of self-esteem, they grew more toward the experienced project manager, or even further into the direction of the lazy person.

"Age makes you lazier, doesn't it," she joked, looking at Jacob, who was the oldest of the group.

"On the contrary! Once you're over the hill, you begin to pick up speed," he cleverly replied.

Action Time (*Shoot*)

"We have defined two thresholds for project control," Emily said. "One for drilling down the work breakdown structure, and one for focusing on a selected set of activities."

Emily told the team that both the threshold for drilling down (threshold 1) and the threshold at which to set the point of focus (threshold 2) determined the *effort of control*. She referred back to her joyful story of the lazy person and the control freak and reminded the team that the project manager should hold the middle ground between those two extremes when setting threshold 2. She explained that a similar reasoning could be applied to the warning signal threshold 1 set at the highest project level.

"Assume that you drill down to search for problems from the moment the SPI(t) drops only 1 percent below the normal 100 percent performance," she said.

"That's an overreaction; you shouldn't panic so fast," Mark said.

"Exactly, and the opposite is also true: you shouldn't wait for very low values," Emily replied.

"Surely not, then it's probably too late to take appropriate action," Mark bounced back.

"You got my point," Emily said. "Control freaks overreact, and lazy people react too late!" and she wrote the following words on the whiteboard:

EFFORT OF CONTROL

setting proper values for thresholds 1 and 2
(drilling down and point of focus)

She explained that minimizing the effort of control could not be a goal in itself, but at least it was an important factor that determined a manager's behavior and his/her way of managing projects. She explained that the lazy person probably exaggerated a little bit in minimizing effort, but at least the general idea was that lower values for the control effort were much better than higher values of control effort. With less effort spent on controlling the project, there would be more time available for contact with the team and the client, maintaining good relations and a positive spirit, probably contributing to the overall project success.

"I'm not so sure about this," Joanna replied. "It is known that people who spend little to no effort on control won't perform very well. Trust is good. Control is better!"

"That is correct, but the control freak will probably have no life at all, pinpointing every little detail to the highest degree, and soon suffer from burnout," Ruth added.

"Exactly, effort of control is only one side of the coin," Emily answered.

She explained that a good project manager should also aim at minimizing his/her effort in order to free some time for the important work, just like the lazy person did, but he/she should take a second criterion into account and borrow some ideas from the control freak. She said that always drilling down and acting like a control freak would be the best approach, not in terms of effort, but certainly in terms of the quality of actions taken to solve the problems. Emily called this quality of actions the second driver for setting appropriate threshold values, and wrote:

QUALITY OF ACTIONS

corrective actions with impact on project objectives
(ability to solve project problems)

She told the team that carefully balancing between a reasonable value for the control effort without giving up too much quality of actions was what a project manager tried to accomplish. She admitted that the quality of action to solve project problems obviously depended not only on the correct threshold settings of the control systems but also on the type of project, the experience and maturity of the project manager, and undoubtedly many other unknown factors. But setting these things aside, she truly believed that one of the main drivers that determined the success of a project was a well-balanced view of the effort spent to control the project, as well as the quality of actions taken once problems were found.

"It's a classical trade-off, as usual: an exercise in minimizing effort and maximizing quality. If you give up on one, the other will improve. Setting proper values for both thresholds is crucial!" Emily concluded.

"Let me illustrate this with our two extreme types of managers," she said.

Avoid overreactions. The control freak won't have the problem of low quality, as he/she is able to detect most problems immediately, but at the cost of a level of effort that's too high. Besides, the freak runs the risk that much of the effort is in vain, searching for problems that really are not important or even have not really occurred during project progress. This is known in statistics as *Type I errors* or *false positives* and should be avoided.

Detect real problems. The lazy person is probably good at minimizing effort, but the quality of actions will be dramatically low. Indeed, being relaxed all the time, both for drilling down and for setting the point of focus, might risk detecting a problem too late, or even not detecting the problem at all. Statisticians would call this *Type II errors* or *false negatives*.

"Whatever the statistical name is, a good project manager is well aware of these two errors and balances between effort and quality, or between these two errors, if you want," Emily continued.

She explained that a good project manager aimed at obtaining quality of actions like the control freak, but with an effort closer to that of the lazy person. This concept was called *control efficiency*, and she looked in Mick's direction.

"Being efficient is the goal!" he said.

The team realized that Mick's analysis of the company's past projects had focused on this new control efficiency concept, and they all saw in his eyes that some interesting and astonishing results were coming up.

Control Efficiency

Mick was not the kind of person for exaggerations and spectacles, and humbly estimating his own merits was how most team members knew him. However proud he was of the speed and quality of his latest development, he was also glad for the back-up of Emily as his spokesperson, since she was much better at selling this integrated project control methodology to her audience. This time, however, he realized that his analysis of the data of the previous projects could give him an important place in the project management team. Even though he would never leave his job as an IT consultant, he had always been eager to explore new management worlds that could benefit from the mutual relationship between management and computer science.

"I wrote a simple script in Python that extracted and analyzed the project data I received from Jacob," he said to the team.

Mick explained that all the project data was automatically loaded into his new software tool (Figure 6-3), and thousands of simulations had been carried out under the guidance of Emily. He mentioned that writing the script was not a big deal for him, as it just boiled down to knowing the relevant points in the data, along with some easy programming. The Monte Carlo simulations required more work, but with some knowledge and programming skills, these simulations could analyze gigabytes of data in less than a couple of days on the quad-processor computers they currently had available. Obviously, no one was really interested in the computer details of his work, and although Mick was the first person in the room to realize this, he couldn't resist sharing some of these exciting details with his colleagues.

