Measuring Operations Performance

Louis Brennan
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International Manufacturing Strategy in a Time of Great Flux

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Contents

Trends in Manufacturing Strategies: A Longitudinal Investigation of the International Manufacturing Strategy Survey

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Abstract How have the competitive priorities of European manufacturers changed over the last 20 years? We investigate this question by conducting a longitudinal analysis of the International Manufacturing Strategy Survey database, holding datasets from 1992, 1996, 2000, 2005, 2009 and 2013. We highlight five trends in the data. First, *quality* and *dependability* remain the highest competitive priorities. Second, *cost* appears to be the most fluctuating competitive priority, and companies seem more concerned with costs during times of economic decline. Third, in general, *service* seems to be on a decline, but an increase in delivery *speed* offsets this tendency. Fourth, *flexibility* and *innovation* is gaining relative importance. Fifth, *sustainability* is among the least important competitive priorities and discontinues its growth trend in relative importance. We also comment on the long-standing debate between the trade-off model and cumulative models of competitive capabilities.

Keywords Manufacturing strategy · Competitive priorities · IMSS

1 Introduction

Manufacturing firms need to decide how they want to compete in the market. Should the firm offer the highest quality products, the lowest cost, the fastest deliveries, the highest degree of customisation, the best after-sales service, the most innovative products, the most environmental-friendly solutions, the best social

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responsibility, or any combination of these? Being among the most important facets of manufacturing strategy, *competitive priorities* like these have been much debated in the operations management literature. Competitive priorities are the strategic preferences firms target to gain competitive advantage (Hayes and Wheelwright 1984; Leong et al. 1990). A limitation of the existing research is that the bulk of it focuses only on the four original competitive capabilities, namely cost, quality, delivery and flexibility. In the last 20 years, however, capabilities like customisation, service, innovation, environmental performance and social responsibility have gained importance. Therefore, our main research question asks if and how the competitive priorities of European manufacturing firms have changed over the last decades. To the best of our knowledge, there has been little or no research on such trends.

Investigating trends in the competitive priorities can also inform the long-standing debate between the trade-off and cumulative models of competitive capabilities; do companies see trade-offs between capabilities or do they believe that all be achieved cumulatively? The empirical evidences in the literature remain mixed. Although our data do not allow confirmation or falsification of either of the models, our second research question investigates which of the two models practitioners seem to prefer. The managers' rating of relative importance of competitive priorities can provide indication whether they *aim* to follow the trade-off model or cumulative capabilities model.

We analyse the changes of competitive capabilities using the European data from the six available datasets of the International Manufacturing Strategy Survey (IMSS). The IMSS is an international survey with research partners in more than 20 countries targeting manufacturing companies mainly in the machining, electronics, and automotive industries (Lindberg et al. 1998). Over the last decades, the IMSS has had a significant contribution to our understanding of manufacturing strategy and how it is practiced (e.g. Cagliano and Spina 2000; Gimenez et al. 2012; Laugen et al. 2005; Acur et al. 2003). After six rounds of data selection, the IMSS dataset is now a unique source for longitudinal research on operations strategy. It contains relative comparable data from more than 20 years, holding datasets from 1992, 1996, 2000, 2005, 2009 and 2013.

2 Literature Review

A manufacturing strategy can be defined as "a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate to meet a set of manufacturing objectives which are consistent with overall business objectives" (Platts et al. 1998, p. 517). This definition highlights the central notion of competitive *priorities* and competitive *capabilities*. Competitive priorities are the objectives of how firms want to compete, whereas competitive capabilities is the realised operative skills (Rosenzweig and Easton 2010). Our research focuses on competitive priorities.

Competitive priorities have been much discussed in the literature (Ward et al. 1998). The word "priorities" is used because it is not practically possible to devote the same amount of attention and resources to all factors of performance. Instead, mangers must allocate scarce resources to develop a set of prioritised competitive capabilities (Hayes and Wheelwright 1984). A higher priority is given to those competitive capabilities that a firm believes it needs to develop in order to win orders in the market.

The four classical competitive priorities are arguably "low cost", "good quality", "short delivery times" and "high flexibility" (Ward et al. 1998; Boyer and Lewis 2002; Hallgren 2007). However, this original list has been expanded. To separate quick deliveries from accurate deliveries, authors have suggested including "dependability" as a distinctive competitive priority (Ferdows and De Meyer 1990; Noble 1995; Miller and Roth 1994; Hayes and Wheelwright 1984). Following an increased focus on "servitization" of manufacturing (Baines et al. 2009; Schmenner 2009; Vandermerwe 1988; Neely 2008), "service" has been added as a competitive priority (Miller and Roth 1994; Noble 1995; Kim and Arnold 1993). Moreover, "innovation" has been suggested (Miltenburg 1995; Noble 1995; Leong et al. 1990). Over the last 20 years, two new competitive priorities have gained much attention: "sustainability" and "responsibility", which we introduce in more detail in the two next paragraphs.

Jiménez and Lorente (2001) argue for the need to include environmental performance, or *sustainability*, as a competitive priority. The Brundtland Report, *Our Common Future* (WCED 1987), put sustainability on the agenda. It defined sustainable development as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, p. 43). Since then, there has been an evidential growth of environmental programs and certifications in practice, and a growing body of literature on sustainability in operations management (Corbett and Klassen 2006). The five climate reports published in 1990, 1995, 2001, 2007 and 2013 by United Nations' Intergovernmental Panel on Climate Change (IPCC) continue to call for action on environmental issues. Today, sustainability (or "green") is an important competitive priority.

Another competitive priority, Corporate Social Responsibility (CSR), was established as a definite strategic issue in the 2000s (Moura-Leite and Padgett 2011; Porter and Kramer 2006; Gimenez et al. 2012). In a report by The World Bank (Moura-Leite and Padgett 2011, p. 17), 61 % of multinational companies reported that "CSR issues are at least as influential as more traditional factors (for example, cost, quality, delivery)". Porter and Kramer (2006) found that 64 % of the largest multinational companies published CSR reports in 2005, and concluded that "CSR has emerged as an inescapable priority for business leaders in every country" (p. 78).

To summarise, Table 1 lists the usually referred competitive priorities in the literature.

Table 1 Different competitive priorities across representative studies and IMSS VI

Competitive priority	Authors										
	Ward et al. (1998)	Boyer and Lewis (2002)	Hallgren (2007)	Hayes and Wheelwright (1984)	Ferdows and De Meyer (1990)	Kim and Arnold (1993)	Miller and Roth (1994)	Miltenburg (1995)	Noble (1995)	Leong et al. (1990)	Jiménez and Lorente (2001)	*IMSS (2013)*
Cost	X	X	X	X	X	X	X	X	X	X	X	*X*
Quality	X	X	X	X	X	X	X	X	X	X	X	*X*
Speed/delivery	X	X	X	X	X	X	X	X	X	X	X	*X*
Flexibility	X	X	X			X	X	X	X	X		*X*
Dependability				X	X		X	X	X			*X*
Service						X	X				X	*X*
Innovation								X	X	X		*X*
Sustainability											X	*X*
Responsibility												*X*

2.1 The Trade-off Versus Cumulative Capabilities Models

A central discussion in the literature on competitive capabilities has been whether companies must compromise between them or if they can be developed in a cumulative pattern. For example, the trade-off model suggests that superior quality or delivery performances are incompatible with achieving low cost (Skinner 1969). Testing this assumption, Boyer and Lewis (2002) concluded that managers still see trade-offs as important. However, in a meta-review of the literature on competitive priorities, Rosenzweig and Easton (2010) found low support in the empirical literature for a trade-off model. One critique is that intensifying competition has left it impossible to ignore any of the competitive capabilities. In addition, the trade-off model has been criticised for being reactive to constantly shifting market environments.

Nakane (1986) was the first to suggest that the trade-off model is misleading. With evidence from Japanese plants, he argued that competitive capabilities could be built cumulatively and together. For example, Toyota's proven capability to produce cars "of the highest quality, on the shortest time, and for the lowest cost" (Krafcik 1988) made authors question the validity of the trade-off model. Ferdows and De Meyer (1990) proposed the "sandcone model" that explains how manufacturers can build lasting improvements by focusing sequentially on quality first, then dependability, then flexibility, and finally cost reduction. The analogy to a sandcone illustrates that, as the firm climbs the stages of higher-level capabilities, it also has to pour sand at the base (for example, keep investing more in quality to achieve higher levels of delivery performance). Noble (1995) discussed the cumulative model as "a pyramid of competitive capabilities" growing from quality at the base, then dependability, delivery, cost, flexibility and to innovation at the top. If the cumulative capabilities model is adopted directly in industry, we would expect managers to—consistently over time—rate quality as a top competitive priority, with the other priorities in a decreasing order.

Also the cumulative capability model has been subject to testing (Bortolotti et al. 2015; Ferdows and Thurnheer 2011; Hallgren et al. 2011; Corbett and Whybark 2001; Rosenzweig and Easton 2010; Rosenzweig and Roth 2004; Peng et al. 2011; Noble 1995; Vastag and Whybark 2003). In their original paper, Ferdows and De Meyer (1990) found support for quality as the basic capability, but did not provide evidence for the sequence of the others. Rosenzweig and Roth (2004) replicated the original sandcone study and found evidence for both a cumulative and sequential pattern taking place. Noble (1995) found some evidence of the cumulative model, but with geographic differences. Evidence from IMSS (2013) showed that firms rather seem to build multiple capabilities simultaneously and dynamically. Similarly, in a survey of 211 plants, Hallgren et al. (2011) found a hybrid model to fit better than a cumulative model. Only, quality was found to be a leading indicator of higher levels of delivery performance, whereas flexibility and cost efficiency are built in parallel. Thus, while being celebrated for being prescriptive and proactive, the cumulative model lacks broad empirical evidence (at least beyond quality as a basis for the other priorities). In summary, the debate between the trade-off model and cumulative models remain with mixed evidence.

3 Methodology

We analyse how the competitive priorities for European manufacturers have changed over the last 20 years by performing a longitudinal analysis of the IMSS database. IMSS includes datasets from 1992, 1996, 2000, 2005, 2009 and 2013. We focus exclusively on the part of the surveys that deal with competitive priorities.

3.1 About the IMSS

The IMSS network was established with its first data gathering in 1992 (“IMSS I”). The original idea was to investigate the connection from strategy via investments and operations, to performance in manufacturing industries. Figure 1 shows the focus areas in IMSS (Cagliano 1998). Competitive capabilities (or priorities) have been central in all data collections.

One key objective of IMSS was to follow the developments in industry and see how dissemination of ideas and industrial competitiveness developed over time. Hence, the subsequent IMSS data gathering in 1996, 2000, 2005, 2009 and 2013 (we also refer to these as IMSS II, III, IV, V and VI, respectively). These next questionnaires both tried to keep as many questions as possible to enable longitudinal trend analyses and to capture new trends. These new trends or ideas can be seen both from the arrival of new topics in the questionnaire and from the data gathered. A brief overview shows a transitional change from emphasis on technology, via lean and human factors (Sun and Frick 1999), to more strategy-, supply chain- and global oriented issues in the later questionnaires (IMSS 2013). It is likely that these changes in the questionnaire reflect a change in focus also in the

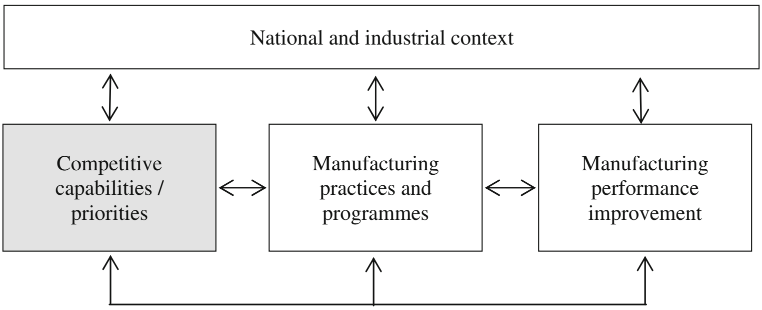

Fig. 1 IMSS focus areas (Cagliano 1998)

Table 2 Descriptive statistics IMSS I–VI

Survey	Year	ISIC[a]	World data		European data	
			# Countries	N	# Countries (ISO 3166 alpha-2)	n
IMSS I	1992	381–385	20	600	12 (AT, BE, DE, DK, ES, FI, GB, IT, NL, NO, PT, SE)	343
IMSS II	1996	381–385	26	703	11 (DE, DK, ES, FI, FR, GB, HU, IT, NL, NO, SE)	306
IMSS III	2000	381–385	23	558	12 (BE, DE, DK, ES, GB, IE, IT, HR, HU, NL, NO, SE)	425
IMSS IV	2005	28–35 (Rev 3.1)	23	709	15 (BE, DE, DK, EE, GB, GR, HU, IE, IL, IT, NL, NO, PT, SE, TR)	478
IMSS V	2009	28–35 (Rev 3.1)	21	750	14 (BE, CH, DE, DK, EE, ES, GB, HU, IE, IT, NL, PT, RO)	445
IMSS VI	2013	25–30 (Rev 4.0)	19	843	14 (BE, CH, DE, DK, ES, FI, HU, IT, NL, NO, PT, RO, SE, SI)	500

[a]ISIC codes are regularly revised. All IMSS versions target similar manufacturing industries: e.g., fabricated metal products; computers, electronic and optical products; electrical equipment; machinery and equipment; motor vehicles and other transport equipment

manufacturing industries (because the involved researchers have strived to include trends and practices in industry). Table 2 gives the descriptive statistics for the world- and European data collected in IMSS I through VI. Note that this research uses the European data only (N = 2497).

3.2 Measures

Table 3 gives the constructs for the competitive priorities that we use in this study. Generally, the items for competitive capabilities are largely similar and comparable across the six versions, with three exceptions that we need to take care of in our research design. First, the different versions of the IMSS surveys contain different number of competitive priorities, ranging from six in IMSS I to fifteen in IMSS VI. Second, there are slight differences in the items used for cost, quality, service and responsibility (see notes in Table 3). Third, IMSS I through IV ask the respondent to judge the *current* degree of importance of the item, whereas IMSS V and VI ask the degree of importance *over the last 3 years*. All versions ask the respondent to answer the question on a Likert scale from “1—not important” to “5—very important”.

Table 4 gives the average actual scores (1–5) and standard deviations of the competitive priorities in each version of IMSS.

To get comparable data across the six versions we normalise the data using z-scores and compare their change in relative importance. The standard z-score is the number of standard deviations an observation is above the mean for its

Table 3 Constructs for competitive priorities across IMSS I–VI

Priorities	Item	I	II[a]	III[a]	IV	V	VI[f]
Cost	Lower selling prices	X[b]	X	X	X	X	X
Quality	Better product design and quality	X	X[c]	X	X	X	X
	Better conformance to customer specifications			X	X	X	X
Dependability	More reliable/dependable deliveries	X	X	X	X	X	X
Speed	Faster deliveries	X	X	X	X	X	X
Service	Superior customer service (after-sales and/or technical support)	X	X	X	X	X	X[d]
Flexibility	Greater order size flexibility		X	X	X	X	X
	Wider product range	X	X	X	X	X	X
Innovation	Offer new products more frequently		X	X	X	X	X
	Offer products that are more innovative				X	X	X
Sustainability	More environmentally sound products and processes			X	X	X	X
Responsibility	Committed social responsibility					X	X[e]

IMSS I, II, III, IV: "Consider the current degree of importance of the following goals to (win orders from) your major customers"
IMSS V, VI: "Consider the importance—in the last 3 years—of the following attributes to win orders from your major customers"
IMSS II–IV had a separate question on *change* of each parameter's importance over the last 3 years that we do no use
Scale IMSS I, II, III, IV, V, VI: 1 not important–5 very important
Notes on variations to items
[a]Includes a separate item for "Other (please write in)" (IMSS II, III)
[b]Cost = "Lower manufacturing cost" (IMSS I)
[c]IMSS II also includes an additional question for "Manufacturing quality" which we do not include
[d]Two questions for Service: "After-sales and/or technical support" and "Training, information, helpdesk" (IMSS VI). We use only the first one
[e]Social responsibility = "Higher contribution to the development and welfare of the society" (IMSS VI)
[f]IMSS VI also includes an additional question for Safety (More safe and health respectful processes) which we do not include. IMSS VI also includes an additional question on Flexibility (Offer more product customisation) which we do not include

population (a population is here drawn from all rated items in one version of the IMSS survey, see Table 3). Focusing on the developments in absolute numbers would be erroneous because respondents to the survey in reality rate the relative importance of the competitive priorities and do not know the numbers from previous years. Normalising the data also reduces the possible misleading effect of the increasing number of items to be evaluated, because we then focus on the relative

Table 4 Actual scores for competitive priorities (averages and standard deviations) IMSS I–VI

IMSS version	IMSS I		IMSS II		IMSS III		IMSS IV		IMSS V		IMSS VI	
Priorities	Mean	σ_X	Mean	σ_X	Mean	σ_X	Mean	σ_X	Mean	σ_X	Mean	σ_X
Cost	4.25	0.89	3.65	1.05	3.70	1.07	3.97	0.95	3.81	1.07	3.76	1.10
Quality	4.52	0.73	4.22	0.83	4.15	0.89	4.18	0.78	4.12	0.88	4.19	0.83
Dependability	4.21	0.90	4.13	0.82	4.07	0.89	4.18	0.79	3.94	0.96	4.11	0.83
Speed	4.11	0.94	3.97	0.90	3.97	0.89	3.89	0.88	3.68	1.08	3.92	0.93
Service	4.40	0.85	3.91	0.89	3.84	1.03	3.79	0.96	3.66	1.12	3.55	1.08
Flexibility	3.31	0.95	3.33	1.15	3.35	1.14	3.39	1.04	3.15	1.17	3.38	1.06
Innovation	–	–	3.24	1.10	3.23	1.15	3.36	1.12	3.12	1.17	3.33	1.09
Sustainability	–	–	–	–	2.90	1.15	3.18	1.09	3.00	1.20	3.08	1.06
Responsibility	–	–	–	–	–	–	–	–	2.68	1.22	2.77	1.05
Total	4.13	1.00	3.72	1.06	3.68	1.11	3.72	1.04	3.47	1.19	3.59	1.10

importance of the competitive priority in each sample and not their absolute values. Finally, normalising the data reduces the concern that some of the surveys asked for the current importance of the priority (as in IMSS I–IV) and other surveys asked for the importance over the last 3 years (as in IMMS V–VI).

4 Findings and Discussion

Figure 2 shows the development of the relative importance of the select competitive priorities from IMSS I through IMSS VI.

The patterns reveal interesting discussion points. We discuss five trends:

- Trend 1: Quality and dependability remain the highest competitive priorities.
- Trend 2: Cost is the most fluctuating competitive priority.
- Trend 3: Service is on a decline, but offset by speed.
- Trend 4: Flexibility and innovation is gaining importance.
- Trend 5: Sustainability is not continuing its growth in relative importance.

4.1 *Trend 1: Quality and Dependability Remain the Highest Competitive Priorities*

Quality is reported to be the highest ranked priority across all studies from IMSS I through VI. Aligned to the idea of the sandcone model (Ferdows and De Meyer 1990), quality is followed by dependability (i.e., accurate deliveries to customers).

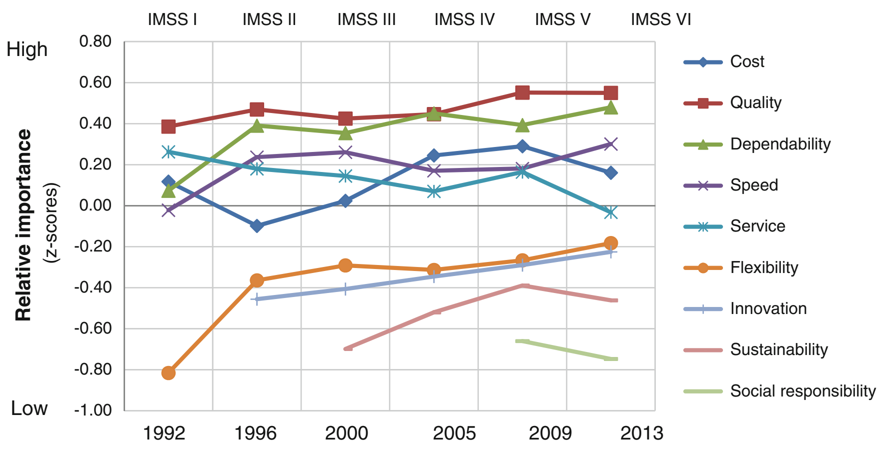

Fig. 2 Change in relative importance for competitive capabilities IMSS I–VI (z-scores)

Quality and dependability are also the two priorities with the highest actual scores and lowest standard variations across the datasets (c.f. Table 4). Hence, the IMSS data confirms, "quality comes first" in industry (Crosby 1979; Ferdows and De Meyer 1990; Hallgren et al. 2011). It is also interesting to see that quality and dependability has strengthened their positions as the highest competitive priorities over the last two decades. Adding trend lines to our data (not shown), it is clear that the focus on these two competitive capabilities is predicted to continue in the future.

4.2 *Trend 2: Cost Is the Most Fluctuating Capability*

Cost is the competitive capability with most relative fluctuation. Because this fluctuation can be related to general economic developments, we compare the changes in relative importance of cost with changes in gross domestic product (GDP) in the Eurozone since 1990 (Fig. 3). We find that the relative focus on cost is highest after periods where GDP has fallen substantially for more than 2 years in a row (1992, 2005 and 2009). Although we cannot test the relationship statistically, these opposite fluctuating patterns may be expected: cost tends to become a more important factor in times of low economic growth.

In Fig. 2, we can also see that the relative focus on speed and dependability declines as the focus on cost increases (and vice versa). Looking at the actual scores around the financial crisis 2008–2009 (Table 4), we also see that cost got its second all-time highest score (3.81) whereas speed and dependability got their all-time lowest score (3.68 and 3.94, respectively). Table 4 also shows that the average actual score for all priorities are all-time low for IMSS V in 2009 (3.47) compared to IMSS I–IV and VI. This is an indication of companies making trade-offs between

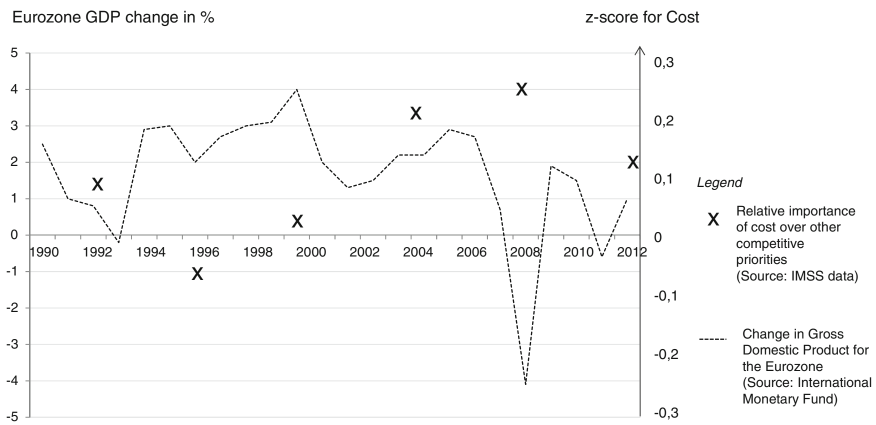

Fig. 3 Changes in GDP for the Eurozone versus importance of cost as a competitive priority

competitive priorities. Like Skinner (1969) suggested, and Boyer and Lewis (2002) confirmed, companies allocate scarce resources towards a certain set of priorities. Based on the IMSS data, we propose that the trade-off model is more apparent in times of economic decline, whereas the cumulative model is more used in stable and growing environments.

4.3 Trend 3: Service Is on a Decline, but Offset by Speed

The data shows that the relative importance of service seems to be on an ongoing negative development (Fig. 2). In addition, the actual scores of service have been on a decline through all versions of IMSS (Table 4). However, we can also see that the decline in service as a competitive priority is somewhat offset by increases in speed. One can argue that faster deliveries is one way to deliver superior service to customers.

Considering the research that emphasise service as a new frontier for competitive advantage in manufacturing industries (Miller and Roth 1994; Schmenner 2009), the slight decline of service as a competitive priority may be surprising. A reason for the declining interest of service may be due to sampling bias of companies in IMSS, which targets classical machining and assembly industries. As "servitization" has become more important for these industries over the last 20 years (Neely 2008), they may have established own service organisations. In other words, the service function may have moved gradually out of the manufacturing unit (that answers the IMSS questionnaire).

4.4 Trend 4: Flexibility and Innovation Is Gaining Importance

A fourth trend in the data is that the relative importance of flexibility and innovation is increasing, but slowly. There are perhaps several reasonable explanations for this trend. First, considering the cumulative model of competitive priorities (Rosenzweig and Easton 2010; Noble 1995; Ferdows and De Meyer 1990) (and taking into account 20 years of cumulative capability building) a gradual shift towards these priorities could be expected. Second, in order to compete against low-cost competition from Asian economies, European manufacturers increasingly shift towards customised and innovative products (European Commission 2013). Third, there is a general trend towards quicker product life cycles and an increasing demand for more customisation.

4.5 Trend 5: Sustainability Is not Continuing Its Growing Importance

A fifth trend is that the growth in the relative importance of sustainability as a competitive priority from IMSS III through V discontinues in IMSS VI. Table 4 shows that it scores around 3.0 (on the scale from 1 "not important" to 5 "very important") in all versions of IMSS where it was included, which leaves it as the least importance competitive priority (together with social responsibility). In addition, social responsibility experiences a reduction in relative importance from IMSS V to VI. With the increasing importance of both sustainability and CSR in the literature (Jiménez and Lorente 2001; Moura-Leite and Padgett 2011; Porter and Kramer 2006; Corbett and Klassen 2006), this is perhaps both surprising and disappointing.

We can only speculate about the reasons for the low and declining importance of sustainability as a competitive priority. One worrisome proposition might be that the attention to environmental issues has declined in the last 3 years. In December 2007, IPCC shared the Nobel Peace Prize with former U.S. Vice-President Al Gore for their work on climate change. The fourth IPCC report was published in 2007 and the fifth was published in 2013 after the IMSS VI data collection. Is it possible that the sustainability issue—while on a rise up to IMSS V—has suffered under an attention gap between 2009 and 2013 (after the financial crisis)? A more hopeful hypothesis might be that the recent slowdown of sustainability and social responsibility is because these issues have moved into legislation in many countries, and become order-qualifying standards and not competitive order-winning issues. Sustainability and social responsibility have yet not been included in recent studies of competitive capabilities, which clearly provide opportunities for more research in the area.

4.6 A Note on the Debate on Trade-offs Versus Cumulative Capabilities

Taken the above discussion together, there are indications that European manufacturers use *both* the trade-off model and the cumulative model. First, the data shows that the relative importance of competitive priorities has not changed much over the last 20 years (with exception of cost and service). Because the competitive priorities reported in IMSS seem to largely follow the ranking suggested in cumulative models (Noble 1995), it can be interpreted as a support for them. Contrasting the sandcone model of Ferdows and De Meyer (1990)—but in accordance with the first cumulative model of Nakane (1986)—we find that "cost" is consistently rated as more important than flexibility. We also find that the ranking of some of the priorities is fluctuating (in particular "cost" and "service"), which we can see as a sign of existing trade-offs. Companies adjust their competitive priorities to changing market requirements. In particular, we see that cost seems to experience an upsurge in relative and absolute importance (on the expense of speed and dependability) in times of economic decline.

5 Conclusions

We have used the six available databases from the IMSS project (1992, 1996, 2000, 2005, 2009 and 2013) to investigate changes in competitive priorities of European manufacturers over the last 20 years. The IMSS databases provide a unique opportunity for longitudinal analyses of changing competitive priorities. We contribute to literature and practice in three ways. First, we summarise several trends: Not surprisingly, quality and dependability have stayed at top priorities for last 20 years followed by a shifting ranking of speed and cost. More unexpected is the continuous decrease in service that partly is offset by increases in speed, flexibility and innovation. Second, we warn that sustainability and social responsibility is far from moving to the top of the agenda among European manufacturers. Building capabilities in sustainability (and responsibility) is ranked at the bottom and show a declining trend in the latest IMSS data collection. Third, we add longitudinal evidence to the long-standing debate between the trade-off model and cumulative models of competitive priorities. We conclude that both perspectives have merit in the priorities of managers, hypothesising that trade-offs are more present in times of economic decline. Future research could propose and test new dynamic and hybrid models of competitive priorities.

5.1 Limitations

Our analyses are not without limitations. First, there are limitations related to the IMSS database [see Frick (2006) for a thorough discussion of reliability of doing longitudinal analyses on IMSS data]. The limitations that usually apply to the IMSS databases also apply to this research; most importantly, the single-respondent bias. A second limitation is that the companies that have answered the IMSS survey have changed over the years. This is also the case for the countries participating. However, all companies belong to the same ISIC codes, and we limit our analyses to the European sample. Even if the companies and countries have changed, a similar sampling profile and size is kept from set to set. A third limitation is small variations in terminology (and understanding of terminology) across the IMSS databases (see notes in Table 3 for details of variations in our data). We limit our analyses to one part of IMSS that has stayed relatively stable across all versions. Despite its limitations, the rich IMSS database now provides unique opportunities for longitudinal analyses.

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The Taxonomy of International Manufacturing Strategies

Reza Aboutalebi

Abstract There are varieties of strategies for manufacturing, and this diversification is increasing to match the ever-increasing demand complexities in international markets. Many manufacturing companies employ multiple manufacturing strategies simultaneously. Although developing new manufacturing strategies to deal with new circumstances in the global market is unavoidable, the volume and variety of manufacturing strategies have become confusing and unmanageable for operations managers. This study aims to manage current strategies, suggest some novel strategies, and guide in developing newly required strategies in the future by proposing the *taxonomy of international manufacturing strategies*. A systematic literature review was conducted to identify and analyze any publications regarding manufacturing strategies at the top five academic journals. Among 349 identified publications, ninety-one papers or books had been found to have new discussions relevant to the topic of this paper. As a result of the analysis, two major themes for categorizing manufacturing strategies emerged that shaped a new taxonomy for international manufacturing strategies with 12 sets of strategies.

Keywords Manufacturing strategy · Taxonomy of international manufacturing strategies · Strategy selection process · Onshore strategies · Reshore strategies · Cross-shore strategies · Near-shore strategies · Offshore strategies · In-house strategies · In & Out strategies · Outsourcing strategies

1 Introduction

Attention to manufacturing strategies started from the late 1960s by a few pioneer scholars such as Skinner (1969), and the volume of publications in this area reached its peak in the 1990s. While hundreds of papers or books have been published about manufacturing strategies since the 1960s, a handful of these publications proposed

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new strategies for manufacturing or production. As correctly stated by Ho (1996, p. 74), “The phenomenon of manufacturing strategy is only beginning to be understood and its development is still in its infancy”. Among the different manufacturing strategies, the international manufacturing strategy is one of the least discussed topics in this field, probably because of its complexity. It is evident that the term ‘manufacturing strategy’ has been defined and used loosely and incorrectly by many researchers to refer to a basic schedule, a short-term plan, a mathematical formula, a manufacturing technique, a computer simulation, or a measurement tool.

Reasons for misunderstanding or misuse of the term ‘manufacturing strategy’ can be understood by exploring two interrelated issues, including the nature of manufacturing and the educational backgrounds of manufacturing researchers. In terms of nature, manufacturing is a multidimensional phenomenon with links to management science, production management, engineering, finance, strategic management, supply chain management, marketing, and partly, environment science and social science. Thus, the same issue can be perceived from different and sometimes contrasting perspectives. Regarding the backgrounds of the researchers in this field, three major specialties can be found. There are many engineers with little or no understanding of management in general and strategic management in particular. The second dominant group of researchers are those management specialists that are barely familiar with the design and engineering sides of the manufacturing. The third batch of scholars are those from relatively unrelated fields, such as social science, or environments that are unfamiliar with management and engineering facets of manufacturing. The first and the third groups of manufacturing researchers, engineers and non-manufacturing specialists, respectively, are more likely to be faced with difficulties in the appropriate use of the notion of manufacturing strategies.

Manufacturing strategy is defined by pioneer scholars in this field with some variations. Skinner (1969) states that manufacturing strategy is a function that creates competitive advantage in terms of production. Hill (1989) believes manufacturing strategy is an organized approach to production in order to achieve higher performance. In a recent publication and with a different opinion, Shavarini et al. (2013, p. 1109) perceive that manufacturing strategy is “a competitive weapon and is of the utmost value.” In this paper, manufacturing strategy is defined as “a long-term plan, action, and direction for manufacturing to enhance the production performance and the overall position of the company in the market”. Based on this definition, international manufacturing strategy is considered to be “a long-term transnational plan, action, and direction for manufacturing to enhance the production performance and the overall position of the company in its prospect or current foreign markets”. The terms ‘manufacturing’ and ‘production’ are used interchangeably in this paper. Also, the words ‘taxonomy’ and ‘typology’ are employed interchangeably with almost similar meaning.

In the remainder of the chapter, first the current literature is reviewed to identify possible gaps and shortcomings that are followed by a brief description of the research methodology employed in this study. Then, outputs of the systematic literature review are discussed, leading to the new taxonomy, which is presented in this section. The next section discusses the limitations, as well as theoretical and empirical implications of the proposed taxonomy. Finally, a conclusion completes the chapter.

2 Literature Review

2.1 Evolution of the Research Regarding Manufacturing Strategies

The *manufacturing strategy* was born in 1969. Skinner (1969) is considered to be the father of this new born subject. In the 1970s, manufacturing strategy was ignored by scholars in operations management. It can be claimed that this strategy was abandoned even by its own father, Skinner, because his only publication in this period was "the focused factory" in 1974 with little or no connection to the manufacturing strategy (Skinner 1974).

The first publications concerning production or manufacturing strategies were started slowly and gradually from the 1980s. Due to the fact that the concept of manufacturing strategy was brand new and mainly unclear, the pioneering scholars took an exploratory approach to research this phenomenon. Researchers in this decade tried to establish basics and fundamentals of this new field of study. The scope and nature of manufacturing strategy were still a barely familiar territory. Thereby, the opportunities to explore this strategy were widely available.

Three attempts were made to develop a taxonomy for manufacturing strategies (Stobaugh and Telesio 1983; Wheelwright and Hayes 1985; Kotha and Orne 1989). The very first taxonomy of manufacturing strategies was proposed by Stobaugh and Telesio (1983). Although this first typology is a primitive and incomplete classification of manufacturing strategies, it is highly valuable for initiating categorization of production strategies. One of these taxonomies was suggested by Wheelwright and Hayes in 1985. Their taxonomy includes only four basic strategies that are shaped based on two continuums; neutral-supportive and internal-external. Even in the 1980s, Wheelwright and Hayes's taxonomy was considered a good try, but not a useful insight into understanding the manufacturing strategies. The major topics in association with manufacturing strategies that were covered in the publications are these.

- Proposing a taxonomy of manufacturing strategies (Stobaugh and Telesio 1983; Wheelwright and Hayes 1985)
- Describing characteristics of competitive advantage in manufacturing firms (Wheelwright 1984)
- Exploring impacts of different production strategies on product structures (Guerrero 1985)
- Suggesting a method to assess manufacturing strategies of an organization (Swamidass 1986)

- An empirical study of the content of the manufacturing strategy (Schroeder et al. 1986)
- Evaluation of main manufacturing strategy variable (Swamidass and Newell 1987)
- An attempt to propose generic manufacturing strategies (Kotha and Orne 1989)

Manufacturing strategy was started to attract the attention of more researchers in the 1990s. During these 10 years, many scholars tried to come up with new manufacturing strategies. Consequently, the largest number of studies was carried out in this decade. The results were an introduction of some new strategies and a few taxonomies of production strategies. That is to say, among the large number of the studies in this period, many of them claimed that they proposed new manufacturing strategies, but only a limited number of these claims are valid.

De Toni et al. (1992) chose an eye-catching title for their paper "Manufacturing Strategy in Global Markets: An Operations Management Model"; however, they ended up talking about anything but global manufacturing strategies. Instead of manufacturing strategies, they discussed the importance of 'organization and management', 'management systems', and 'technology' in the four stages of the operation value chain.

Tunalv (1992) conducted a research study to find suitable manufacturing strategies for the four major manufacturing objectives. He proposed 'low prices', 'consistent quality', 'rapid design change or rapid product introduction', and 'dependable deliveries' strategies to cover 'cost', 'quality', 'flexibility', and 'dependability' objectives, respectively. The recommended strategies are acceptable but very basic. Tunalv (1992) made no attempt to suggest any advanced manufacturing strategies or any international production strategies.