"I believe Emily can tell you better exactly how we have set up these simulations," he laughed.

Emily started her argumentation by thanking Mick once again for the wonderful work he had done the past few weeks, and also mentioned Jacob as an infinite source of inspiration and wisdom thanks to the numerous projects he had been responsible for in his long career. It was Jacob who had provided Emily and Mick with most of the project data, and although much of it could not be used due to lack of accurate measurement points or simply because the data did not completely fit the purpose of the analysis, without him the analysis would simply have been impossible.

"Most of the project data are construction projects, but also other engineering projects, as well as software development, maintenance, and education projects," Jacob responded proudly, as if the data reflected an overview of his long and successful career.

Effort of control: Emily said that, once the data had been loaded into the software tool, various settings for the two thresholds had been set, and the computer program had imitated the project progress under random numbers, and therefore had simulated cost overruns and project delays, each time automatically measuring whether the two threshold values had been exceeded.

"Monte Carlo simulations aim at imitating the world under a controlled design," she said.

"How can you know which thresholds have been set for these projects," Ruth replied, "knowing that these projects have not been managed with this approach?"

"We simply can't know," Emily replied. "That's why we have simulated a wide variety of values for both thresholds, ranging from very low to very high."

She continued explaining that they simulated all kinds of thresholds, varying from imitating very lazy persons ("people we would never recruit!") to super-scary control freaks ("the ones whose effort is way too high to be realistic"), but also all intermediate values between these two extremes had been used in the experiments. These values were set for both the drill-down threshold 1 and the point-of-focus threshold 2, and all of these experiments had resulted in the literally gigabytes of data Mick had previously referred to. During each simulation run, the effort of control had been measured as discussed before as the number of times both thresholds had been exceeded, since exceeding these thresholds led to spending effort (for drilling down or for focusing on a set of activities).

"The closer the threshold settings were to the control freak, the higher the reported effort," she summarized.

Quality of actions: "Once the threshold values had been varied in the huge amounts of experiments, and the effort of control had been measured, the quality of artificial actions should be simulated," Emily continued immediately.

She told the team that this was not as easy as simply varying threshold values and measuring effort, but instead required some additional input and imagination that might be subject to interpretation and discussion. Since the quality of actions could only be measured as the impact on the project after corrective action had been taken, this required an *automatic corrective action decision-making process*, which was not a straightforward task for a computer.

"Basically, the computer simulation should act like a human being and make decisions about corrective actions when problems occur to bring the project back on track," she said.

She told the team that there was a wide variety of possibilities to make changes to bring projects back on track, and each of them depended on the specific characteristics of the project, such as the available budget, the criticality of time, the relationship with the client, and undoubtedly much more.

"Can you name a few of these solutions," she asked her team members in an attempt to generate some interaction.

"Shifting people to shorten or increase durations, obviously at a certain cost," Joanna answered, always thinking about her people as the driving force of projects.

"Overlapping activities that normally can't overlap, although this often requires some extra work," Mark quickly interjected.

"Reducing quality on parts of the project, but this often leads to extra effort later in the project," Mick said, and he mentioned that in IT it's often the case that bugs are found late in the project when quality has not been carefully controlled from the very beginning.

"I told you that there are tons of possibilities," Emily said.

After this short discussion with her colleagues, she told them that she and Mick had implemented some simple decision rules that would be used once the two thresholds had been exceeded. These easy decision rules included resource shifts, activity time and cost changes, implying changes in the network, and some others—but she immediately admitted that these decision rules probably were simplifications of the real decisions good project managers would make.

"I believe these corrective actions make sense," Jacob said, strongly supporting the impressive analysis of Emily and Mick.

Emily said that some corrective actions had a huge impact on the project objectives and brought the project back onto the right track, while others had little to no impact at all, and this degree of impact was measured and reported as the quality of actions she previously discussed.

To her surprise, the team members didn't question or criticize her approach, and she realized that they all easily understood that—although it was not perfect, because of the artificial nature of simulations—such an analysis required some assumptions and would never lead to a perfect imitation of reality. However, it allowed them to measure some metrics that could be used to assess the accuracy of the system they were about to implement to run real projects. She explained to the team that both the *effort of control* and *quality of actions* had been integrated in a single performance measure, and she wrote the following words on the whiteboard:

CONTROL EFFICIENCY

quality of actions / effort of control

She explained that the division between quality and effort led to a new concept she called *control efficiency*, and it was clear she was proud to present some results to her team members. She told the team that this control efficiency measure allowed them to integrate both *effort of control* and *quality of actions* in a single metric to measure the most important driver for making good decisions in project control.

"High quality of actions with low effort are favored above lower quality actions or higher effort for control," she said.

"Forget the lazy person and the control freak," she added, "as their efficiency is much lower than the project manager's."

"A good project manager holds the middle ground between the two and aims at maximizing efficiency of control."

Experimental Learning

Emily's suggestion to take a small coffee break was quickly refused, since every team member was eager to see the results of the simulation study. Even Jacob, known for his coffee addiction, rolled his eyes when he heard the suggestion to have a coffee in the middle of the discussion. Before Emily gave the floor to

Mick, she summarized the specific settings used during the simulation study. She told the team that the values for the first drill-down threshold were set on the *cost performance index* CPI metric for cost control, while the *schedule performance index* SPI(t) (and not the SPI, for obvious reasons) was used for time project control.