Voss (1995, p. 6) claimed that proposed strategies in manufacturing have shaped three paradigms. "The first of these can be characterized as competing through capability. This is achieved through aligning the capabilities of manufacturing with the competitive requirements of the marketplace. The second is the approach based on internal and external consistency between the business and product context and the choices in the content of the manufacturing strategy. This is effectively a contingency-based approach. Finally, there are approaches based on the need to adopt Best Practice". The mentioned paradigms by Voss (1995) are general approaches to studying operations management. They are barely relevant to manufacturing strategies. Swink and Way (1995) intended to propose a typology for manufacturing strategies, though they just categorized studies about manufacturing strategies without discussing the manufacturing strategies.

One simple, but useful suggestion about manufacturing strategies was mentioned by Dellaert and Melo (1996). They considered the degrees of predictability of demands that can be low or high to propose make-to-order strategy or make-to-stock strategy respectively. In common with many other scholars, Dellaert and Melo (1996) made no attempt to consider internationalization of manufacturing as worthy of having its own strategies. Dominant research themes in this period are as follow.

- Correlating the marketing and manufacturing strategies to choice of technology (Kleindorfer and Partovi 1990)
- Reasons for failure of manufacturing strategies (Kinnie et al. 1992)
- A process approach to studying manufacturing strategy (Platts 1993)
- Correlation between manufacturing strategies with cost, quality, flexibility, and dependability (Minor et al. 1994)
- Introducing a categorization of manufacturers as a taxonomy of manufacturing strategies (Miller and Roth 1994)
- Production process focus (Wathen 1995)
- Defining boundaries of the manufacturing strategy (Leong and Ward 1995)
- Examining competition in dynamic product markets from the resource-base and flexibility perspectives (Sanchez 1995)
- Considering environmental uncertainty and the managerial choice (Ho 1996)
- The multi-focused manufacturing paradigm for flexible production (Spina et al. 1996)
- Exploring reasons behind absent of research paradigm (Kim and Arnold 1996)
- Assessing one of the theoretical frameworks regarding manufacturing strategies (Spring and Boaden 1997)
- Process of formulating the manufacturing strategy (Menda and Dilts 1997)
- Identifying and documenting manufacturing strategies inside of an organization (Mills et al. 1998)
- Strategizing manufacturing based on resource-based view instead of market-based one (Gagnon 1999)

A reduction in the number of research studies and subsequent lower number of new manufacturing strategies can be seen in the 2000s. Prasad et al. (2001) unsuccessfully tried to identity and categorize publications about international operations strategies. The vast majority of their discussed publications have little or no connection to international strategies. Almost all of these publications are about operations activities in one country only. In common with many other researchers in this field, Prasad et al. (2001) did not have accurate understanding of strategy, so on many occasions they incorrectly considered some of the organizational capabilities or production systems as strategies. Main research themes concerning manufacturing strategies in this decade are as follow.

- Product customization process (Spring and Dalrymple 2000)
- Testing the correlation among environment, competitive strategy, manufacturing strategy, and performance (Ward and Duray 2000)
- Alternative forms of manufacturing strategy processes (Kathuria 2000; Swamidass et al. 2001)
- The status of literature in manufacturing strategy (Dangayach and Deshmukh 2001)
- Suggesting a configuration for project management based on operations strategies (Oltra et al. 2005)
- Process of operations strategies (Lowson 2002)

- Sophistication of formulating the manufacturing strategy in practice (Barnes 2002)
- A resource-based assessment of manufacturing strategy (Schroeder et al. 2002)
- Introducing other's work regarding trend in operations strategy and performance management (Bourne et al. 2003)
- Impact of flexibility on service operations strategy (Aranda 2003)
- Claiming his suggested paradigms are still valid (Voss 2005)
- Changes of manufacturing strategies inside of a company (Cagliano et al. 2005)
- Proposing a Chinese taxonomy of manufacturing strategies (Zhao et al. 2006)
- A typology of factories in the international manufacturing network (Vereecke et al. 2006)
- Assessing usefulness of organization theory for supply chain management (Ketchen and Hult 2007)
- Strategies for managing a portfolio of alliances (Hoffmann 2007)
- Capacity development based on postponement strategies (Anupindi and Li 2008)
- Suggesting a classification based on competitive priorities relating to cost, quality, flexibility, delivery, service and environmental protection (Martin-Pena and Diaz-Garrido 2008).
- Importance of considering innovation in formulation of manufacturing strategies (Nair and Boulton 2008)
- A knowledge-based approach to the manufacturing strategy process (Paiva et al. 2008)
- Operations strategy for product-centric servitization (Baines et al. 2009)
- Strategic decisions regarding resource allocation in manufacturing companies (Jayanthi et al. 2009)
- Investigating the profit advantage of pioneering firms with a broad product line strategy (Boulding and Christen 2009)

Although the number of operations-related journals and their papers have increased substantially in the 2010s, compared to other decades, the least number of directly relevant publications regarding manufacturing strategies can be seen in recent times. Many of the publications are partly connected to the manufacturing strategy. Yang et al. (2011) suggested five operations strategies. Each strategy is in fact a combination of investments or lack of it, either in flexible capacity or in flexible technology. These five strategies are (A) no investment in capacity or technology, (B) investment only in technology, (C) investment only in capacity, (D) investment in technology followed by investment in capacity, and (E) investment in capacity followed by investment in technology. These strategies are relatively basic and they do not take into account the international aspect of manufacturing strategies.

Jayaswal et al. (2011, p. 717) focused only on the capacity aspect of manufacturing and suggested two capacity strategies, including "dedicated capacities for each customer segment or shared capacity for all segments". Although manufacturing capacity is one of the most influential on choice of manufacturing strategies, Jayaswal et al. (2011) did not try to suggest any new strategies for manufacturing as a whole in general and international manufacturing in specific.

In one of the most recent papers, Briskorn et al. (2016, p. 1) introduce ‘cyclic production schemes’, “where each product may occur more than once in the production sequence”. While this scheme is interesting, it is not a strategy because it does not provide any long-term direction for the manufacturing. These are the prime topics related to manufacturing strategies in the 2010s.

- The effect of manufacturing offshore on technology competitiveness (Fuchs and Kirchain 2010)
- Tailored base-surge allocation to near-shore and offshore production (Allon and Van-Mieghem 2010)
- The role of operational flexibility in the development of international product networks (Fisch and Zschoche 2012)
- Decentralized operation strategies (Hu et al. 2012)
- Services and income generation in product companies (Suarez et al. 2013)
- Importance of alignment between business strategy and operations strategy (Shavarini et al. 2013)
- An integrative approach to formation of the operations strategy (Kim et al. 2014)
- Exploring reasons behind recent trends of onshoring and vertical integration (Gao 2015)
- Integrating manufacturing and distribution location and capacity decisions with transfer pricing decisions (De Matta and Miller 2015)
- Integration of operations and finance (Zhao and Huchzermeier 2015)
- Evaluating connectivity of carbon emission reduction mechanisms and manufacturing optimisation (Wang and Choi 2015)
- Strategy of being nice in contrast to strategy of being mean for knowledge exchange in supply chain innovation (Nasr et al. 2015)
- Research paradigms in manufacturing strategy (Chatha and Butt 2015)
- Structuring a make-to-forecast production strategy (Meredith and Akinc 2007; Meredith et al. 2015)
- Assessing the effect of managerial controls on deployment of corporate-lean strategies (Netland et al. 2015)
- Evaluating the optimal pricing of new and remanufactured products (Abbey et al. 2015)
- Effect of service design and process management on quality (Ding 2015)
- Importance of considering pollution accumulation in manufacturing and supply strategies (Ouardighi et al. 2016)
- Breaking down of the global production network into sub-networks (Ferdows et al. 2016)
- Examining the usefulness of resource-based view to operations management (Bromiley and Rau 2016)
- Resource-based view in operations management (Hitt et al. 2016)

The systematic literature review in this research divulged that the vast majority of publications regarding manufacturing strategies have been about assessing contents or process of formulating strategies. Topics such as barriers to strategy implementation (Aboutalebi 2016a) or failure-avoidance in the implementation of the strategy (Aboutalebi 2016b) are ignored. Some publications recommended a new manufacturing strategy. Just a handful of the studies tried to propose relevant taxonomies of manufacturing strategies. In the next section, the existing taxonomies of manufacturing strategies will be explored briefly.

2.2 Relevant Taxonomies to Manufacturing Strategies

Developing taxonomies has helped theory building and structuring of future research. According to Martin-Pena and Diaz-Garrido (2008, p. 455), "The development of configurations, typologies and taxonomies is fundamental to strategy research and particularly useful when the research goal is to determine the dominant patterns in organizations". In a similar vein, Zhao et al. (2006, p. 621) state that "A taxonomy not only provides a parsimonious description of strategic groups that is useful in discussion and research, but also aids theory building". Thus, "Taxonomic research is extremely useful for identifying which strategies enable business organizations to be more competitive" (Martin-Pena and Diaz-Garrido 2008, p. 456).

In this section, the focus is on manufacturing taxonomies, so the taxonomies of other related topics such as supply chains (Aboutalebi 2016c) are disregarded. There have been a few attempts to develop a taxonomy for manufacturing strategies. It seems the first taxonomy of production strategies was developed by Stobaugh and Telesio in 1983. Although their typology is shaped by only three primitive strategies, including low-cost, technology-driven, and marketing-intensive, they will always be remembered for pioneering classification of manufacturing strategies. One of the first taxonomies was suggested by Kotha and Orne (1989). They recommended the 'generic manufacturing strategies' with eight strategies. However, they borrowed too much from 'generic strategies' by Porter (1980). Therefore, it is hard to distinguish Kotha and Orne's (1989) typology from Porter's one that has almost nothing to do with manufacturing. Probably the most known typology was suggested by Miller and Roth (1994). That is a numerical taxonomy with only three groups of producers (caretakers, marketers, and innovators). In fact, the recommended issues are not strategies, they are categorization of manufacturers. Furthermore, this taxonomy disregards widely international and many national level manufacturing strategies. Replication of this research by Frohlich and Dixon (2001) questioned the validity and the majority of the findings of Miller and Roth's (1994) study. An attempt by Sanchez and Perez (2001) fell short and ended with preparing a 'check-list' instead of a taxonomy.

Table 1 illustrates the typology of manufacturing/production strategies in a chronological order. Five issues that shape the main parts of the majority of the taxonomies of manufacturing strategies are cost, delivery, quality, innovation and flexibility.

Table 1 Existing taxonomies of manufacturing strategies

Scholars	Suggested strategies	Main shortcomings
Stobaugh and Telesio (1983)	Low-cost Technology-driven Marketing-intensive	The strategies are primitives and the taxonomy is basic
Wheelwright and Hayes (1985)	Internally neutral Externally neutral Internally supportive Externally supportive	These are general strategies with partial relevance to the manufacturing
Kotha and Orne (1989)	Segment, neither cost nor differentiation Segment, differentiation Segment, cost leadership Segment, mixed Industry-wide, mixed Industry-wide, differentiation Industry-wide, cost leadership Industry-wide, cost and differentiation	These strategies are different combinations of Porter's generic strategies They are barely related to production
De Meyer (1992)	High-performance products group Manufacturing innovators Marketing-oriented group	None of the mentioned issues are strategies. They are categorizations of organizational groups
Akhtar and Tabucanon (1993)	Defensive Aggressive Innovators	These are general strategies with partial relevance to the manufacturing
Kim and Lee (1993)	Pure differentiation Pure cost leadership Cost and differentiation	These are repetition of Porter's generic strategies
Miller and Roth (1994)	Caretakers Marketers Innovators	These are types of producers, not strategies
Ward et al. (1996)	Niche differentiator Broad market differentiator Cost leader Lean competitor	These are types of producers not strategies These are almost a repetition of Porter's generic strategies

(continued)

Table 1 (continued)

Scholars	Suggested strategies	Main shortcomings
Avella et al. (1996)	Flexible manufactures focused on the market Low-cost-quality manufacturers Manufacturers focused on delivery	The strategies are basic and non-comprehensive
Sweeney and Szwejczewlski (1996)	Variant producers Innovators Mass producers Mass customizers	These are types of producers, not strategies
Christiansen et al. (2003)	Low price Quality deliverers Speedy deliverers Aesthetic designers	The strategies are minor alterations of Porter's (1980) and Avella et al. (1996) strategies
Sum et al. (2004)	All-rounders Efficient innovators Differentiators	These are types of producers, not strategies
Lei and Slocum (2005)	Consolidator Concept Learner Concept Drivers Pioneer	These are types of producers, not strategies
Zhao et al. (2006)	Quality customizers Low emphasizers Mass servers Specialized contractors	These are types of producers, not strategies
Martin-Pena and Diaz-Garrido (2008)	Pursuing excellence Focusing on quality and delivery	This taxonomy with two strategies is the least comprehensive typology

The common weakness of all of the 15 taxonomies is disregarding international aspects of manufacturing strategies. It seems the scholars who proposed these taxonomies assumed that their recommended strategies can be used nationally or internationally. The degree of complexity of international markets and the increased number of factors that influence formulation and implementation of strategies in general and manufacturing strategies in particular in global market are just two of the reasons for having exclusive strategies for manufacturing at international level.

Another relatively common difficulty in these taxonomies is confusing types of manufacturers with types of manufacturing strategies. A lack of familiarity with the notion and nature of strategy among some scholars in the field of operations and manufacturing management has led to inappropriate use of the term 'strategy' to describe issues that are not strategy in any sense. The employed methodology in this study is discussed in the next section.

3 Research Methodology

A systematic literature review was conducted to identify and analyze any publications regarding manufacturing strategies. As stated by Boland et al. (2013), the review question was defined and inclusion and exclusion criteria were identified. By considering the scope and aim of this paper, eight keywords were prepared, including 'manufacturing strategy', 'production strategy', 'operations strategy', 'typology of strategies', 'strategy taxonomy', 'strategy classification', 'strategy categorization', and 'types of strategies'. The top five journals were chosen for literature review based on their ranking and the relevance to the manufacturing strategies. These journals are *Management Science* (MS), *Journal of Operations Management* (JOM), *European Journal of Operational Research* (EJOR), *International Journal of Operations & Production Management* (IJOPM), and *Strategic Management Journal* (SMJ).

The 'inclusion criteria' in this study were all papers from the top five journals (MS, JOM, EJOR, IJOPM, and SMJ) that include at least one of the eight keywords. In addition to the papers of these top five journals, when in the papers of the five journals a reference was made to good publications in other journals or books, these publications are considered and analyzed too. As stated by research methodologists, it is often the case that many of the included publications, after deployment of the inclusion criteria, may have little or no information about the intended keywords (Petticrew and Roberts 2005; Booth et al. 2012; Gough et al. 2012; Boland et al. 2013). Thereby, the next necessary step has been to define and use suitable 'exclusion criteria' to screen the shortlisted papers that fulfilled the requirements of the inclusion criteria; however, they may not have anything useful for this research (Booth et al. 2012; Gough et al. 2012). The exclusion criteria in this research were a lack of discussion regarding relatively new manufacturing/operations strategies or new typology of manufacturing strategies. In other words, it was decided to exclude any of the included papers or books that did not suggest any relatively new manufacturing/operations strategies or novel taxonomies of manufacturing strategies.

The eight keywords were used in the five journals to find relevant publications for review and analyzes. The following table (Table 2) illustrates the number of found papers or books by using each of the keywords in each of the journals.

Initial counting of the publications indicates 529 papers or books that fulfil 'inclusion criteria', having at least one of the eight keywords in one of the five journals or other top publications mentioned in these five journals. As it was expected that some of the papers or books would include more than one of the keywords, these were repeated in the initial counting. After disregarding the repetitions, the remaining papers or books were 349. The defined 'exclusion criteria' were used to eliminate those papers or books with no new strategies or typologies. Consequently, in these five journals, ninety-one papers or books had been found to have new and relevant discussions to the topic of this paper. Distribution of the reviewed publications from each journal and other sources can be found in Table 3.

Table 2 Number of initially identified publications

Keywords	Name of journals					Other publications
	MS	JOM	EJOR	IJOPM	SMJ	
Manufacturing strategy	42	33	7	48	34	8
Production strategy	25	11	32	24	5	5
Operations strategy	20	54	22	15	7	3
Strategy typology	1	9	0	6	10	1
Strategy taxonomy	1	6	0	2	3	2
Strategy classification	0	1	0	4	9	0
Strategy categorization	1	1	0	1	2	0
Strategy types	14	14	6	11	29	0

Table 3 Distribution of the reviewed publications

Name of journals	Number of papers from each journal	Percentage of papers from each journal (%)
Management Science	9	10
Journal of Operations Management	19	21
European Journal of Operational Research	13	14
International Journal of Operations & Production Management	35	38.5
Strategic Management Journal	6	6.5
Other relevant publications	9	10
Total	91	100

As evident from the table, *International Journal of Operations & Production Management* has been the richest source for manufacturing strategies.

Although the only intended information in these papers was their suggested new or relatively new manufacturing strategies or taxonomies, their utilized methodologies to come up with these new strategies or typologies were considered and analyzed, too. The next section is dedicated to the outputs of this study that used the systematic literature review to examine the publications regarding manufacturing strategies.

4 Findings and Discussions

4.1 Papers' Background

Ninety-one out of 349 papers or books, initially identified, were analyzed due to their relevance in the search for manufacturing strategies or any typologies of these strategies. In this section, the research designs used in the analyzed papers will be

Table 4 Employed research designs in the publications

Research designs	Number of publications that used each research design	Percentage of publications that used each research design (%)
Conceptual qualitative	31	34
Conceptual quantitative	22	24
Empirical qualitative	16	17.5
Empirical quantitative	17	19
Empirical mixed method	5	5.5

mentioned briefly. In terms of research designs, according to Chatha and Butt (2015), there are five common research designs for operations management papers in general, and papers regarding manufacturing strategies in particular. These research designs are conceptual qualitative, conceptual quantitative, empirical qualitative, empirical quantitative, and empirical mixed method. As suggested by Minor et al. (1994), empirical papers are those that include primary or secondary data collection and analysis. On the other hand, conceptual papers tend to analyze notions and theoretical frameworks instead of data. Almost all of the top five chosen journals in the field of operations or production management give high publication priorities to those papers with quantitative research design. It was, therefore, intriguing to see that nearly half of the publications that contained some discussions about manufacturing strategies utilized qualitative research design, either conceptual or empirical. Table 4 indicates the utilized research designs in these ninety-one papers.