For the second threshold, to determine the point of focus on the activity level, the three sensitivity metrics (*criticality index*, *significance index*, and *schedule sensitivity index*) were used for time control, as she had explained a couple of months ago during the schedule risk analysis meeting. For cost, an alternative cost metric had been used that hadn't been discussed in the previous meetings, but this metric (which was known as the *cruciality index*) followed an idea similar to the time risk metrics. She showed the results in a single graph (Figure 6-6) and paused for a couple of seconds to let the team members take it in. Realizing that this graph needed further explanation, she interrupted the silence and said: "Mick will clarify the different lines and points of the graph, and I will translate this into results and conclusions for our project."

No doubt, the audience was listening.

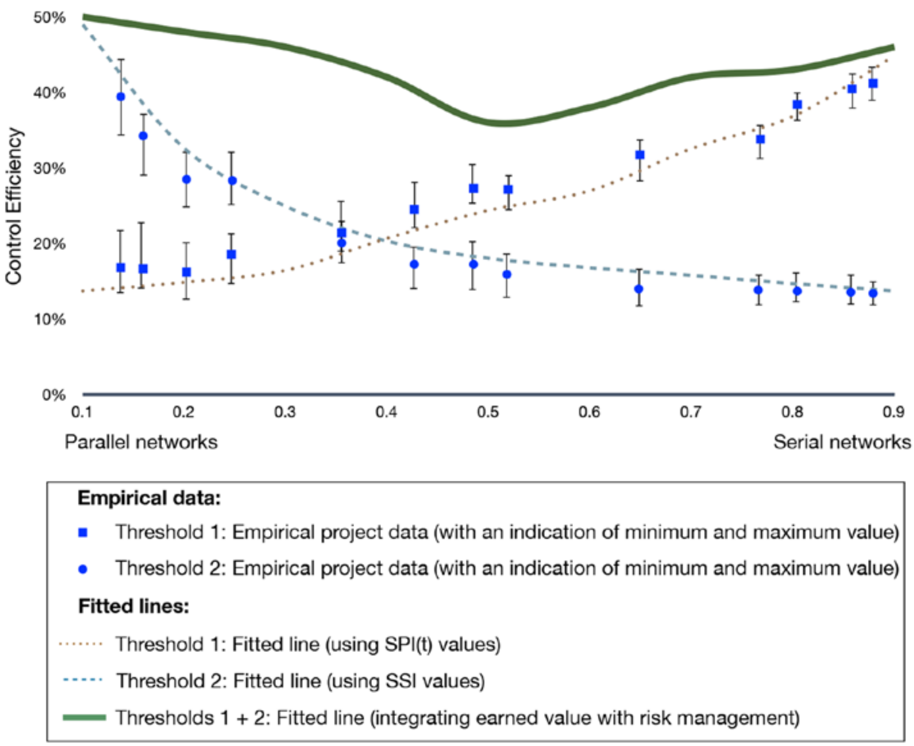


Figure 6-6. Simulated control efficiency results on Jacob's project database

Mick first explained how the graph had been automatically generated using another Python script, and he named some data analysis software tools that most of the team members hadn't heard of. After this short introduction, he told the team members that the graph looked more complex than it actually was, and told them it might need some clarification, which he briefly summarized for them.

The two-dimensional graph had an x-axis and a y-axis, which needed to be clarified first:

Network structure (x-axis)**.** All the projects from the database had been classified along their network structure, measured by their proximity to a completely parallel (left) or completely serial network (right). This classification of the project networks along this dimension allowed him to get results that differed from project to project, and he had learned from the previous discussions that paths and chains in networks were often crucial for project and resource management. The proximity to a parallel or serial network was shown on the x-axis of the graph. He told the team that the project network of the tennis stadium construction project (Figure 3-1) lay exactly in the middle, between a completely serial and a completely parallel network. "I won't bother you with the details, but its serial/parallel value is equal to 47 percent, which is just between 0 percent (completely parallel) and 100 percent (completely serial)," Mick said.

Control efficiency (y-axis)**.** The control efficiency, explained earlier as a combination of the lowest possible effort and the highest possible quality of actions, was displayed on the y-axis. Higher values on the y-axis were meant to display best project management practices.

The graph also contained some lines and dots that also needed to be clarified:

Empirical data. The values reported by the simulation performed on the real project database were labeled by the dots on the graph. Since simulations are repeated several times to guarantee sound results, the reported values always slightly differ between the simulation runs. This margin of error was shown by the horizontal lines on the box plots, representing their minimum and maximum values of control efficiency (y-axis).

Fitted lines. In order to bring structure and clarity to the labyrinth of points and dots, dotted and straight lines were drawn between those points that best fit the observed values for each set of experiments. Mick occasionally mentioned that such a fitted drawing could be made easily with any statistical tool free for download from the internet.

"IT technology and the software tools . . . it's a strange thing," Jacob said, and he thanked Mick for his crucial contribution to today's meeting.

"Emily, show us some results and teach us something," he continued.