As was expected, conceptual papers have been identified as having more contributions to development of new manufacturing strategies. While mixed method research design has gained some popularity among the researchers recently, it is the least commonly used method in these ninety-one papers or books. It is worth mentioning that although empirical papers may not contain as many manufacturing strategies as the conceptual ones, they have been of great help in testing the validity and reliability of the conceptual strategies and taxonomies in real-world organizations.

4.2 *Emergent of the Taxonomy*

Although a typology can be built on any two suitable and interrelated continuums, it may not be able to accommodate major existing or required strategies (Verter and Dincer 1992). The employed systematic literature review in this study revealed that two crucial factors in formulating or organizing manufacturing strategies are 'location of production' and the 'type of producers'. Location of production can be *onshore* (inside of border of the home country), *cross-shore* (partly in the home country and partly in other countries), *near-shore* (in nearby foreign countries), or *offshore* (in distant foreign countries). Manufacturing in terms of its producers can be *in-house* (fully produced inside of the organization), *in and out* (partly produced by the company and partly produced by other companies), or *outsource* (fully manufactured by other companies).

The notions of 'cross-shore' strategies and 'in and out' strategies have been introduced for the first time in this paper in this taxonomy. While apart from the concepts of 'cross-shoring' and 'in and out', the remaining elements of the two continuums of this research (onshore, reshore, near-shore, offshore, in-house, in and out, and outsource) are mentioned in the literature, the fifteen stated strategies in the taxonomy are new to the literature but may not be new to experienced manufacturing or operations managers. The systematic literature review indicated that current proposed strategies for manufacturing in international or even national levels in the literature do not reflect the real-world manufacturing strategies that are more complex and diversified. The introduction of the taxonomy is an attempt to get closer to the real-world manufacturing strategies.

All manufacturing strategies can be categorized into twelve groups based on the extent of two factors: location and producer. The *Taxonomy of International Manufacturing Strategies* has emerged as a result of a systematic combination of four possible locations with the three types of producers. The taxonomy of international manufacturing strategies has twelve sets of strategies. The fifteen major manufacturing strategies in the form of twelve groups of strategies in the taxonomy are 'In-house Onshoring', 'In-house Reshoring', 'In-house Cross-shoring', 'In-house Near-shoring', 'In-house Offshoring', 'In and Out Onshoring', 'In and Out Reshoring', 'In and Out Cross-shoring', 'In and Out Near-shoring', 'In and Out Offshoring', 'Outsourced Onshoring', 'Outsourced Reshoring', 'Outsourced Cross-shoring', 'Outsourced Near-shoring', and 'Outsourced Offshoring'. Figure 1 illustrates the taxonomy of international manufacturing strategies.

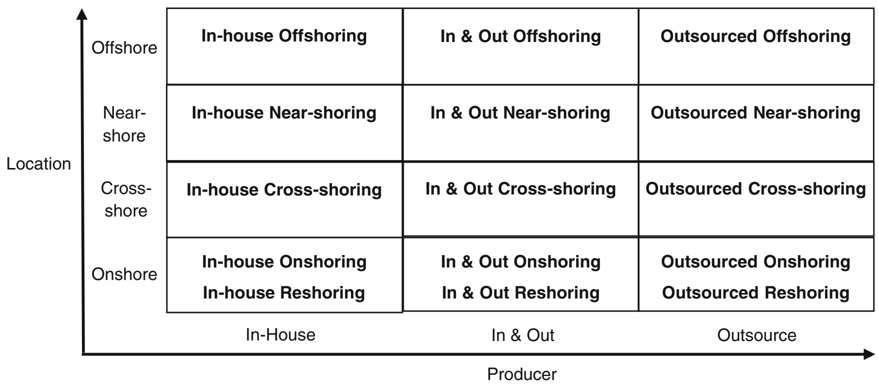

Fig. 1 The taxonomy of international manufacturing strategies

All of the stated strategies in the taxonomy are hybrid due to combining two separate but interrelated sets of strategies, location-related strategies and producer-related strategies. Brief definitions of these strategies are as follows. In-house onshoring strategy is about manufacturing all of the products and preferably their components inside of the company and only within the home country. In-house reshoring strategy indicates the company's decision to restart production in the home country by the company alone after closure of its foreign manufacturing activities in part or totally. Simultaneous manufacturing of products by the company in the home country and in its overseas' facilities is called in-house cross-shoring strategy. In-house near-shoring strategy refers to moving manufacturing operations to the company's factories abroad that are located in the nearby countries. In-house offshoring strategy is defined as establishing manufacturing facilities by the company only in distant foreign countries.

In and out onshoring strategy is considered to be concurrent manufacturing of products by the company and other contracted firms for the company in the home country. In and out reshoring strategy refers to returning manufacturing activities from abroad to the home country and then dividing manufacturing jobs between the company and its contractors in the home country. In and out cross-shoring strategy is about simultaneous production in the home country and other countries by the company and its external contractors. In and out near-shoring strategy proposes concomitant manufacturing in nearby countries by the company and other contracted producers for the company. In and out offshoring strategy can be defined as concurrent production in distant countries by the firm and its contractors.

Allocation of all production activities to other contracted companies in the home country is called outsourced onshoring. Outsourced reshoring strategy focuses on resuming manufacturing activities only in the homeland by other companies for the firm. Outsourced cross-shoring strategy is defined as concurrent manufacturing of products in the home country and overseas solely by other companies for the firm. Outsourced near-shoring strategy is about transferring manufacturing responsibilities to other contracted companies in nearby countries. Outsourced offshoring strategy refers to relying on foreign manufacturers that are located in distant countries for the production of the intended products for the company.

4.3 Connectivity of the Taxonomy to Corporate-Level Strategies

While manufacturing strategies are generally considered to be functional-level strategies within strategic business units, international manufacturing strategies have some noticeable overlaps with business and even corporate-level strategies, due to their corporate-wide impacts. "The primary function of a manufacturing strategy is providing consistency between the manufacturing strategy and the overall business strategy," (Ho 1996, p. 74). Manufacturing strategies are expected to be aligned with the business and corporate-level strategies (Ho 1996; Hoffmann 2007; Kim et al. 2014). Growth strategies are some of the major corporate-level strategies that have considerable effects on choice of manufacturing strategies. Growth strategies can be categorized into organic, semi-organic, and inorganic strategies, depending on the extent to which an organization relies on its internally generated resources or externally acquired ones for growth.

In-house manufacturing strategies (in-house onshoring, in-house reshoring, in-house cross-shoring, in-house near-shoring, and in-house offshoring) correspond to the 'organic growth' strategies that encourage natural growth via internally resourced and produced products. In contrast, *outsourced* manufacturing strategies (outsourced onshoring, outsourced reshoring, outsourced cross-shoring, outsourced near-shoring, and outsourced offshoring) are supported by 'inorganic growth' strategies that are in favor of speedy growth by utilizing resources and capabilities of other companies. *In and out* manufacturing strategies (in and out onshoring, in and out reshoring, in and out cross-shoring, in and out near-shoring, and in and out offshoring), which match with 'semi-organic growth' strategies, are mixed strategies with equal reliance on internal and external resources and capabilities for balance growth.

Another key corporate-level strategy that shapes and guides manufacturing strategies markedly is internationalization strategy. Internationalization is a step-by-step process toward expansion into the foreign markets. Degree of internationalization can be easily ignored, limited, medium, or widespread in terms of the extent to which products are manufactured in the home country, cross-countries, nearby countries, or far countries. Thus, there are one-to-one connections between *onshore*, *cross-shore*, *near-shore*, and *offshore* manufacturing strategies with easily ignored, limited, medium, or widespread internationalization strategies respectively.

4.4 Choosing Strategies from the Taxonomy

Considering the company's strategic objectives and priorities at corporate and manufacturing (functional) levels would help managers to select the most appropriate manufacturing strategy or strategies that can fulfil these objectives. The *in-house* manufacturing strategies (in-house onshoring, in-house reshoring, in-house cross-shoring, in-house near-shoring, and in-house offshoring) can be the prime strategies for the company that values highly these eight strategic objectives. (A) Protecting the company's unique core competencies such as a patented product, process, or system; (B) Maintaining an uncompromised ethos, such as good working conditions for all staff or being socially or environmentally responsible; (C) Consistency of the managerial styles that are known to be effective; (D) Organic and gradual growth of the organization; (E) More effective and clear communication and coordination; (F) Assuring quality products by quality staff; (G) Fostering loyalty and pride among the staff; and (H) Faster and more organized reactions to the changes in the market and customers' expectations.

The *in and out* manufacturing strategies (in and out onshoring, in and out reshoring, in and out cross-shoring, in and out near-shoring, and in and out off-shoring) are good for those companies that have the following objectives or priorities: (A) Win-win collaboration with competitors; (B) Sharing costs of new facilities or technologies with other companies; (C) Sharing risks associated with new investments or technologies with allied companies; (D) Faster growth compared to an organic one with semi-organic growth strategy, due to access to external resources; (E) Exchanging experience and expertises with other companies; (F) Ease of covering periodic fluctuations in customer's demand; and (G) Possibility of growth with less or no new investment because of using other companies' facilities for growth.

The *outsourced* manufacturing strategies (outsourced onshoring, outsourced reshoring, outsourced cross-shoring, outsourced near-shoring, and outsourced off-shoring) would suit those companies whose ambitions and priorities are any of these five strategic objectives. (A) Fastest possible growth via inorganic growth strategy; (B) Least possible investment for growth by relying on other companies facilities; (C) Least risk taking in terms of investment for establishing manufacturing facilities; (D) Most flexible way to develop new product due to large variety of production partners; (E) Least expensive retrieval strategy if the new production development fails; (F) Easiest way for the related or unrelated diversification strategies because of not needing to have required resources and capabilities internally.

The *onshore* strategies (in-house onshoring, in-house reshoring, in and out onshoring, in and out reshoring, outsourced onshoring, and outsourced reshoring) are appropriate choices in these circumstances. (A) The home country is known for its quality products, so impact of 'country of origin' is high on the international consumer's decision to buy; (B) Main target customers are residents of the home country; (C) The home country has the best required resources and materials for production; (D) The home country has the most skilled staff; (E) The home country is the best country to run business in terms of tax, employment laws, currency value, and economic, social and political stability; and (F) Wanting to be socially responsible to create employment for fellow countrymen or countrywomen;

The *cross-shore* strategies (in-house cross-shoring, in and out cross-shoring, and outsourced cross-shoring) can be suitable for organizations that have one or more of the following objectives or priorities: (A) Initiating the internationalization process on a relatively limited scale; (B) Benefiting from exceptional opportunities for manufacturing abroad while maintaining home country production activities; (C) Having the chance of getting to know the international market; (D) Showcasing the company's brand to potential foreign customers even at a limited scale; (E) Getting to know or even work with foreign competitors; and (F) Distributing economic, political and security risks to more than one country or homeland.

The *near-shore* strategies (in-house near-shoring, in and out near-shoring, and outsourced near-shoring) may be appealing for organizations with these objectives or intentions. (A) Internationalizing into neighbouring countries with close psychic distance; (B) Benefiting from country-specific advantages of the nearby countries;

(C) Exploiting better supply conditions of the close-by countries; (D) Market development by entering relatively familiar or similar markets on the doorstep countries; (E) Having acceptable transportation costs when sending the finished products to the home country; and (F) Less or no need for sophisticated and expensive information technology systems to facilitate communications and collaboration between the headquarters in the homeland and production facilities in neighbouring countries.

The *offshore* strategies (in-house offshoring, in and out offshoring, and outsourced offshoring) work well for organizations with any of these priorities or objectives. (A) Going global by expanding production unites in far reach countries; (B) Taking advantage of economies of scale by being in populated counties in different continents; (C) Benefiting from good production opportunities anywhere in the world; (D) Reducing manufacturing risks by distributing the operations worldwide; (E) Making the company's brand globally known; and (F) Utilizing the best resources and most skilled staff that can be acquired in the world.

Suitable manufacturing strategy or strategies can be chosen by considering two interrelated factors of the company's capabilities and the company's priorities/objectives. For example, if cost leadership is not one of the company's capabilities, but one of its objectives is becoming the cost leader, it would be reasonable to consider outsourcing. The taxonomy has two dimensions that should be considered in the process of selecting appropriate manufacturing strategy or strategies.

The strategy selection process has five steps (see Fig. 2). The first step would be deciding on the organizational and operational objectives and priorities of the firm. Identifying current corporate-level and manufacturing strategies would be the second action toward choosing the right strategies. The third stage is determining existing and acquirable resources and capabilities in the organization. In the fourth step, it should be decided on who is going to produce the intended products, by considering the organization's objectives, corporate and manufacturing strategies, and capabilities. The last stage is identifying the location(s) of manufacturing, after considering results of all four previous steps.

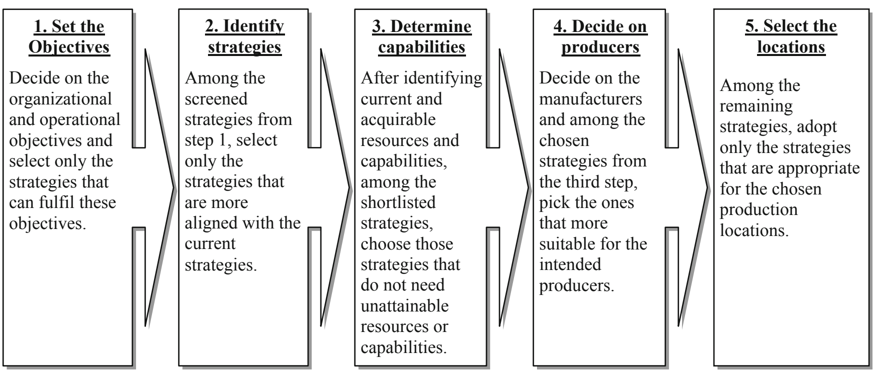

Fig. 2 The strategy selection process

Deployment of any of the fifteen manufacturing strategies can have long-term financial and non-financial consequences. Thus, it is highly recommended to employ the five-step process for strategy selection to have guidance in choosing the right manufacturing strategies. This research had some limitations and its findings have some implications that are mentioned in the next section.

5 Limitations and Implications

5.1 Limitations

The major limitation of this research is the need to restrict its findings to the papers of only five top journals. Probably, some additional manufacturing strategies are discussed in other journals that have not been included in this study. The lack of primary data in this research may be perceived as a limitation by some researchers. Although there is no doubt in the value of having first-hand data from operations managers, the scope of research with primary data is often narrower than the scope of this research. Another limitation is the theoretical nature of the research, with no possibility of testing the proposed taxonomy in real-world companies. These limitations can be seen as opportunities for other researchers to test the practical side of the taxonomy.

5.2 Theoretical Implications

The taxonomy of international manufacturing strategies can be used as a theoretical framework in categorizing and analyzing current or future manufacturing strategies. The result of the systematic literature review revealed that the vast majority of studies regarding manufacturing strategies are limited to suggesting one or more production strategies for a specific situation or industry. The taxonomy would provide a chance for other researchers to classify these separate strategies based on the twelve sets of strategies in the taxonomy. Operations researchers can even re-categorize those strategies that are already grouped in the limited existing taxonomies. Furthermore, the taxonomy may contribute to the development of new manufacturing strategies by providing opportunities to synthesise different combinations of some of the existing strategies in the taxonomy.

5.3 Empirical Implications

The taxonomy can help managers make the right decisions in the selection of the intended manufacturing strategies, by considering the company's strategic objectives and priorities, as well as the advantages and disadvantages of selecting each strategy. For example, relying on an ‘in-house’ manufacturing strategy has some important benefits such as protecting the organization’s core competencies (e.g. patents), having better control over the quality of products, and faster responses to changes in market demands and trends. However, selecting any of the ‘in-house’ strategies requires a considerable amount of investment and acquiring competitive skills and capabilities. Mistakes in the chosen ‘in-house’ strategies can be fatal. The suggested five-step process for selecting suitable strategies among the mentioned ones in the taxonomy can be a useful tool to assist managers in adopting the right strategies.

6 Conclusions

While there have been some attempts by operations researchers to suggest new manufacturing strategies or even typologies of operations strategies, especially in the 1990s, there is a gap in the current literature regarding a relatively comprehensive taxonomy for international manufacturing strategies. This study aims to manage current strategies, suggest some novel strategies, and guide in developing new required strategies in the future by proposing the *taxonomy of international manufacturing strategies*. Instead of conducting another limited empirical research study, the researcher decided to review the existing literature systematically. The analysis indicated two major factors; location of production and type of producers used to develop the new taxonomy.

The *Taxonomy of International Manufacturing Strategies* has emerged as a result of a systematic combination of four possible locations (onshore, cross-shore, near-shore, and offshore) with the three types of producers (in-house, in and out, and outsource). The taxonomy of international manufacturing strategies has twelve sets of strategies that accommodate the fifteen major manufacturing strategies. The five international manufacturing strategies with emphasis on organic growth via production within the company are ‘in-house onshoring’, ‘in-house reshoring’, ‘in-house cross-shoring’, ‘in-house near-shoring’, and ‘in-house offshoring’ strategies. In contrast, there are five inorganic manufacturing strategies that favor complete allocation of manufacturing activities to other contracted companies. These outsourced-centered manufacturing strategies include ‘outsourced onshoring’, ‘outsourced reshoring’, ‘outsourced cross-shoring’, ‘outsourced near-shoring’, and ‘outsourced offshoring’. The remaining five semi-organic strategies in the taxonomy encourage a balanced approach to manufacturing by concurrent production by the company and its external contractors. These balanced manufacturing strategies are ‘in and out onshoring’, ‘in and out reshoring’, ‘in and out cross-shoring’, ‘in and out near-shoring’, and ‘in and out offshoring’.

Four major examples of evidence of originality and contribution of this study are the notions of ‘cross-shore’ and ‘in and out’, ‘the taxonomy of international manufacturing strategies’, and the ‘process of selecting the strategy’ that are introduced for the first time in this paper. The cross-shore strategy is the missing link in the location-related literature. It reflects the real-world practice of many international manufacturers that have concurrent manufacturing activities in their home countries and abroad. The 'in and out' strategy would fill the gap in producer-related literature. The proposed taxonomy in this research is capable of accommodating current and future manufacturing strategies. Furthermore, the taxonomy can help in developing new strategies based on the company's capabilities and the market's requirements. By considering the fact that implementation of any of the fifteen manufacturing strategies would have lasting positive or negative financial and non-financial consequences, a five-step process for strategy selection was recommended to assist managers in choosing the most suitable strategies.