Emily reminded the team that she had just explained how the different threshold values had been set for the simulation results, and once again she mentioned that this particular approach to experiments could have been done in many other ways, for better or worse, with some minor changes likely in the results. "I believe the results show us something about the accuracy of the threshold values," she said, and she summarized the main contributions as follows:

Experiment threshold 1. In the so-called threshold 1 experiments (represented by one of the dotted lines), threshold values were only set to drill down in the work breakdown structure, and the thresholds on the point of focus were completely ignored. These settings implied that every time a drill-down was made when the thresholds were exceeded, all activities at the low WBS levels were subject to control (similar to the control freak). These sets of experiments tested the importance of a good drill-down threshold 1 and tested the accuracy of the time/cost performance metrics of an earned value management system for project control and their ability to act as sanity checks and warning signals.

Experimental results. Emily explained to her team members that the results clearly showed that the drill-down thresholds were crucial as the project became more and more serial. She concluded that earned value management, the engine behind the drill-down methodology, could not provide reliable warning signals for very parallel projects, but the accuracy of these signals improved along the serial dimension, and even out-performed the other experiments, which she was about to explain.

Experiment threshold 2. Similar to the previous experiments, the so-called threshold 2 experiments (represented by the other dotted line) always invoked a drill-down, regardless of the values for the SPI(t) and CPI measures, but carefully determined how to focus on the activities at the low levels of the work breakdown structure. These experiments completely ignored the use of EVM warning signals and always drilled down to the lowest activity level, but were set up to measure the importance of a good focus and hence the importance of risk management.

Experimental results. Emily told the team that the results for this experiment couldn't have been more beautiful than what she came up with in her own imagination, since they were completely opposite to the first set of experiments. She pointed to the graph and showed her colleagues that setting the right focus threshold on the activities became more and more important for parallel networks, but this relevance decreased as the project became more serial in structure. She reminded the team that these experiments had been done with the three risk metrics discussed earlier: the *criticality index*, the *significance index*, and the *schedule sensitivity index*. While they had concluded in a previous meeting that the last one (SSI) was more complete, as it measured both probability and impact, tests had now also revealed that its use also led to the highest control efficiency, relative to the others. "It might sound like a logical conclusion," Emily said, "but to me it is not that straightforward without experimental evidence."

Experiment thresholds 1 + 2. A third set of experiments tested the usefulness of combining both thresholds in a single integrated system, represented by the thick line on the top of Figure 6-6. This is the approach shown in Figure 6-4 in which both thresholds were carefully set to proper values to optimize both the point of drilling down at the high WBS level as well as the point of focus at the activity level. This experiment tested whether proper values for both thresholds should lead to low values for effort of control and high values for the quality of actions, in order to obtain high values for control efficiency. If that were true, then an integrated project control system, combining both earned value management and schedule risk analysis, would lead to the best results for monitoring and controlling projects.

Experimental results. Emily showed her team that the correct use of both thresholds led to astonishing improvements in control efficiency. The efficiency doubled—and sometimes tripled—compared to the separate approaches, and she expressed her enthusiasm by stating that the most important conclusion of all these simulations lay in the experimental observation that integrating earned value management (threshold 1) with schedule risk analysis (threshold 2) led to a unified project control system that paid off. "Imagine what you could do with the extra free time of less effort, without losing the quality of corrective action," she said.

Jacob was happy to see that his team members all reacted enthusiastically to the approach, and he was confident that their critical look at the results would enable them to put the whole analysis in the right perspective, keeping the relevant aspects to improve future project management, but also removing the superfluous parts and putting them aside for further investigation. This was exactly how he saw his company evolving—from a single-person start-up years ago without a clear mission or direction to a data-driven, innovative learning organization.

"I might be an old-style project manager," he said, "but I never doubted the value of data integration."

"Me neither; I always believed in it," Mark replied.

"But now it's more than just a thought—it's experimental evidence," Emily added.

"Let me summarize the main findings," Jacob concluded. He told the team that Emily had taught them that both thresholds determined the effort of control, but that thanks to Mick's experiments they now knew that the use of proper values for these threshold values was crucial to control efficiency, and therefore to the time people spent controlling projects and the quality of actions they took when project problems had to be solved. He continued to explain that the team now knew that the selection of the right metrics was crucial when using this unified project control system. "I remember that we should never use the traditional SPI for setting threshold 1, but rather its corrected alternative SPI(t) for time control," he said.

"What I've also learned is that there is a preference for using the SSI for setting threshold 2, rather than its CI and SI alternatives," he continued.

He concluded that a proper use of this integrated project control methodology might have a positive effect on the overall success of the project, but it required an accurate interpretation of EVM warning signals, a reliable view of the activity risk metrics to define a well-balanced focus, and a good and sound decision-making platform to define high-quality corrective actions.

"If it doesn't help us much as a company, it won't hurt us either," Emily concluded.

"It will! Time for coffee," Jacob said. "I won't tolerate any resistance this time."

A Bright New Future

After a short coffee break, the team started to discuss some of the performance values on the dashboard (Figure 6-3). They quickly realized that, with values of 93 percent for the project time performance and 88 percent for the cost performance, and a project completion of 56 percent (measured by the current EV at week 30 divided by the BAC), it might be time to take some corrective action.

"Action time, ladies and gentlemen, threshold 1 is clearly exceeded," Jacob said. "Drill down, and you know what to focus on!"

A quick scan of the SSI metric revealed that activities 1, 6, 7, 8, and 10 had significantly higher values than most of the other project activities, and therefore it was reasonable to state that they exceeded threshold 2. So, these activities should be part of the main focus of the search for solutions to bring the project back on track. While the team focused primarily on time control of the project, a similar reasoning could be followed for cost control, and the team, ambitious as never before, already scheduled a quick follow-up meeting to analyze the current project performance in more detail.