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International Manufacturing Strategy: The Impact of Misalignment Between National Culture and Organizational Structure

Mouhcine Tallaki and Enrico Bracci

Abstract While globalization has reduced bureaucratic barriers to do business abroad and increased foreign investment, national culture can potentially create a hurdle for the successful transfer of approaches developed elsewhere (Hope in The impact of national culture on the transfer of "best practice operations management" in hotels in St. Lucia. Tour Manag 25:45–59, 2004). The international manufacturing strategy is considered as a mechanical process in which managers with extensive rationality seek to make appropriate linkages between strategy, structure, and performance (Boyer et al. in Operations strategy research in the POMS journal. Prod Oper Manag 14(4):442–449, 2005). If there are some conflicts at the organizational structure, the success of international operation strategy could be put under questioned. In this paper we attempt to highlight some empirical evidence that support the contention that national culture does potentially create a barrier to the transfer of best practices from parent company to the foreign subsidiaries. The paper, also, aims at understanding how these might may create conflicts at the organizational level and influence effectiveness of the international operation strategy.

Keywords Management accounting · National culture · Transfer · Inter-organizational process

1 Introduction

The relationship between the national culture and management is quite discussed in the literature. This field of research has grown significantly in recent years (López-Duarte et al. 2015). While globalization has reduced bureaucratic barriers to do business abroad and increased foreign investment, national culture can potentially

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create a hurdle for the successful transfer of approaches developed elsewhere (Hope 2004). The management style continues to be considered cultural specific. According to this approach differences in the beliefs, values and attitudes of people could affect the way to do business. In this paper, we investigate about the success of international manufacturing strategy and the national culture. Various authors stressed about the importance of the alignment/consensus among different decision makers within organizations (Hayes 1992; St. John and Young 1992; Voss and Winch 1996) to the success of the international operation strategy. Due to an overly rational view of strategic processes, a company with an appropriate strategy in terms of content and process is well positioned for success, but in truth operational decisions are made with such great frequency by such a large number of individuals within an organization that there is often a high-degree of misalignment (Boyer et al. 2005).

The international manufacturing strategy is considered as a mechanical process in which managers with extensive rationality seek to make appropriate linkages between strategy, structure, and performance (Boyer et al. 2005). If there are some conflicts at the organizational structure, the success of international operation strategy could be questioned. The conflict may arise when management practices are culturally different with respect to the people that use them. Managerial practices have a cultural aspect that reflects the context in which they were born. This is because differences beliefs, values and attitudes of people could impact the way to do business, and consequently the managerial practices widespread. As a consequence, in order to work successfully and to be performing, practices need to be adapted.

We observed how cultural diversity could create conflicts at the organizational structure and thus calls into question the success of the international manufacturing strategy. This means that there is a difficulty in transferring operational practices, considered as best practices, developed elsewhere. However, in multinationals the parent company, with the intention to promote a similar philosophy within the group, tends to transfer its management style to the foreign subsidiary (Schneider 2006). A shared management philosophy could, in fact, increase efficiency, reduce communication time and contribute to the success of corporate strategy (Roth et al. 1991). Despite the growing attention to research in management accounting in the last years, there is still a significant lack of research concerning the influence of culture on management (Keplinger 2012). In this paper we attempt to highlight some empirical evidence that support the contention that national culture does potentially create a barrier to the transfer of best practices from parent company to the foreign subsidiaries. We are also interested in understanding how these might may create conflicts at the organizational level and influence effectiveness of the international operation strategy. In this sense, the company that internationalizes the production needs to have a management system along and across the value chain. The companies have to establish management practices that permit them to act or behave consistently with this philosophy (Mentzer et al. 2001). Having an adequate organizational structure certainly enables the success of management across the value chain i.e. supply chain management. Coordinated upstream and downstream integration in the supply chain differentiates performance in the company (Hines et al. 1998; Tan et al. 1998; Johnson 1999) and reduces uncertainty (Davis 1993; Lee et al. 1997).

The paper will be structured in the following sections: Firstly, we will review the main literature stream related to management and the national culture. In the second section we will emphasize how the conflict generated by cultural diversity in organizational level could affect the international operation strategy. Subsequently, we will analyze the case study. Finally, we will discuss and comment results.

2 Management and National Culture

An organization is considered as open social system composed of interdependent elements, joined to one another forming an autonomous entity. It interacts with the external environment, it can influence and be influenced by it (Kast and Rosenzweig 1972). The interaction and the adaptation to external environment come through people which are rather driven by their cultures and beliefs. The literature suggests that people from different cultures have different attitudes to similar management practices (Chow et al. 1997). The managerial attitudes, values and behaviors differ across national cultures (Hofstede et al. 2010). There is no one best way to manage a business. Differences in national culture require different approaches to do business. Several contributions have tried to highlight the cultural diversity at the national level (Hofstede et al. 2010; House 2004; Trompenaars and Turner 1997). These authors have defined various cultural dimensions that, through their comparison, we can point out the cultural diversity. Hofstede (1980), Hofstede et al. (2010) defined six cultural dimensions: power distance, uncertainty avoidance, individualism, masculinity, time orientation, indulgence. Trompenaars and Turner (1997) defined tree categories of characteristics: Which arise from our relationship with other people, from the passage of time and those, which relate to the environment. They identified seven fundamental dimensions of culture. According to Trompenaars and Turner (1997) the relative position along these dimensions allows to define the cultural characteristics of the individual that guide the beliefs and the actions. These dimensions are: universalism versus particularism, individualism versus communitarianism, neutral versus emotional, specific versus diffuse culture, achievement versus ascription, orientation in time, attitudes towards the environment. Another model that have attempted to improve the cultural dimensions defined by Hofstede is the Globe Project mode (House 2004). This model produced a set of nine dimensions. The nine cultural dimensions they identified as independent variables are Uncertainty Avoidance, Power Distance, Institutional Collectivism, In-Group Collectivism, Gender Egalitarianism, Assertiveness, Future Orientation, Performance Orientation, and Humane Orientation. Instead, Schwartz (1992) defined theory of basic human values. It discusses the nature of values and sets out the characteristics that are common to all values and what distinguishes one value from another. The theory identifies ten basic personal values that are recognized across cultures and explains the culture characteristics of people. These values are: self-direction, stimulation, hedonism, achievement, power, security, conformity, tradition, benevolence, universalism. In the literature we can highlight other models, the ones we have mentioned are those mostly widespread. Some dimensions are similar, other are different. The Hofstede model is the most popular model despite that it suffers from methodological and conceptual problems. The Hofstede model is criticized in particular for (Baskerville 2003; Harrison and Mckinnon 1999):

- The assumption of equating nation to culture
- The difficulties in quantifying culture represented by cultural dimensions and matrices
- The assumptions of stability in cultural differences
- The status of the observer outside the culture

To overcome the limitations of this approach and the tension between the general and the specific characteristics of culture. D'Iribarne (1991) adopts a broader view of culture as a code of interpretation and to consider the specific characteristics of each country. Therefore, he adopted an ethnographic methodology that seeks to explore the cases of intercultural comparison taking into account the specific characteristics of each country, instead of making a nomothetic research such as that adopted by other authors. Many authors of cross cultural studies have a tendency to focus on a few dimensions and ignore various aspects of cultures which might have equally significant bearings on people's values, attitudes and behaviors. In this paper, we aim to highlight the cultural diversity and how this diversity might create conflicts at the organizational level that could affect the international operations strategy. Therefore, the deepening and analysis of models is not the objective of this work.

Prior research does suggest that cultural differences will impact on international operations management (Huyton and Ingold 1995; Purcell et al. 1999; Roney 1997). Pagell et al. (2005) verified that national culture significantly explains international operations management behaviors. The diversity in national culture could be central element to analyze the diversity in management. The literature suggests that people from different cultures have different attitudes to similar management practices (Chow et al. 1997). Therefore, management theories developed in one culture cannot be exported easily to other cultures (Keplinger 2012). Effective management in one environment can prove dysfunctional in other environments (Chow et al. 1996). In fact, Etemadi et al. (2009) investigated the impact of national culture on participation in budgeting and performance in Iran. They concluded that the management control developed in the West is not efficient in the Iranian context. Newman and Nollen (1996) have verified that companies are more performing when management practices are congruent with the national culture. (Tallaki and Bracci 2015) verified that national culture is relevant element in the in the explanation of diversity in management control systems. If we want to make an organization more efficient and effective, then it is important to understand the role played by cultural values (Schein 2000).

Since culture is central to the functioning of management system, the transfer of management system from one culture to another may not give the same results.

The management system transferred should be adapted to the specificities of the new cultural context. Varela et al. (2010) suggested that managerial practices require local customizations addressing the cultural variations of employees' behaviors. This is because managerial practices are functional to a cultural synergy (Kanungo 2006). In fact, Mathews et al. (2001), in their study of quality management approaches in various cultures, concluded that cultural models can help to explain much of the variation observed and constitute a basis for understanding why particular quality management approaches are adopted. The successful transfer of best practice can be influenced by the national culture (Hope 2002).

The influence of national culture on the organizational system can be represented in different dimensions of the managerial system. We can highlight, for example, the cultural influences on human resources management, incentive system, budgeting process and on management control system. Ichniowski and Shaw (1999) verified that cultural differences make it difficult to import Japanese human resource policies into American plants. Chow et al. (1994) analyzed the preferences of management control systems using a sample of MBA students from two different cultures, American and Japanese culture. The authors confirmed that the perception of the management control systems might differ from one culture to another. Birnberg and Snodgras (1988) made an exploratory study to compare the perception of managerial system by workers in the U.S. and Japan. The authors argued that, unlike the U.S., the managerial system perceived by the Japanese is less bureaucratic. The results confirmed that the managerial system is less bureaucratic in Japan. In another work, Chow et al. (1999) showed that Taiwanese national culture is an important determinant of the managerial system designs used by the Japanese and U.S. firms in their Taiwanese subsidiaries.

3 Theoretical Framework

As pointed out, there is a relationship between the national culture and management system. This relationship is expressed in particular at organizational level and it implies that management system used in a cultural context should reflect and respect the national culture of that context. Nevertheless, the parent company is interested to transfer the management system to the various foreign subsidiaries. In particular, the parent company is interested to transfer the managerial system if these conditions are satisfied (Johnson et al. 2001):

- Strategic importance of the foreign subsidiary
- Similarity of the business lines and product between the parent company and the foreign subsidiary
- Experience of the foreign subsidiary
- Dependence of foreign subsidiary

The presence of the foregoing conditions induce the parent company to activate control procedures and to intervene in the foreign subsidiary management. This would allow the parent company to share the same management philosophy. Having a shared management philosophy could increase efficiency, reduce communication time and contribute to the success of corporate strategy (Roth et al. 1991). Furthermore, without successful knowledge transfer from their parents companies, it is difficult for these subsidiaries to build up knowledge base, improve capabilities, accelerate management localization, and survive intense competition to generate good returns for their parents (Wang et al. 2004). Successful transfer requires certain conditions. The first condition is that the parents companies (transferors) have to be capable to transfer (Gupta and Govindarajan 2000; Tsang 2001). The second condition regard the foreign subsidiaries (recipients) that they have to be capable to receive new knowledge (Lane et al. 2001). Another condition to be met in the transfer process is the respect of cultural values. Failure to comply with the cultural values might create conflicts at the organizational level and influence effectiveness of the international operations strategy.

Our research focuses therefore on two elements (see Fig. 1), on the one hand the willingness of the parent companies to transfer the managerial systems to have a shared philosophy. Elsewhere, the cultural diversity that somehow questions the transferred management system. The transfer on management system without

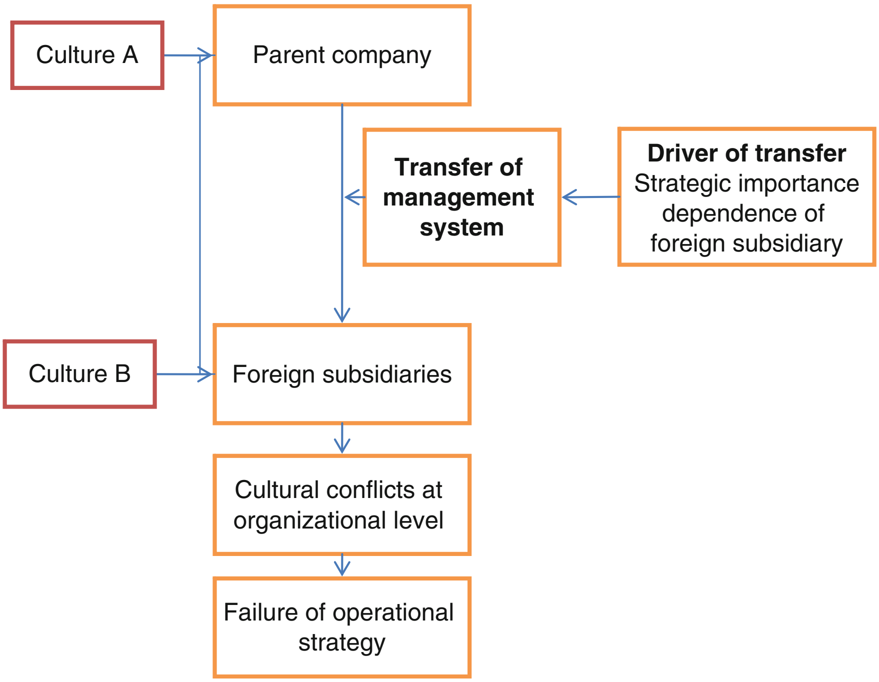

Fig. 1 The transfer process and influence of national culture. *Source* Adapted from Tallaki (2013)

considering the cultural elements gives rise to cultural conflicts at the organizational level. We argue, consistent with Burgess (1995), that national culture is an equally relevant lens through which the viewing of these systematic differences makes sense to advance the field of operations management and related research. This conflict in the organizational level puts into question the international strategic operation, because the international operations strategy is considered as a mechanical process in which managers with extensive rationality seek to make appropriate linkages between strategy, structure, and performance (Boyer et al. 2005). The international strategic operation is a discipline of operations management, that is generally defined as containing topics that are associated with management of the resources required to produce the goods and services provided by the organization (Chase and Aquilano 1992).

4 Research Methodology

In this research, we chose the qualitative method with case study (Yin 2002). Case research has consistently been one of the most powerful research methods in operations management, particularly in the development of new theory (Voss et al. 2002). We chose the case study method because our research satisfy the requirements of this method of research. In particular, the case study is recommended as a particularly instructive research method in studies where research has exploratory nature, the phenomenon under study is complex and the aim is to build/generate theory, as it helps to draw out new insights on phenomena, which can significantly enhance existing knowledge on a topic (Lincoln and Guba 2000; Yin 2002). Another reason for the choice case study is the field of this research. According to Drejer et al. (1998) operations management differs from most other areas of management research, it addresses both the physical and human elements of the organization. In this research, our focus is the national culture, human characteristics that interact with organization. Case study method allows clarifying more how national culture could affect the organizations.

A case study is a history of past or current phenomenon, drawn from multiple sources of evidence. It can include data from direct observation and systematic interviewing as well as from public and private archives (Leonard-Barton 1990). Therefore, to conduct research we chose the semi-structured interview and the document analysis (reports, financial statements). In addition, various other interviews were carried out (via phone). Considering the research question, we chose a case study of an Italian multinational company that has foreign subsidiaries in various countries. We focused the analysis on the foreign subsidiaries located in Morocco. The choice to compare parent company with its subsidiary allows overcoming some limitations of the research. Management diversity may also be affected by sector, technology and other organizational factors (Child 1981). Further, comparing the foreign subsidiary and the parent company will overcome all the limitations related to the industry, technology and the type of products. In addition,

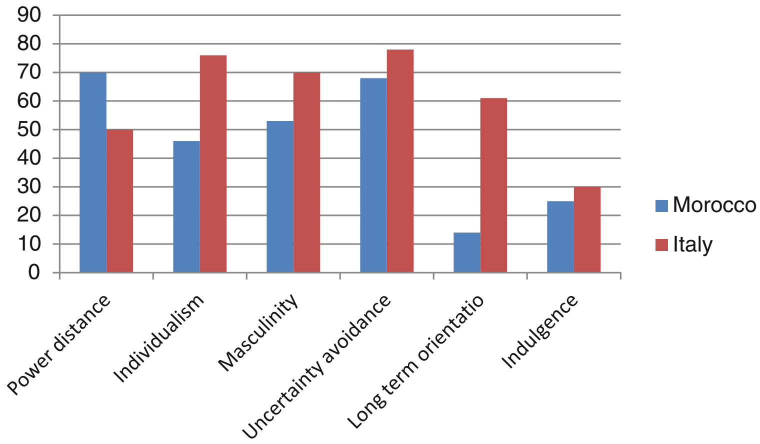

Fig. 2 Cultural comparison between Morocco and Italy

according to Hofstede model Italian and Moroccan cultures are different (see Fig. 2), so we can better understand how cultural diversity affects management system.

The interviews were carried out in Italian language in the parent companies, while the interviews in the foreign subsidiary were made in Arabic language (one of the authors is Arabic mother tongue). The following organizational roles were interviewed: responsible of management control systems, chief financial officer of the parent company and the chief financial officer of the subsidiary. The interviews were transcribed, translated and analyzed. Then we identified the keywords that relate to the cultural differences. The data has been interpreted according various sources and points of view (Yin 2002).

Based on the work of Chow et al. (1999) in the interviews we focused questions on various dimensions of the organizational structure of company. These dimensions are: Budget process, participation, centralization of power, formalization of procedures, accountability for results. Furthermore, various questions were posed to understand if first of all there was the decision to transfer the management system from the parent company to the foreign subsidiaries. In this way it was covered up the transfer process, that starts with the desire to transfer the managerial systems and ends with the cultural conflicts that arise.