"I'm confident you'll make the right decisions," Jacob said.

During an informal talk after the meeting, Jacob told Emily that the data-driven approach certainly was a totally new approach for GlobalConstruct. He warned her that it wouldn't be so easy to convince everyone (as it was with the small core team) that collecting data and using new methodologies would benefit the company. Still, he assured her that the new integrated project management and control approach was undoubtedly a good start and the way to go forward.

Emily told Jacob that she was certainly aware of some difficulties lying ahead, but expressed once again her true belief that a balanced project control approach—mixing experience and gut-feeling with a sound analysis of project data and the use of new methodologies—would lead to a new mindset for GlobalConstruct.

"I'm not looking for drastic changes immediately—I prefer to work in small but manageable steps," she said.

"Don't forget, Emily, data will never replace experience," Jacob said.

"I know. I would call the new system 'a system for making data-informed gut decisions,'" she answered.

"But first come the data, and then the gut decisions," Jacob replied.

Jacob thanked Emily in a way he never had before. While he was usually cautious and prudent with private compliments, he now gave her a big hug before he left the room. Somewhat surprised by the unexpected affection from her boss, Emily had the sudden feeling that this was a sign indicating the end of an era for GlobalConstruct. She didn't know exactly why and how, but she would find out soon. Jacob would soon send her, and all other company employees, a message with a clear explanation.

CHAPTER

7

Exciting Times Ahead

Jacob was extremely satisfied with the way things were going in GlobalConstruct. Although the completion of the tennis stadium construction project was still months away, he was convinced that with the collective strengths of all team members and their choice for open communication, the project would follow the right path to reach a successful end. He was also well aware of the little rumors that were going around the company about his close relationship with Joanna. Although he had never heard a sense of negativity around this gossip, he realized that the pressure to hold a formal communication moment could not be postponed forever. So, he had finally decided to share his hidden—but, to most of the members, known—secret with his closest board members. It was no secret that Joanna, ever since her acceptance as board member, had been a close collaborative friend to Jacob. The company leader had always expressed his respect for her communication skills and her ability to inspire team members to take one step beyond the normal. Although his decision to leave the company might have come as a surprise to some people in the company, the choice of Joanna as the new Chief Executive Officer did not.

Although he had made the decision some months ago, he thought he should wait to finish his CEO task satisfactorily before finalizing a specific milestone. Before he left, he wanted to make sure that he had provided a sound basis for a more data-driven project management approach, founded on the knowledge and expertise of the core team, but eventually spread through the whole company. He was convinced that Emily had done an excellent job in providing

M. Vanhoucke, *The Data-Driven Project Manager*,
https://doi.org/10.1007/978-1-4842-3498-3_7

a solid foundation for the core team, who were all well aware that further dispersion to all company members was now in the hands of every board member.

Today, on his last formal day as Chief Executive Officer, he knew that everything should be well prepared for the important transition to a new CEO. Relaxed and confident of a new visionary future without him, he was ready to bring the news to everyone in the company in a final email as a way of expressing his gratitude for the hard work of all the people working for the company he had founded many years ago. After sending this email, he was ready to close the door of his office on the third floor, to leave his precious company for good. His advisory role to the board would only be called upon in exceptional circumstances, and no one had really defined what those circumstances would be. He knew that day would never come, and was happy with the way he was leaving the company. Finally, he pressed the Send Message button and left his office in a state of happiness and intense joy, ready for a new challenge.

FINAL GOODBYE EMAIL

To: EmployeeList@GlobalConstruct.com

Cc: Joanna.Barnes@GlobalConstruct.com

Subject: Ready for a new challenge

From: Jacob.Mitchell@GlobalConstruct.com

Dear All,

Today is a very humbling day for me.

Now that most of the team meetings have been successfully finished and choices about the future of our company have been made, I would like to take this opportunity to say a few last words to you.

Most of you know by now that I am leaving the company and placing it into the good hands of Joanna Barnes, supported by all of you. I'm confident you will give it a good future! After having been on board as captain of GlobalConstruct for over 30 years, I look forward to finalizing this wonderful experience, and I am now ready to take a new step in my life (you have probably heard that I will now focus on research on animal welfare, a totally different—but also a new exciting and challenging—step).

As CEO, I communicate with my team members mostly about profit margins, strategic decisions, practical arrangements, difficulties with clients, or feedback on reports, but seldom about the really important things in life. That's why I want to say a few words to you before I leave this wonderful ship.

My advice for the future is this: Take all facts, statistics, and data into account, and only after empowering yourself with that knowledge, determine what your gut tells you.

I wish you all a beautiful career, with the necessary ups and downs, with lots of joy, new experiences, and unrealistic challenges. Work hard, learn a lot, mix business with pleasure . . . and don't forget that your job will only be the second most important thing in life (I leave it up to you to choose your number one).

Thinking back on the start of this company several decades ago, and being a music fan in every bone of my body, I must wish you all the best with a quote from my favorite singer, David Bowie, who sadly left us too soon:

"I don't know where I'm going from here, but I promise it won't be boring."

I wish you an uncertain but nevertheless non-boring future!

Take care!

Warm regards,

Jacob (former CEO)

P.S. The reason uncertainty about the future is so much better than a safe and deterministic life path is discussed in one of my favorite books, entitled *Fooled by Randomness* by Nassim Nicholas Taleb. I highly recommend this book! Take it as good advice from someone who has been in charge of managing multiple projects under uncertainty. Some of them were pretty successful (yes, I'm proud of what I've done), while others were a complete mess. But non-boring they were! All of them :-)!

CHAPTER

8

Afterword

In the course of writing this book, I have relied on an almost endless list of research papers written by friends and colleagues all over the world that clearly have defined the structure and content of this book. Also, the recommendations and advice of several project management professionals with a heart and a passion for data-driven project management have been an inspiration. In the 20 years of my passionate research career, I have tried to pick up much of their advice so it would inspire my own research, which always brought me, after some occasional trips to related fields, to the field of data-driven project management. Nowadays, my research is focused on three subdomains: project scheduling, risk analysis, and project control. While I initially investigated these domains in isolation from each other, after some years, my research had become—in my opinion—mature enough to be combined. From that moment on, I referred to this integrated approach as *dynamic scheduling* or as *integrated project management and control*, which eventually became the topic of the current book.

In the next paragraphs, I will give a summary of the research studies carried out by my *operations research and scheduling* (OR&S)[1] group that have been relevant to writing this book. Initially, this OR&S group focused solely on the development of algorithms for various classes of *project scheduling* problems, with a clear preference for the well-known *resource-constrained project scheduling problem*. This challenging problem has been investigated widely, and I believe that the OR&S group has made a significant contribution to this field by presenting exact and (meta)heuristic solution strategies for the problem

[1]The university website of the OR&S group can be found at www.projectmanagement.ugent.be.

M. Vanhoucke, *The Data-Driven Project Manager*,
https://doi.org/10.1007/978-1-4842-3498-3_8

that aim at minimizing the project's duration, maximizing the net present value, and augmenting the problem with setup times, multiple execution modes, learning effects, fast tracking, and much more. However, it took the OR&S group several years and a lot of effort to extend the unilateral focus on scheduling to *schedule risk analysis* and *project control*. Ever since the publication of the research study *Measuring Time—Improving Project Performance using Earned Value Management* (Vanhoucke, 2010a) and the much appreciated research award by the International Project Management Association (IPMA), the OR&S group has focused on investigating the relationship between these three challenging research domains. A challenge it was, and I believe it will be a challenge in the future to further extend this integrated research domain.

In the next paragraphs, the use of references will be restricted to the research studies of the OR&S group, and only when no results in our OR&S group are available will I mention other references from literature. Needless to say, all of our research work cited in the next paragraphs is based on the excellent work of other researchers. I have chosen not to mention the enormous list of references to papers and books that I have used as a background or source of inspiration for my own research for two reasons. The first, and most obvious, reason is that the list of references would simply be too long, and the risk that I should forget an important reference is not worth taking. A second, and what I believe to be a very pragmatic, reason is that most, if not all, of the references can be found in my own work (books, papers, websites) that I have mentioned here. However, by not mentioning other sources from literature, I by no means wish to give the impression that these external references and their authors are less important. On the contrary—these authors have been crucial in formulating my own research ideas and hypotheses, and they have played an essential role in my reviewing and updating my own work. They have been my main inspiration and the driver for gradually defining my own research track—and without them, there would be no me.

Where relevant and possible, I will make a distinction between several sources of references. First and foremost, the *academic research* studies contain results that have been published in international peer-reviewed academic journals. The importance of the peer-review process cannot be underestimated. It is an essential and critical part of the functioning of the scientific community, of quality control, and of the self-corrective nature of science. I therefore consider the references to the peer-reviewed articles as the most important and interesting ones for readers who want to explore the domain. Second, I will often refer to overview articles or summary studies. Rather than presenting new ideas, research summaries aim at collecting various ideas in an integrated way, and references to *summary books* or *overview articles* of the OR&S have been given. Third, where appropriate, I will mention the availability of databases with real or artificial *project data*. They have been crucial to my research from the very beginning. Finally, as previously mentioned, when no research paper is available at the OR&S research group, or when a reference can simply not be ignored for whatever reason, I will add this external reference for the relevant chapter.

Chapter 2: PLAN

The literature on the PERT/CPM methodology used in this chapter is rich and diverse and spread over numerous papers, internet sites, videos, blogs, and handbooks. Not surprisingly, since PERT/CPM constitutes the heart of any project management methodology, it has been the foundation of all academic research on integrated project management and control. The OR&S research group has added little to nothing to the excellent work done in this domain, and it would be useless to mention all the existing references to that field. In my student book entitled *Project Management with Dynamic Scheduling: Baseline Scheduling, Risk Analysis and Project Control* (Vanhoucke, 2012b), I have spent a chapter on PERT (Program Evaluation and Review Technique) and one on CPM (Critical Path Method), with some references to the most important sources in the literature.

Chapter 3: RISK

Schedule risk analysis has been investigated widely in the academic literature, and it has become one of the foundations of my own research. Although a lot of references are undoubtedly interesting for further exploration (but won't be mentioned here), it would be unfair not to mention the work of Williams (1992, 1995) and Hulett (1996), on which my own research, and hence this chapter, has heavily relied.

The central idea of this *schedule risk analysis* chapter has been published in the research article entitled "Using Activity Sensitivity and Network Topology Information to Monitor Project Time Performance" (Vanhoucke, 2010b). This article is an extended version of a chapter of the previously mentioned book *Measuring Time—Improving Project Performance using Earned Value Management* (Vanhoucke, 2010a) and simulates more than 4,000 artificial projects generated under a controlled design to test the usefulness of activity risk metrics to dynamically improve time performance during project progress.