5 Case Study Analysis

5.1 General Presentation

The company under investigation is an Italian multinational that works exclusively with the automotive sector. This company has two foreign subsidiaries one in Morocco and another in Poland. The foreign subsidiaries produce exclusively on

Table 1 Case study main data

Area of activity	Wiring harnesses for automotive
Revenue	€ 250 million
Number of subsidiaries	2
Employees	6.472 (77 %) in Morocco

behalf of the parent company, some products are also produced in the parent company but most of the products are produced and processed in the foreign subsidiaries. The commercial area is therefore governed by the parent company, the subsidiaries are then production companies. This means that the parent company has to implement an efficient management control, quality and logistics systems at the international level to meet the needs of various clients. The revenue of the group amounts to € 250 million. The group has 6472 employees, most of them work in the Moroccan subsidiary. In the Moroccan subsidiary Managers of quality and design are Italians, while the CFO is Moroccan. Table 1 summarizes the information about the company.

In this research we compared the Moroccan subsidiaries and the parent company. We tried to understand first of all if the system implemented in the foreign branch was placed by parent company. Then we tried to detect, if any, the conflicts caused by cultural differences.

5.2 Transfer of Managerial System

In this section, we analyse the drivers and the results of the transfer process of managerial system. As anticipated, the drivers of the transfer are: strategic importance of the foreign subsidiary, similarity of the business lines and product between the parent company and the foreign subsidiary, experience of the foreign subsidiary (less experience means more chance of transfer), dependence of foreign subsidiary, The Moroccan subsidiary is strategic for the company. This is clear both from interviews with managers and from both documents analyzed. As has been pointed out previously, the parent company manages only marketing and research activities. The production is made by foreign subsidiaries, and in particular that by Moroccan subsidiary. This confirms the importance and the role of Moroccan subsidiary along the value chain. It contributes to increase the economic income considering that labor and raw materials have low cost in Morocco. The CFO said that: "*we have invested in Morocco because there are lot of prospects there. So far, the Moroccan establishments have given us a good part of the products sold at low cost in comparison to Italy*". The strategic nature of the Moroccan subsidiary is also due to market trends and competition. The low cost of raw materials and direct labor in Morocco allows the company to be more competitive. The strategic importance is also confirmed by the commitment to improve the Moroccans production sites, and also by the investments made in Morocco in recent years to strengthen the production. The 60 % of investments are made in the Moroccan establishments. The second condition relating to the similarity of the business lines implemented is satisfied. In fact the parent company and the Moroccan foreign subsidiary produce the same product. As for the third condition, the parent company has accumulated over time experience in the sector, which may be used by the foreign subsidiaries. The last condition concerns the dependence of the parent company on the foreign subsidiary. This condition is satisfied because the Moroccan subsidiary gives access to a critical resource for the parent company. As mentioned prior, when a partner gives access to a critical resource, it could also take a dominant position that allows him to intervene in the management of its partners (Pfeffer and Salancik 1978).

All the drivers of transfer have been verified, and the will to transfer the managerial system to the Moroccan was verified. Indeed, the managers have confirmed that the company has tried for years to transfer the managerial system used by the parent company located in Italy. The objectives to transfer, according to the responsible of the parent company, is to monitor the performance and the quality of production. The transfer decision does not take into account the cultural diversity existing between the Italian and Moroccan cultures. The company reasoned only in terms of efficiency, the transfer in fact aims to monitor production efficiency. The transfer of the management system enabled company to unify the procedures in all subsidiaries and to reduce inspection time and increase the efficiency. The transfer has been strengthened by the power that holds the Italian company as it was emphasized by the responsible of management control of the parent company "*the Moroccan company is ours, we are the owners*". Another element that could lead to the success of the transfer process is the power and the relational ratio.

5.3 Budget Process

The strategic objectives relating to the type of product are defined by the parent company, while the objectives related to production standards are conferred to the Moroccan subsidiary. The group uses the budget as a management control and empowerment tool. Budget objectives are discussed between the commercial area, design and quality area, and the administrative area. The objectives are defined considering the automotive market forecasts. As confirmed by the controller of the parent company "*the discriminating factor is the planned sale and the trend of the sector*. After several meetings the responsible of various areas defined quantity to product, new product line, costs and investments. The budget processing is consultative and involves all areas of business. This is also evident from the budget regulation (It is the formal document that defines the process times and responsibilities). For instance, in the budget regulation we can read "*By 16/01/12: All responsible must submit to the Directorate of Human Resources the formative requirements for the year 2012. The same time must be given to Dr. XXX all requests related to personnel, in terms of new hires, and in terms of merit increases and training. Based on this information, the personnel department together with* *management control will estimate the cost of the staff for 2012 including increases, hires, resignations, contract renewals, seniority. By 13/01/12: All investments planned for the year 2012 will be sent directly to the ing. XXX XXX. The ing. XXX and XXX, after consultation with Dr. XXX will provide the detail for 2012, inclusive of the carry-over in 2011, no later than 16/01/12*". This emerges not only from documents but also from the interviews as stated by the CFO of the parent company "*each one has its role, the sales director, the director of purchases*". He added "*once a month we meet and we try to find solutions to our problems*".

The Moroccan subsidiary, considered as production company, does not participate in the definition of business objectives. The objectives defined by the parent company are shared with the Moroccan subsidiary to verify if there are some limits. As pointed out by the controller of the parent company "*they do their meetings for the preparation of the budget and they define their goals, for example the number of rejects per turn, the level of productivity, in terms of waste of components, a series of indicators related to the production process objectives*". The controller of the parent company added "we give the general objectives of quantities and types, we stop at this level objectives (to quantitative targets)", everything else depends on the director of the Moroccan subsidiary who translates all the goals in terms of numbers.

The budget process in the Moroccan subsidiary was defined by the parent company, not only the budget process but also the procedure and all regulations were formalized by the parent company. As affirmed by the CEO of the parent company "*the Moroccan subsidiary has its internal and quality procedures, some is required by law, others are imported from Italy*". In fact, the budget process corresponds exactly to the budget process adopted by the parent company. The budget process was imported from the parent company and the timing was also dictated by the parent company.

One aspect that emerged during the interviews is that in spite of all they have a clear responsibility in the Moroccan subsidiary, it has not created a relationship between the various areas of the group. The parent company interacts only with the director of the Moroccan subsidiary. This is because the CEO of the Moroccan subsidiary tends to centralize power The Moroccan CEO confirmed "*if the document drawn by various areas isn't good, usually I ask they to rework it, the final document that I send to the company in Italy usually it checked by me before sending*". Although the budget regulation provides a system of delegation and clear responsibilities, the CEO continues to centralize power. Despite the presence of management system that encourages collaboration and sharing of objectives, in Moroccan subsidiary there are also some authoritarianism aspects. The results confirm what has been emphasized by the literature about the relationship between power distance and goals setting (Harrison 1992; Chow et al. 1999; O'Connor 1995; Tsui 2001; Ueno and Wu 1993; Daley et al. 1985; Harrison et al. 1994; Brewer 1998). The influence of national culture on budget process and objectives definition depends on the power distance and individualism (Harrison 1992; Chow et al. 1999; O'Connor 1995; Tsui 2001; Ueno and Wu 1993; Daley et al. 1985). In cultures where it is accepted the unequal distribution of power, people who have power tend to exercise it (Hofstede et al. 2010). The centralized process emerged in Morocco, unlike Italy, is explained by the fact that in Morocco there is a considerable respect for those who hold power (Hofstede 1980, 1991; Hofstede et al. 2010) In other words, the acceptance of power, as a cultural characteristic in Morocco, led subordinates to accept and follow the top management decision. The acceptance of power distance characterizes the Moroccan culture can be confirmed by others concepts like the family and Religion dominate. In fact, the Islam has strengthened the concept of the family and the relationships that are built inside (Boutaleb 2001). Before Islam, Morocco had tribal system in which the family was an important component (Slaoui 2006). The affirmation of Islam did not mean the abandonment of cultural values, however. Therefore, the widespread of a tribal system and the family concept implied the presence of a hierarchy and respect for authority. The family structure has a great influence on the way of doing business in Morocco (Mezouar 2002).

5.4 Organizational Structure

In the organizational structure we analyzed the following dimensions: participation, centralization of power, formalization of procedures. We compared the system used in the parent company and the Moroccan subsidiary. The parent company has a decentralized structure. It has a very clear and articulate system of delegation like budget process. Everyone has a clear responsibility and function. This is also evident from the organization chart and the interviews. The responsible of management control stated: "*we have a map of the various functions, with job description, the map of functions lists all the functions with the relative power, we call it Job description or skill mapping* ". He added: "we respect our job and we know our task because". Further, in Morocco, there is a map of functions, which has been imported from the parent company. The CFO of the parent company said: "*the Moroccan subsidiary has internal procedures, some are required by law, others are imported from Italy*". Although the procedure provide a system of delegation and clear responsibilities and task in Moroccan subsidiary there are also some authoritarianism aspects. The presence of Italian managers at the Moroccan subsidiary has permitted to maintain a system of delegation. For example by comparing the organization chart in the parent company the CEO does not have a secretary, while in Morocco, the responsible has yet the secretary. In Morocco there is still the "book signing" that is brought by the secretary to the responsible in a specific time. While in Italy these elements are no longer. The cultural dimensions used in the literature to explain the differences at organizational level are: power system and collectivism/individualism (Chow et al. 1999, 1996; Harrison et al. 1994; Daley et al. 1985). The difference between Italy and Morocco relate in particular to the power distance and individualism. In Morocco, the power is centralized in the hands of the manager, while in Italy it is decentralized. This is in fact in the religious dogmas and is confirmed by the respect of the roles in the family. In Italy, however, the vision of a shared power has given rise to a decentralized system with delegation system. In Morocco, the manager tends and centralize all decisions, and yet the employees collaborate. That depends strictly on the vision that they have of the group concept and the respect for authority. The implemented system favors the decentralization but management tends to centralize. Decentralization sometimes remains only formal.

Regarding the formalization of procedures, we noted that the procedures followed by the parent company are similar to the Moroccan company. If we see the budget regulation and the job description we note some similarities. The responsible of parent company said: "*the procedures are followed by all areas, in the management control area almost activities are formalized, also for the administrative area, and especially the procedures of budgets*". This is verified by the budget regulation that describes step by step all procedures. Also in Morocco the procedures are formalized, in part they have been imported from the parent company and others are impost by law. The degree of procedures formalization changes from one culture to another. The variable used to explain differences in the degree of procedures formalization is the uncertainty avoidance (Chow et al. 1999, 1996; Daley et al. 1985). Subordinates that feel threatened by future events tend to reduce risk by establishing procedures and clear guidelines. As a result, in culture with high degree of uncertainty avoidance people use more procedures for reducing risk (Hofstede 1980). In this case, we did not notice the resistances related to the formalization of procedures in the Moroccan subsidiary, this is probably because there are no differences between Morocco and Italy with respect to the cultural dimension that explains this organizational characteristic.

Another interesting aspect is the personal relationships. As noted by the responsible of management control: "*they seek a lot more contacts and relationship, we tend to do things a lot faster without wasting time*". The CFO of the parent company added: "*when I need some information, I do not care anything else, instead of them it is important to making speeches and creating contacts, sometimes I can get much more by doing as they do*". In Morocco there is not a difference between professional and personal relationships as stated by the CFO of the parent company: "*they create groups of friends before being colleagues, here we are colleagues, there is one that is known for longer and therefore he has more confidence, the professional relationship is created before personal relationship*". This can be explained by the specific versus diffuse culture (Trompenaars and Turner 1997). According to this cultural characteristic in the specific culture, people keep work and personal lives separate. As a result, they believe that relationships do not have much of an impact on work objectives, and, although good relationships are important, they believe that people can work together without having a good relationship. In the diffuse culture, people see an overlap between their work and personal life. They believe that good relationships are vital to meeting business objectives, and that their relationships with others will be the same, whether they are at work or meeting socially. People spend time outside work hours with colleagues and clients.

5.5 Control of Results and Incentive System

The parent company monitors the results once a month. In addition, every month the subsidiaries in fact sends the data to the parent company, which proceeds to their consolidation. Once a year, in June, the objectives of the budget are reviewed and are redefined according to the performance of the first six months.

The same reporting system used by the parent company is also employed by the subsidiary in Morocco. The system use various indicator to evaluate the performance. The system tends to empower responsible on the results achieved, once the budget approved by management becomes a reference point for the control and evaluation. Both the parent company and the subsidiary use a budget by center cost. Each area has its goals, and it is evaluated regard to the objectives achieved. The CFO of parent company declared, "*In Italy there is meritocratic plan*". However, the amount of the bonus is not formalized, the company do not define a priori what will be the amount of bonus at year-end, all depends on the annual results. The CEO said: "*the evaluation is not standardized, not as American companies, the amount of bonus in our company is not standardized, could be an increase in level, a financial bonus*". Each area is evaluated separately, those who reach the objectives have a bonus. While in Italy almost all areas have the bonus, in Morocco only the production area and the direction have it.

The responsibility for results is not the same in all cultures, in some cultures there are predefined rules to encourage people, while in other the bonus is discretionary (Chow et al. 1999; Bailes and Assada 1991). The literature suggests that in individualistic cultures incentive systems are widespread, while in collectivist cultures, the bonus is discretionary (Chow et al. 1999; Hofstede et al. 2010). In the collectivist cultures the companies is like family, the managers do not tend to empower subordinates. Another cultural variable that may affect this process is uncertainty avoidance (Kagono et al. 1985). In the Moroccan subsidiary the incentive system implemented was transferred from the parent company. The system is based on the performance indicators and on the merits, this is explained by the culture of individualism prevalent in Italy that it incentives the competition. The system transferred from the parent company to its Moroccan subsidiary in the second case did not consider the cultural characteristics of Morocco. The incentive mechanism provides that subordinates will have the bonus if they reach certain results in terms of production. This could have consequences in a collectivist culture where prevails the sense of the group. This aspect has not been verified as the interviews were made only with the responsible, not with all employees.

5.6 Final Considerations

The approach adopted by the parent company is consultative. All subordinates participate in the budget processing. This can be explained, as before, by the individualism that characterizes the Italian culture. Therefore, the various directors, as they belong to an individualist culture, tend to work with each other because their interests coincide with the interests of the company and employees are encouraged to collaborate, doing so they will have economic benefits (Hofstede et al. 2010). The system that emerged in the Moroccan subsidiary is a hybrid. Shimoni and Bergmann (2006) have shown that the standard cultural approach, according to which the company has to adapt their managerial system to the cultural characteristics, is no longer sufficient to describe what is happening in multinationals. Further, the local leaders maintain their managerial culture even if the corporate culture has different values. Consequently, within the company emerges hybrid or mixed managerial system that combines both aspects of the local and the MCSs transferred.

6 Discussion and Conlusion

In this paper we attempt to highlight some empirical evidence that support the contention that national culture does potentially create a barrier to the transfer of best practices from parent company to the foreign subsidiaries. Consequently, these might may create conflicts at the organizational level and influence effectiveness of the international operation strategy. We analyzed the process transfer of managerial system from Italian parent company to Moroccan subsidiary. The research confirms that parent company, when specific conditions are met, tends to transfer the managerial system (Johnson et al. 2001), in particular when the foreign subsidiary has strategic importance for the parent company. The study confirms also that in the process of transfer the parent company does not consider the cultural differences. We have also been able to verify that there is a relationship between national culture and managerial system. In particular using the Hofstede model (Hofstede 1980; Hofstede et al. 2010) we were able also to explain the difference in the managerial systems and their relationship with the national culture. The non-consideration of the national culture in the transfer process of the managerial system could create conflicts at the organizational level. In the analysis of case study we have identified several aspects which confirm this aspect. As pointed out by Boyer et al. (2005) there is need to link manufacturing structural and infrastructural decisions with overall business plans, and thus guide business by building capabilities essential to the formulation and achievement of the firm's overall strategy. Conflicts in the organizational structure could lead to the failure of international manufacturing strategy. This is because international manufacturing strategy at relatively high organizational levels, comprising many structural and infrastructural decision areas (Boyer et al. 2005). The failure of the strategy reduces the degree of performance. The misalignment between national culture and organizational structure is caused by a different perception of managerial system. A large number of individuals within an organization that there is a high degree of misalignment creates a climate of conflict that affects both the international operational strategic and the performance. This is because cooperative behaviors between parent company and subsidiary are positively associated with product performance (Kelly and William 2001).

In this sense, the company that internationalizes the production needs to have a management system along and across the value chain. The companies have to establish management practices that permit them to act or behave consistently with this philosophy (Mentzer et al. 2001). Having an adequate organizational structure certainly enables the success of management across the value chain i.e. supply chain management. This is because a coordinated upstream and downstream integration in the supply chain differentiates performance in the company (Hines et al. 1998; Tan et al. 1998; Johnson 1999) and reduces uncertainty (Davis 1993; Lee et al. 1997). The supply chain management is defined as the process of managing relationships, information, and materials flow across enterprise borders to deliver enhanced customer service and economic value through synchronized management of the flow of physical goods and associated information from sourcing to consumption (La Londe and Bernard 1997). The management system is fundamental to the success and management of supply chain management and accordingly to the international operations strategy. The need for an adequate management system is also apparent from the various activities carried out along the supply chain of an international manufacturing strategy.

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Catch-Up Strategies of Emerging Market Firms: Lessons Learned from India and China

Wiboon Kittilaksanawong

Abstract Market liberalization in emerging economies has attracted a large number of multinational enterprises that possess advanced technological and managerial capabilities to enter the market. As domestic firms in these markets are mostly technologically and managerially backward, they are pressured to catch up by acquiring strategic resources and capabilities to compete with these multinationals in the home and overseas markets. This study discusses their catch-up strategies in the form of strategic linkages building through inward internationalization, compositional offering, agglomeration, and internationalization of research and development. Such discussion is then illustrated by the selected cases of Indian and Chinese firms. The study concludes with key implications for advanced economy firms as well as emerging economy firms and governments.

Keywords Absorptive capacity · Agglomeration · Catch-up strategy · Compositional strategy · Internationalization · Emerging market · Strategic asset seeking

1 Introduction

With the introduction of market liberalization in emerging economies, domestic firms are facing substantial changes in their institutional environments. These changes are significantly different from those in advanced economies during the industry deregulation (Peng 2003). Governments and regulatory bodies in emerging economies have increasingly reduced their influences on market forces, while emphasizing efficient market operations and business capabilities of firms. Such liberalization has attracted a large number of multinational enterprises (MNEs) that

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possess advanced technological and managerial capabilities to enter the market (Kumaraswamy et al. 2012).