In Chapter 3 of this book, three risk metrics have been mentioned—the *criticality index*, the *significance index*, and the *schedule sensitivity index*—but no detailed information about their exact formula has been given. Of course, if one wants to implement these metrics in a software tool or a simple spreadsheet, the correct formulas should be known and available. The detailed formulas of these risk metrics, and some illustrative calculations on three project examples, can be found in the book *Integrated Project Management and Control: First Comes the Theory, then the Practice* (Vanhoucke, 2014). In addition, an overview of the use of the schedule risk analysis methodology has been published in an article entitled "On the Use of Schedule Risk Analysis for Project Management" (Vanhoucke, 2015).

Chapter 4: BUFFER

Although I mentioned in the introduction of this afterword that the main focus of the OR&S group initially lay on project scheduling with limited resources, no detailed work has been carried out at our research group on the use of the buffering methodology originally proposed in the book *Critical Chain* by Eli Goldratt (1997). His work, together with the follow-up work of authors who extended, praised, and criticized the methodology, has been the main foundation of this chapter. In the previously mentioned book *Project Management with Dynamic Scheduling: Baseline Scheduling, Risk Analysis and Project Control* (Vanhoucke, 2012b), I have written an overview chapter on the main steps of this so-called *critical chain/buffer management* methodology.

In Chapter 4 of this book, the activity-duration reduction from normal to aggressive time estimates has been illustrated using a 50 percent cut of the normal duration. This is probably not realistic, and any other value could have been arbitrarily chosen without losing the general overview and idea of the chapter. Moreover, the sizing of each buffer has been done based on a 50 percent length of the chain that feeds the buffer. Again, this is just an arbitrary number without any sound motivation. In the text, it is stated that other, more clever and realistic sizing techniques could have been used, but no details have been given since it would lead us too far from the discussion at hand without adding a lot of new insights. In the literature, however, various alternative sizing methods have been discussed, and in the technical book *Project Management Knowledge Sourcebook: The Technical Guide to Project Scheduling, Risk and Control* (Vanhoucke, 2016b) I have discussed some of the most commonly used buffering techniques that have been described in the literature.

Chapter 5: MONITOR

The *earned value management* (EVM) methodology is a well-known monitoring and control technique that has been described in the literature by various sources. It goes without saying that a reference to the book *Earned Value Project Management* (Fleming and Koppelman, 2010) is appropriate here.

The previously mentioned book *Measuring Time—Improving Project Performance using Earned Value Management* (Vanhoucke, 2010a) has been an important foundation for Chapter 5 of this book, but it has also been the start of my exciting and inspiring research quest for improvements to the EVM methodology. Two research papers in particular have been my main inspiration for this chapter. The first paper, entitled "A Comparison of Different Project Duration Forecasting Methods using Earned Value Metrics" (Vandevoorde and Vanhoucke, 2006), gives a basic overview of three different duration forecasting methods using EVM. In a second paper, "A Simulation and Evaluation of Earned Value Metrics to Forecast the Project Duration" (Vanhoucke and Vandevoorde, 2007), a simulation study has been carried out to test and compare the performance of these EVM predictors on a wide and diverse set of artificial projects.

Ever since the publication of these two previously mentioned papers, much work has been done at the OR&S group beyond the work presented in Chapter 5. Extensions to *statistical project control* and *artificial intelligence* methods using EVM have been published in various journals. Moreover, validation of these and other extensions on *empirical project data* have also been made available in various published papers. Although these extended research studies have undoubtedly influenced the content of the book, they have not been explicitly used in any chapter, and so I won't mention them here. I refer the interested reader to the free book *Do Research, Create Knowledge, Feed your Talent: A Summary of Research at Operations Research & Scheduling* (Vanhoucke, 2016a), which gives an overview of all research endeavors of the OR&S group (available for free on the bookstore of `www.or-as.be`).

Chapter 6: CONTROL

The use of two thresholds, one on the EVM performance metrics (threshold 1 in the text) and another on the activity sensitivity metrics (threshold 2 in the text), has been the topic of various studies at the OR&S group. Probably the research study most relevant for Chapter 6 of this book is the control efficiency study entitled "On the Dynamic Use of Project Performance and Schedule Risk Information during Project Tracking" (Vanhoucke, 2011). In this paper, two alternative control methods, known as *bottom-up project control* and *top-down project control*, have been proposed and compared to test their ability to take good corrective actions. In the current book, I have not used the same terminology as in the paper to avoid introducing new concepts into the various chapters and to maximize the consistency among chapters. Nevertheless, despite the differences in the terminology, the meaning and results are exactly the same. In the book, I referred to *threshold 1. using SPI(t) values* which is identical to the *top-down project control* approach of the paper, and *bottom-up project control* is now called *threshold 2. using SSI values*. The top-down project control approach relies on the earned value management performance metrics of Chapter 6, while the bottom-up control mechanism makes use of the schedule risk analysis method of Chapter 3. In the previously mentioned paper, it is shown by a computational experiment that a top-down approach is highly efficient for project networks with a serial activity structure while a bottom-up approach performs better in a parallel structured project network. This is exactly the same as what is shown in Figure 6-6 of this book.

The concept of control efficiency introduced in the previously mentioned paper has been validated on a small sample of Belgian projects in the paper "Measuring the Efficiency of Project Control using Fictitious and Empirical Project Data" (Vanhoucke, 2012a). As a matter of fact, Figure 6-6 of this book has been copied from this empirical validation paper, with only one very important difference. In the original paper, the EVM and SRA lines were switched, leading to an error in the original figure (for the readers of the paper, this is "Figure 7. Efficiency of project control"). The description in the original text of the paper is flawless, and only the way the lines are displayed in the graph is wrong. For the sake of clarity, the error was mine, and the publisher is not to blame. Regardless of the minor error, the results are still "SRA works better for parallel networks, EVM works better for serial networks," just as I describe in Chapter 6 of this book (this time with the corrected Figure 6-6).

The attentive reader has probably noted that, in my description so far about references to relevant papers, I occasionally refer to the use of both artificial (generated, not real) and empirical (collected, real) project data. Therefore, this calls for a few words on the use of project data. *Artificial project data* have been overwhelmingly used in academic research, generated under a design to control the network structure and resource requirements. Most of the project data used in the research papers mentioned in this chapter have been generated by a network generator published in the article "An Evaluation of the Adequacy of Project Network Generators with Systematically Sampled Networks" (Vanhoucke et al., 2008). In addition to a process for generating artificial project data, this paper also presents metrics to classify project networks. The classification of projects along the parallel/serial dimension shown in Figure 6-6 is based on the so-called Serial/Parallel (SP) indicator proposed in this paper. Its formula is equal to the longest path of the network minus one (not the longest path as in the critical path (including activity durations), but the longest path as in the number of activities) divided by the total number of activities minus one. For the project network of this book, this equals $\frac{8-1}{16-1}=0.47$, as mentioned in Chapter 6. Thus, the tennis stadium construction project example holds the middle between a completely parallel and a completely serial project. It is worth noting that the OR&S group has not been the only one active in generating project data, and consequently there is a wide variety of (mainly) artificial project data available in the literature. An overview of the most important databases and their parameters used during the generation process is summarized in the paper entitled "An Overview of Project Data for Integrated Project Management and Control" (Vanhoucke et al., 2016). Most of the project data is freely available from the previously mentioned OR&S website, and a recent small overview movie was recorded during my stay in Lisbon in 2016, which can be viewed at `https://youtu.be/QwyBs_TJMYo`.

Despite the widely available use of artificial project data, the use of *empirical project data* in research was often restricted to occasional case studies and small samples of real project data, until the OR&S group decided to collect project data under a strict format to make it publicly available. While the advantage of real project data is undoubtedly their close connection to the real world, the project data often lack a good structure and are therefore not always suitable for testing research hypotheses. Therefore, the OR&S research group has proposed a strict project data collection, structuring, and classification method for empirical project data, which is recorded in a paper entitled "Construction and Evaluation Framework for a Real-life Project Database" (Batselier and Vanhoucke, 2015). These empirical project data have been used to test the power of the well-known reference class forecasting methodology in the paper "Practical Application and Empirical Evaluation of Reference Class Forecasting for Project Management" (Batselier and Vanhoucke, 2016) published in the *Project Management Journal*. At the time of writing this book (the summer of 2016), I gave the keynote presentation *Academics like what they do and professionals know what they want* at the *Creative Construction Conference* in Budapest (Hungary), in which I demonstrated that the use of empirical project data for research purposes is not as easy as most practitioners think. This presentation was partly based on the study *Empirical Perspective on Activity Durations for Project Management Simulation Studies* (Colin and Vanhoucke, 2015), which is heavily based on the excellent methodology and calibration method proposed by Trietsch and colleagues (2012). I believe that such a study shows that bridging the gap between theory and practice is more than simply connecting real project data with academic methodologies, but instead requires a sound and statistical calibration method to link the features of the empirical world with the requirements of academic research.

Some of the project dashboards used in Chapter 6 of this book are screenshots from a project management software tool that I use in my classroom. This tool—called ProXL (an abbreviation for PROject management in eXceL)—is not a commercial tool and therefore cannot do what most other tools can. However, it is a simple spreadsheet-based software tool that focuses on planning projects, analyzing their schedule risk, and monitoring and controlling their progress using earned value management. Readers who wish to download the data used in this book and see exactly how all the calculations explained in the various chapters work should visit www.or-as.be/books/ddpm.

Finally, readers who are interested in the challenging domain of project control can find lots of interesting references in the project control summary paper entitled "Classification of Articles and Journals on Project Control and Earned Value Management" (Willems and Vanhoucke, 2015). Although I hope this article will be relevant for researchers eager to learn about the research endeavors conducted in the past, by the time they read it, it will probably be outdated. We live in a vigorous and dynamic world, and even the current state of academic research changes rapidly these days! Nevertheless, I believe the summary article can be a good starting point for exploring this wonderful research domain.

Before I Leave…

The project used in this book is a tennis stadium construction project. Although I have to admit that I have no specific expertise in tennis stadiums, I have an endless passion in the general theme of the book, referred to as *data-driven project management* or *integrated project management and control*. Data-driven project management has been my work and my passion since the start of my career, and I will continue investing time in this topic for the years to come. I truly hope that this new book *The Data-Driven Project Manager: The Statistical Battle Against Project Obstacles* will also be a trigger for developing a passion for learning in you—not only at the university, business school, or company, but throughout your entire life.

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