Domestic firms in emerging markets like India and China are mostly technologically and managerially backward in the beginning of market liberalization. Most of them do not have market power, or resource advantages, in terms of proprietary technology and brand. However, many of them have successfully caught up and competed with MNEs from advanced economies at their home and abroad. Particularly, these firms are able to identify and acquire resources available in the market and combine them in a highly creative way that quickly adapts to the market requirements (Luo and Child 2015). In the early stages of market liberalization, emerging economies are mostly low-cost manufacturing bases for MNEs from advanced economies. Domestic firms in emerging markets mostly catch up by acquiring strategic resources through such inward internationalization as contract manufacturers (Kittilaksanawong 2015a; Kumaraswamy et al. 2012; Lamin and Livanis 2013; Li et al. 2010).

Due to the economic growth potential, emerging markets like India and China have also become the target markets of these MNEs. Because markets in advanced economies are relatively mature with limited growth opportunities, MNEs have increasingly made substantial investments not only in manufacturing but also in research and development (R&D) to better respond to requirements in emerging markets (Li and Kozhikode 2009). Accordingly, emerging markets, which traditionally play a peripheral role in the global innovation landscape, have emerged as important players in several knowledge-intensive sectors (Mathews 2006). This phenomenon is evidenced by an increasing number of innovation clusters in emerging markets and patents issued to domestic firms and MNEs in these markets (Li et al. 2010; Li and Kozhikode 2009).

Such inward internationalization has importantly opened up opportunities for domestic firms to catch up and compete with these MNEs at home and abroad. As the liberalization proceeds and the competition at home becomes more intense, an increasing number of domestic firms begin to look for better opportunities in overseas markets (Luo and Tung 2007). To compete successfully on the global stage, these firms begin to directly acquire more advanced strategic resources in advanced economies (Cui et al. 2014). More competent domestic firms even internationalize their R&D in knowledge-intensive industries to fulfill this aspiration (Awate et al. 2015).

In fact, both advanced and emerging market firms are relocating value-creation activities globally to control operation costs and to leverage strategic resources. The geography of these activities is essentially the outcome of a dynamic process. In particular, domestic firms from emerging economies are striving to catch up by developing competencies in higher value-added activities while firms from advanced economies are reducing operation costs by relocating high value-added standardized activities to emerging economies (Mudambi 2008). Innovation clusters, often established by emerging market governments, hence play an important role as a location-specific source of technological and knowledge externalities where domestic firms draw upon as a part of their catch-up strategies. Essentially, these clusters provide opportunities for domestic firms to have direct contacts with MNEs and other established domestic firms, which facilitate knowledge transfers (Li et al. 2010).

Given these recent phenomena, this study begins with the discussion about drivers of emerging market firms in seeking strategic resources for catching up and then investigates major catch-up strategies of these firms. First, we investigate their catch-up strategy as the result of inward internationalization. Second, we highlight a very unique compositional strategy of these firms to develop competitive advantages and compete with competitors from advanced economies that have sophisticated technological and managerial capabilities. Third, we investigate the means by which these firms use innovation clusters at home to access strategic knowledge of foreign and other established domestic firms. Fourth, we discuss the means by which these firms catch up by establishing overseas R&D subsidiaries. We then illustrate theoretical arguments derived from these catch-up strategies with cases of Indian and Chinese firms. Finally, we conclude the study with key implications for advanced economy firms as well as emerging economy firms and governments.

2 Drivers in Seeking Strategic Resources

Governments in many emerging economies have increasingly liberalized their domestic markets by providing policy incentives to attract foreign direct investments (FDIs) (Mathews 2006). This liberalization has attracted a large number of MNEs that possess advanced technological and managerial capabilities to enter the market (Kumaraswamy et al. 2012). Domestic firms in emerging markets thus experience increasing competitive pressure from the competence gaps vis-à-vis these MNEs (Cui et al. 2014). When existing competence becomes inadequate to cope with future competition, these firms are likely to initiate the catch-up processes. In particular, they begin to acquire strategic complementary resources through inward or outward internationalization (Dunning and Lundan 2008).

The catch-up strategies of emerging market firms are driven by their motive in seeking strategic resources. These resources are largely knowledge- and reputation-based, including technology, brand, and managerial know-how, available externally to the firm's current boundaries. This motive is typically characterized as aggressive and long-term oriented actions intended for transforming and building up core competences that are necessary for them to successfully position and compete with the global market leaders (Luo and Tung 2007; Kittilaksanawong and Dai 2014). The extent to which emerging market firms are driven to pursue such strategic actions is determined by their awareness, motivation, and capability for competitive catching up (Chen et al. 2007; Cui et al. 2014).

The awareness of opportunities and strategic needs of emerging market firms to close the competence gaps is shaped by their exposure to competitors and their own experiential knowledge about the competitive environment (Chen et al. 2007; Kilduff et al. 2010). In particular, emerging market firms are exposed to immediate and future competitive threats in direct competition with foreign rivals in their home market. This competition creates the awareness of competence gaps between these domestic firms and their potential global rivals, and strategic resources they need to close these gaps. The more they face competitive pressures from or engage in competition with foreign competitors in their home market, the more they become aware of these competitors' behaviors, their competence gaps, needed strategic resources, and the means to seek these resources to build or reinforce their capabilities and competitive market positions.

The motivation for catching up involves perceived incentives of the firm from pursuing such strategic actions to close the competence gaps (Chen et al. 2007). These incentives come from the firm's long-term perspective of growth opportunities and competitiveness. Firms in emerging markets with large competence gaps may not successfully compete against global leaders by only protecting their current competitive edge. Therefore, they are likely to perceive great incentives to proactively explore complimentary strategic resources through inward or outward internationalization to transform or rebuild their competitive positions. This incentive is especially relevant to privately-owned firms in emerging markets where state-owned firms have the prominent role in the economic development. Without implicit state protection, these privately-owned firms experience higher competitive pressure from increasing market liberalization and foreign competitors. Therefore, they are likely to have both strong awareness and motivation to seek strategic resources to catch up for long-term survival and growth opportunity.

The capability to catch up refers to the firm's internal financial resources and managerial capabilities to support competitive actions (Hambrick et al. 1996). Internal financial resources in the form of slack or retain earnings are critical in financing the high-risk and large upfront investments associated with the acquisition of sophisticated strategic resources. Sufficient financial slack reduces concerns over the success of such investments while promoting risk-taking behaviors during the catch-up processes. Firms are less likely to implement such risk-taking strategies, when their survival is questionable (Staw et al. 1981). Therefore, stronger past performance is an indicator that a firm has greater willingness and capability to make strategic investments to close the competence gaps. Accordingly, internal financial resources provide firms with both motivation and capability to pursue the catch-up strategies.

Managerial capabilities of firms in emerging markets are largely built on their experiential learning from inward internationalization as contract manufacturers for foreign buyers (Kittilaksanawong 2015a). Contract manufacturing provides these firms an opportunity to have direct interaction with foreign customers and exposure to global operations and competition. These firms are thus more knowledgeable about the customer needs and economic potential in overseas markets. Such experience mitigates the liability of outsidership and helps firms to better evaluate their competence gaps and catch-up potentials (Johansen and Vahlne 2009). Higher levels of such experience therefore strengthen managerial awareness about current and future competitive situations and their needed resources and capability to close the competence gaps.

3 Inward Internationalization and Strategic Linkages

Knowledge is a fundamental competitive asset in catch-up processes (Grant 1996). Firms can learn such knowledge internally and externally (Kogut and Zander 1992). However, as a latecomer, firms in emerging markets typically have limited human and technological resources while they are not located in mainstream sophisticated international markets. These limitations reduce their motivations to invest substantial efforts in developing technological innovation internally. They often overcome innovation hurdles and build up their capabilities by acquiring knowledge from external sources such as through strategic alliances, acquisitions, or innovation clusters.

As the market liberalization in emerging economies progresses, MNEs are increasingly internationalizing their operations into these economies mostly to quickly develop innovative products at highly competitive costs (Chesbrough 2003). These operations are not limited to only manufacturing. MNEs have also increasingly relocated their R&D activities in fast-growing, large emerging markets to better respond to local market requirements while innovating closer to their customers and manufacturing facilities (von Zedtwitz 2004). Such inward investments importantly provide opportunities for domestic firms in emerging markets to catch up in certain technology sectors, particularly through collaborations with these MNEs while leveraging supports from their home government (Li and Kozhikode 2009; Mathews 2006).

In the early periods of market liberalization, the government of emerging economies generally offers a number of policy incentives to attract the entry of MNEs (Dunning and Lundan 2008). The most appropriate entry mode choice for MNEs is one that maximizes the rents accruing from the combination of the MNE's firm-specific advantages (FSAs) and the host country's country-specific advantages (CSAs) (Chen 2010). FSAs of advanced economy MNEs are usually sophisticated technologies, products, processes, and organization while domestic firms in emerging economies are likely to possess CSAs in the form of local complementary knowledge including market- or distribution-related expertise. When these FSAs and CSAs are difficult to exchange in the market due to high transaction costs, which is usually the case, the preferred mode of entry is an equity joint venture (Hennart 2009). Importantly, equity joint ventures can mitigate risks from uncertain institutional environment in emerging markets (Peng 2003).

Equity joint ventures and technology collaborations offer domestic firms an opportunity to upgrade their technological competencies. However, domestic firms may not have sufficient absorptive capacity in terms of related human capital, financial capital, complementary assets, and appropriate organizational structures to assimilate and exploit advanced such advanced technologies (Cohen and Levinthal 1990; Kittilaksanawong and Ren 2013; Van den Bosch et al. 1999). Domestic firms are required to invest in such foundation early for successful catching up in the long run. In the early years of market liberalization and catching up, firms investing to build up absorptive capacity may however perform worse than those not doing so. Without incurring such costs, firms that are incapable or not able to do so may survive in the short run by continuing to serve existing market demands that remain unchanged.

Over time, as the market liberalization proceeds, the institutional framework in the host country becomes more developed. By then, MNEs may have already developed the competency to bundle their FSAs with complementary CSAs of domestic firms. MNEs may be more motivated to buy out the joint venture to fully control over operations in the host country (Cantwell and Mudambi 2005). However, to ensure the continuing technology transfer, the host government may impose additional requirements on MNEs. Although the collaboration remains continued, domestic firms, as contract manufacturers are likely mostly to learn manufacturing competencies from MNEs rather than more valuable marketing or advanced R&D knowledge (Mudambi 2008). To catch up further, domestic firms have to increasingly invest the relationship-specific asset to create trust with MNEs as their customer (Kittilaksanawong 2015a, b). Over time, such relation-specific investments reduce concerns of MNEs about supplier opportunism, thereby allowing the partners to recognize additional opportunities out of the collaboration (Gulati and Gargiulo 1999).

With trust, MNEs are more willing to transfer knowledge related to the product, production, and consumers to domestic firms as their contract manufacturers to ensure the performance and quality of the manufactured products. Through this opportunity, domestic firms are able to develop capabilities in fulfilling the sophisticated foreign demands, including new product designs. Indeed, many latecomer firms from Asia have successfully caught up by initially working as an original equipment manufacturer (OEM) for foreign buyers. Subsequently, these firms learn to master the manufacturing and design technology and become an original design manufacturer (ODM). Some of them have even successfully developed internal R&D capabilities or launched their own brand to become a global own-brand manufacturer (OBM) (Kittilaksanawong 2015a).

In fact, MNEs are likely to locate the high-value activities such as R&D and marketing in advanced economies, while outsourcing the low-value activities such as manufacturing to emerging economies (Mudambi 2008). The suppliers of these activities in emerging markets view this outsourcing as an opportunity to learn and move into higher value-added activities. Through this opportunity, many of them invest significant efforts to develop their own R&D and marketing capabilities (Kittilaksanawong 2015a). These efforts often generate negative cash flow in the short run as they draw resources from contract manufacturing and transfer them to R&D and marketing efforts where they are not experienced. However, over time, this dynamic capability links marketing knowledge to creating novel knowledge based on R&D (Winter 2003).

As the market liberalization proceeds further, the host government would be more interested to integrate domestic industries into the global marketplace by relaxing earlier restrictions on MNE's operations. During this period, the domestic market will become more competitive while MNEs have more sourcing options. To compete in the global marketplace, domestic firms need to invest in absorptive capacity and develop internal R&D competencies (Cohen and Levinthal 1990;

Kumaraswamy et al. 2012). As the liberalization matures, technology collaborations, customer relationship development, and internal R&D investments all become critical elements of successful catch-up strategies of domestic firms.

4 Innovative Imitation and Compositional Strategy

Most domestic firms in emerging economies are technologically and managerially backward. They do not possess valuable brands or sophisticated technological and marketing resources (Mudambi 2008). However, most emerging market firms are more able to distinctively compose ordinary internal and external resources in such a way that creates competitive advantages (Li et al. 2010; Luo and Child 2015). In particular, these firms achieve such competitive advantages by creatively combining open and generic technology, brand, and other input resources, which individually are not advantageous to the firm, to generate superior efficiency, speed, and price-value ratios (Luo and Child 2015).

Such individual resources are indeed neither idiosyncratic nor costly to imitate, and they are tradable in the market. Contributing to this compositional success are essentially the firm's market intelligence, organizational resilience, creative imitation, and entrepreneurship. These unique organizational attributes allow emerging market firms to integrate low cost with new product functions, and organize them in such an innovative way that quickly responds to the market dynamics, and provides increased competitive values to customers. Such compositional strategy is essentially formed via compositional offering, compositional competition, and compositional capability (Luo and Child 2015).

Compositional offering is a unique set of consolidated product functions within one product, which creates better responsiveness to customers than other competitive products. Compositional competition involves a set of consolidated means, including low cost, premium brand, and new functionality to successfully compete against rival firms. Many emerging market firms, especially small- and medium-sized enterprises (SMEs), realize that they do not have sufficient scale to pursue pure cost leadership (Zeng and Williamson 2007). Besides, these firms also lack advanced technologies and brand reputation to pursue pure differentiation (Luo et al. 2011). The composition of these two competitive measures thus provides an effective way for them to compete against competitors from advanced economies. Compositional capability refers to the extent to which a firm can synthesize and integrate disparate generic resources available in the open market in such a way that creates competitive advantage.

The composition strategy emphasizes the use of imitation as the input in the pursuit of adaptation rather than as the straight outcome (Luo and Child 2015). Emerging market firms leverage their unique imitation skills to generate competitive innovative edge. This innovative imitation is used to develop a new competitive strategy while becoming the foundation that supports future novel innovations. In particular, these firms select only certain aspects of the innovations available in the market that fit their goals and creatively adapt them to meet the local market requirements. Although the technology, design, or function of existing innovative products in the market are imitated, they are often significantly modified or improved to become competitive advantages of the imitator's new product offerings.

This innovative imitation creatively combines product, process, and organizational innovations available in the market (Hamel 2006). Many successful emerging market firms combine these three aspects of innovation they have learned from being contract manufacturers for advanced economy MNEs with their own distinctive managerial and innovative business model. They exploit both internal and external resources in the concurrent pursuit of OEM, ODM, and OBM for their advanced economy buyers in such a way that allows them to learn and build their compositional capability. In particular, the successful firms are able to concurrently leverage both exploitative learning from OEM and exploratory learning from ODM and OBM to generate a competitive compositional strategy.

5 Innovation Clusters and Agglomeration Economies

The increasing entry of foreign firms in emerging markets has imposed significant competitive pressure on domestic firms to upgrade and build up their competences. Catching up by these firms can occur from intentional transfers of technical and managerial competencies through joint ventures and technology collaborations, and knowledge transfer to these firms as a subsidiary of MNEs. Alternatively, catching up can also occur from unintentional spillovers such as through labor mobility, leakage of intellectual property, and imitation (Alcacer and Chung 2007). These unintentional spillovers are more likely to take place in innovation clusters, which are typically established by the governments in emerging economies to expedite the catch-up processes of domestic industries.

Innovation cluster is an important channel for knowledge transfer in emerging economies. Clusters refer to geographic concentrations of firms and institutions that are interconnected in a particular field (Porter 1998). By co-locating manufacturing facilities and other activities including R&D, firms can benefit not only from economies with respect to supplies and demands, but also from spillovers of valuable knowledge (Almeida and Kogut 1999). Firms in emerging markets are often superior in combining outside technologies with their own resources (Luo et al. 2011). Innovation clusters and co-location therefore offer an efficient way for emerging market firms to learn from other proximity firms and accelerate their own capability building.

As MNEs offshore more sophisticated and higher-value activities including not only advanced manufacturing processes but also designs and R&D to emerging markets, domestic firms in these markets are likely to benefit more from the knowledge spillovers (Meyer and Sinani 2009). This dynamics implies that the location choice of both foreign and domestic firms can determine the success of catching up. Geographical proximity of firms in a cluster increases the frequency of personal contacts and thus accruing the strength of social relations, which in turn, reduces transaction costs between companies, thereby facilitating the flow of knowledge (Saxenian 1991).

Domestic firms may locate their operations geographically close to foreign or other established domestic firms in the same or different industries within clusters in their home country as a way of facilitating the sharing of complex tacit knowledge (Lamin and Livanis 2013; McCann and Folta 2008). Such co-locations allow domestic firms to utilize their local social capital to better gain access to external knowledge and resources (Lamin and Livanis 2013). Although knowledge flowing freely in clusters is mostly standardized and more easily imitated (Mudambi and Swift 2012), it can be the foundation for domestic firms, which are mostly technologically and managerially backward, to initially engage in creative adaptation (Luo et al. 2011).

Same-industry agglomeration can facilitate specialized knowledge spillovers between nearby organizations, thus enabling domestic firms to generate new related knowledge (Glaeser and Kerr 2009). Domestic firms can benefit from spillovers of specialized labor, technology and, other inputs, as well as greater customer demands (Marshall 1898). Same-industry agglomeration also attracts specialized suppliers in the areas of market research, testing, and consulting services (McCann and Folta 2008). Labor markets in same-industry agglomeration are thus likely to have higher quality (Hanson 2000). Firms in emerging markets typically have a distinctive ability to obtain necessary resources from outside (Luo et al. 2011). These locations thus offer domestic firms an opportunity to learn through observation, environmental scanning, as well as, formal and informal relationships with industry peers (Uhlenbruck et al. 2003).

The benefits of agglomeration can also occur between firms in different industries. The technologies diffused from one industry can create more value when they are applied in different industries (Rodan and Galunic 2004). In particular, cross-industry knowledge spillovers can complement or extend existing knowledge. The cross-fertilization of knowledge between industries can also strengthen a firm's absorptive capacity that increases the opportunity of unexpected innovations (Feldman and Audretsch 1999). Indeed, many firms in emerging markets have demonstrated their distinctive ability in identifying, assimilating, and modifying the externally acquired knowledge and effectively adapting it to fit their local market conditions (Luo et al. 2011).

Established domestic firms are likely to possess localized knowledge and institutional ties (Kittilaksanawong et al. 2013). Novel ideas may be available and easier to flow among firms with similar background that are situated within the proximity locations (Glaeser and Kerr 2009). Therefore, co-location with established domestic firms may provide access to easily duplicate, absorbed, and integrated domestic knowledge and resources. Domestic firms may also expect to locate near foreign firms to access more sophisticated strategic resources. One way for these firms to appropriate advanced technologies from MNEs is through unintentional spillovers such as mobility of labor, leakage of intellectual property, and imitation (Kumaraswamy et al. 2012). Domestic firms can also benefit from knowledge spillovers through transacting with foreign suppliers, customers, and competitors.

6 Outward Internationalization of Research and Development

With the escalating competition at home and abroad, firms in emerging markets have begun to internationalize their operations not only to seek new market opportunities but importantly to also acquire more advanced knowledge to strengthen their long-term competitiveness. As such competition has increasingly focused on geographically dispersed technology and innovation, internationalization of R&D is an important strategic move for emerging market firms to build up new resources and capabilities (von Zedtwitz and Gassman 2002). Emerging market firms pursue catching up not only through inward internationalization as discussed earlier but also through outward internationalization of their R&D. In particular, by establishing R&D subsidiaries in advanced economies, these firms can create alliances with suppliers, customers, competitors, universities, and public R&D institutes in those economies, which facilitate valuable knowledge flows, learning, and successful technological catching up (Oxley and Sampson 2004).

In the context of emerging market MNEs, the headquarters often gives a high level of autonomy to the foreign subsidiaries in creativity and innovation activities, while expecting them to generate new knowledge that may also be replicated, recombined, and used within the MNE's network (Awate et al. 2015). In the early years of this outward internationalization, the headquarters thus assumes a distant role in the overseas subsidiary. The headquarters is viewed as the network administrator of intra-organizational knowledge flows among overseas R&D subsidiaries for the corporate's catch-up purpose (Mudambi and Navarra 2004). The headquarters often possesses a lower level of strategic knowledge than its subsidiaries. Therefore, to catch up, the headquarters has to initiate reverse knowledge flows from the overseas subsidiary.

Technological catching up is generally more complicated and it takes much longer time than traditional output or production catching up (Awate et al. 2012). The relevant processes of building technological capabilities are usually causally ambiguous and socially complex (Dierickx and Cool 1989). Replicating these capabilities within an organization involves significant cooperation among the R&D subsidiary, the headquarters, and the other organizational units within the firm. The bargaining power of R&D subsidiary depends on the extent to which it controls important knowledge (Mudambi and Navarra 2004). Therefore, the R&D subsidiary may opportunistically retain its knowledge advantage vis-à-vis the headquarters (Gupta and Govindarajan 2000).

In particular, the interest of subsidiary managers may not always align with that of the headquarters. Instead, the subsidiary manager may focus on rent seeking for benefits of the subsidiary rather than the organization as a whole. To minimize such opportunisms and ensure successful catching up at the corporate level, the headquarters of emerging market firms has to devise appropriate incentives and monitoring mechanisms to ensure its access to the knowledge of overseas subsidiaries. However, the legal and legitimate authority of headquarters tends to diminish as the subsidiary accumulates more strategic knowledge, which enhances its negotiation power vis-à-vis the headquarters (Mudambi and Navarra 2004). Accessing knowledge of overseas subsidiaries within the emerging market MNE's network is thus a difficult and time-consuming process (Awate et al. 2015).

The extent to which a firm can exploit external knowledge regardless of acquisition modes critically depends on its ability to absorb such knowledge. This absorptive capability is essentially determined by its internal efforts including investments in R&D and marketing activities. Particularly, R&D efforts allow firms to be able to modify externally acquired knowledge to fit local market requirements (Li et al. 2010). With sufficient levels of absorptive capacity, firms are more able to absorb, assimilate, and adapt externally acquired knowledge and accordingly are more able to generate novel innovations.

7 Illustrations of Catch-Up Processes by Indian and Chinese Firms

Domestic firms in India and China have made significant changes to their strategies and structures in recent years in response to globalization and market liberalization in their home country (Kittilaksanawong and Dai 2014; Kumaraswamy et al. 2012). These firms have accelerated their technological catch-up efforts as evidenced by the growing number of their international strategic alliances and acquisitions (Luo and Tung 2007). They have also increasingly invested in internal knowledge building activities such as R&D and marketing in order to develop competencies in response to the increasing transfer of higher-value activities from advanced economy MNEs to their home economy (Mudambi 2008). The strategic intent of these emerging market firms to pursue catching up is importantly driven by their awareness, motivation, and capability as discuss earlier (Chen et al. 2007; Cui et al. 2014).

Traditionally, firms in India and China largely control low-value, thin-profit manufacturing operations. These firms thus have strong incentives to acquire the higher-value strategic resources such as R&D and marketing to increase control over the higher-value upstream and downstream activities (Kittilaksanawong 2015a). Many firms invest their R&D and marketing activities in advanced economies to strengthen their absorptive capacity and build their own innovation capability (Luo and Tung 2007; Zahra and George 2002). Meanwhile, firms from advanced economies that mostly control high-value activities are faced with increasing cost competition from new entrants from emerging markets that are catching up. These firms thus have strong incentives to increase the efficiency of their high-value activities by outsourcing standardized activities from the upstream R&D and downstream marketing to emerging markets (Mudambi 2008). This dynamics importantly generate knowledge spillovers into emerging markets, which in turn, facilitate the catch-up processes of domestic firms in these markets.

The global mobile handset industry well reflects this dynamics as both innovation and cost continue to impose intense competitive pressure on all of the industry's value chains (Mudambi 2008). While the global sales of mobile devices, particularly in emerging markets like India and China continues to rise, the profitability of the industry becomes relatively modest. Consumers in both emerging and developed markets are highly conscious about product design differentiations. The Chinese firms like Huawei that began as OEM for MNEs have successfully built marketing competencies and developed their own brands. Initially, the company competed with popular brands on the basis of low cost, but over time, its brands have become more valued and accepted.

Facing this competitive pressure from emerging entrants, advanced economy manufacturers like Apple, Nokia, Ericsson, and Motorola have strived to innovate by focusing on designs that met diverse needs of individual markets to enhance the value of their brands. In the short run, these high-value design activities largely remain concentrated in advanced economies. However, as consumers in emerging markets continue imposing demands on the product's designs, in the long run, these advanced economy leaders would have to relocate such activities to emerging markets and deliver location-specific product designs.

The automotive industry in India during market liberalization (1992–2002) well illustrates the catch-up process dynamics through inward internationalization of MNEs (Kumaraswamy et al. 2012). Global automobile manufacturers have followed the Japanese in outsourcing components, while developing long-term close relationships with a few key suppliers (Cusumano and Takeishi 1991; Kittilaksanawong and Palecki 2015). The mature nature of the automotive industry and sophisticated technology have induced intense cost competition among firms. MNEs are required to develop local supply chains as well as rigorous quality and testing procedures in the new markets (Humphrey 2003). Meanwhile, the liberalization in emerging markets have also imposed significant challenges on domestic suppliers in upgrading and building their competences to integrate themselves into the MNE's global supply chain network (McDermott and Corredoira 2010).

In the automotive components sector, the Indian government placed fewer restrictions on inward internationalization to attract the entry of MNEs during the onset of market liberalization (1992–1997). During this transition period, MNEs began entering the market, while domestic firms began to adapt to this open market competition. Domestic firms mostly caught up during this period through forming technology licensing or joint ventures with these MNEs. These strategic alliances facilitate the linking, leveraging, and learning (LLL) processes of catching up (Mathews 2006). Few domestic companies are able to develop necessary skills in-house and such collaboration thus provides an opportunity for them to quickly obtain complementary skills or technologies. Strategic alliances allow firms in collaboration to share risks and costs involved in the development of expensive and uncertain technologies. The alliances also facilitate learning of tacit knowledge and creation of new knowledge through close contact with other partner firms.

However, as the liberalization continues and MNEs have acquired more complementary knowledge from the domestic firms, the motivations of MNEs to continue these collaborations tend to decrease. With sufficient local knowledge, MNEs would prefer to have full control through buying out the venture. To induce MNEs to continue helping upgrade domestic firms and industries, the Indian government imposed a more restrictive policy on MNEs in exchange for market access (1998–2002). During this period, domestic Indian firms attempted to upgrade their capability, while MNEs adjusted to this new policy and consolidated their position in the industry. Finally, during the global integration period (from 2002), the Indian government implemented the new automotive policy, which removed most restrictions on MNEs to increase global integration of the domestic industry. Domestic Indian firms have attempted to integrate themselves into the MNE's global value chain through developing strong relationships with downstream firms. Successful domestic firms have also emphasized in-house knowledge creation by investing in internal R&D (Kumaraswamy et al. 2012).

Great Wall Motors, a Chinese automotive company founded in 1984, successfully caught up by emphasizing R&D rather than scale building. Great Wall began as a vehicle-repair company and then manufactured trucks for the Chinese market. The company built up its own R&D strength from the very beginning by investing in a world-class testing facility (Jullens 2013). It formed alliances with global suppliers to develop advanced technologies and to maintain high quality standards. Great Wall carefully expanded its dealer network and kept close relationship with dealers to ensure their service performance. When expanding the market, the company concentrated resources on only a few models that were built on an existing platform to ensure successful competition. With the strong technological foundation, the company emerged to become one of the largest automakers in China.

Similarly, Wanxiang Group, a Chinese automotive component supplier, founded in 1969, initially focused on only one product line while improving quality performance and lowering costs (Jullens 2013). Through superior quality at the low cost, the company won major contracts from world-class multinationals. It then gradually moved from low-value to higher-value part suppliers. While emphasizing R&D along the catch-up processes, Wanxiang also scaled up its operations by acquiring over 30 companies around the world.

China International Marine Containers, a Chinese container manufacturer founded in 1980, initially focused only on their strength in low-tech containers while scaling and consolidating its position in China (Jullens 2013). The company grew by acquiring local competitors to become the largest container manufacturer in the country. With sufficient scale, it diversified into high-quality refrigerated containers through joint ventures and acquisitions while heavily investing in its own container technology. Nevertheless, the company kept focusing on its strong capabilities in high-quality, low-cost container manufacturing.

Chery Automobile, a Chinese automotive company founded in 1997, well demonstrates the use of strategic alliances as the foundation for accelerated technological catching up (Zhang and Yang 2015). Compared to the Western popular automotive manufacturers, Chery lacked technological resources and brand name. Despite these obstacles, the company successfully developed and positioned itself to be the top automobile exporter among Chinese automobile companies. Its motivation to focus on export markets was due to intense competition in the domestic market. Most of the automobiles sold in China were jointly produced by the large state-owned enterprises under global well-known brands. Chery initially exported to other emerging markets like Brazil, Russia, Iran, Mexico and South Africa. The lessons learned from these markets facilitated its subsequent entries in advanced markets.

Chery adopted open innovation along with its international expansion path. During the initial stage of capability development, the company relied on its supplier's innovation. As the outside-in process of open innovation, it commissioned several R&D projects for specific car and engine designs to leading foreign automobile companies. As the inside-out process, Chery established a number of international strategic alliances and joint ventures in emerging countries. Chery transferred its technological and management knowledge the manufacturing of cars in these countries, while reducing the costs for international sales and services. Its main catch-up and growth strategy was through strategic alliances. The company established factories in Russia and Argentina to reduce costs of transportation and to increase efficiency of manufacturing. Sales and marketing experience in these developing markets was foundation for Chery to further expand in developed markets.

In China, Chery built many relationships with foreign companies and domestic suppliers, as well as universities and research institutes to develop multiple car brands and models as well as new technologies. However, the company was not quite successful in the home market operations (Jullens 2013). In particular, Chery lacked capabilities for managing multiple brands and models. It produced over 30 models in China but could not generate sufficient sales to cover investments in each model. Instead of adopting a balanced growth strategy, Chery aggressively expanded networks of dealers. However, the sales volume could not support the continued operations of these dealers. The company eventually had to reduce the number of brands and models while significantly cutting down the number of dealers and personnel.

BYD, a Chinese rechargeable battery company founded in 1995, was originally a Chinese manufacturer of low-cost batteries for cell phones. After achieving the global leader in the battery market, BYD aspired to become the global leader in electric vehicles (Jullens 2013). It borrowed car designs from Japanese manufactures. The company produced not only cars but also almost all other necessary parts. Initially, it primarily focused on scale building by rapidly diversifying to preempt competitors. It rapidly expanded dealerships in China to boost sales volume. However, it did not sufficiently invest to build up the capability to master the complex automobile product development while pursuing such scaling up. After the consumer demand for electric vehicles declined, BYD's market share was taken away by competing manufacturers of better-quality vehicles.

Xiaomi Technology, a Chinese smartphone company founded in 2010, well represents the successful compositional strategy of emerging market firms (Luo and Child 2015). The company was changing the competitive landscape of smartphone in China and potentially in the world. Its compositional offering included all-in-one numerous product features and functions through hardware, software, and internet at mass-market prices. These features and functions were not just added to the device, but rather, they involved technological reconfiguration, and recomposition with redesign of integral components. Such compositional offerings became widely available because of the greater access to open technical platform and low-cost alternative technologies.

Instead of building new product innovation, most Chinese companies apply scale-based technology and invest in resources that improve cost efficiency via process improvement and recombination of existing technologies (Zeng and Williamson 2007). Similarly, Xiaomi integrated the key components purchased from the top suppliers through innovative long-term supply agreements. The close relationship with suppliers allowed Xiaomi to use world-class off-the-shelf components that its partners jointly developed with global competitors like Apple and Samsung.

Xiaomi's catch-up strategies were mainly built on reverse engineering, benchmarking, advanced technology licensing, and adaptive technological innovation. The company effectively used creative low-cost methods including online social media on its own platform to sell products and maintain intimate relationship with users, which further drove its innovation. Xiaomi's business model innovation was distinct among other industry leaders. The company sold good-quality cellphones at a low price, while keeping shelf life of each model longer. With its creative business model, instead of charging high prices for state-of-the-art components, Xiaomi's phones were only a little more expensive than those of other industry leaders.

Suzlon Energy, an Indian wind turbines manufacturer founded in 1995, successfully caught up with the global leaders by establishing an extensive network of R&D subsidiaries in advanced economies (Awate et al. 2015). It combined knowledge of Indian market and foreign technologies and devised a customer-oriented strategy. Only four years after the inception, the company became dominant in the Indian wind power market. Suzlon internationalized its R&D to access advanced wind turbine technologies of firms in developed markets, which facilitated its technological catch-up processes. The company pursued a series of acquisitions to obtain the novel foreign technologies and to enter new markets.

Initially, the company focused on output catch-up to develop sufficient production capabilities to gain sufficient revenue stream before investing in innovation capabilities. Knowledge management in this output catch-up was mainly imitative. Such knowledge was initially used to manufacture the latest products to scale up the sales volume. For example, Suzlon entered technology collaboration with a German company, Sudwind in 1995 and acquired it in 1997 to gain the basic engineering and manufacturing knowledge to enter the global wind turbine market. Later on, the company acquired firms with significant R&D assets to leverage their advanced technologies while investing to build its own capabilities.

Particularly, the subsequent acquisition of REpower, a German wind turbine manufacturer, in 2007 was to access its R&D knowledge and combine this knowledge with its capabilities in low-cost and efficient manufacturing. However, after the acquisition, REpower refused to share its technology with Suzlon. In all cases, Suzlon’s headquarters held lower levels of strategic knowledge than its R&D subsidiaries in advanced economies. As the subsidiary, acting as the agent, holds more strategic knowledge, it has more negotiation power than the headquarters. The opportunistic behavior of the subsidiary's managers can be a problem. Suzlon had to negotiate with REpower to initiate even the reverse transfer of manufacturing knowledge. REpower leveraged the protection under the German law to exercise the right to refuse sharing advanced R&D with Suzlon. It was very time-consuming for Suzlon to negotiate with REpower to initiate the reverse transfer of such strategic knowledge.

8 Discussion and Conclusions

Catching up refers to the processes by which firms in developing economies improve their technological know-how and develop capabilities in high value-added activities (Kumaraswamy et al. 2012; Mudambi 2008). The strategic intent of emerging market firms to pursue such catch-up actions is driven by their awareness, motivation, and capability (Chen et al. 2007; Li et al. 2010). Catching up is a dynamic process that changes as the market liberalization in these economies proceeds (Kumaraswamy et al. 2012). The liberalization and catching up require that domestic firms make significant changes to their strategies and structures.

To successfully catch up, domestic firms must be able to identify, acquire, and use externally generated knowledge. The inability to successively adapt their strategy and structure within such uncertain competitive environment may result in the catch-up failure. An important reason of catch-up failures is the lack of investing in absorptive capacity (Cohen and Levinthal 1990). Absorptive capacity essentially helps firms to identify, absorb, and adapt relevant external knowledge to generate new knowledge and successful product innovations.

During the high market growth following the liberalization in emerging economies, domestic firms mostly focus on scaling up the outputs to meet such market growth rather than investing in R&D or marketing efforts to build up innovation capabilities or strengthening brand values (Jullens 2013). They often acquire technologies by all means or simply imitate the products and processes of firms in advanced economies. Imitation and efficiency to drive outputs to rapidly catch up the market growth are an effective approach when markets are rapidly growing. Besides, political connections of some domestic firms through their founders who were once key government officials are also their competitive advantage. However, as the liberalization becomes more mature and the market growth slows down, most of these firms are unprepared to compete on quality, designs, or innovative branding.

Most domestic firms in emerging markets do not conduct in-house R&D or emphasize marketing efforts (Li et al. 2010). Investments in these high-value activities are the essential foundation for creating ability of firms to absorb external knowledge, which further strengthens the positive effects of knowledge access channels on product innovations. Particularly, R&D investment has a direct influence on a firm's absorptive capacity (Cohen and Levinthal 1990). Although firms have access to external advanced knowledge, without sufficient investments in internal resources to strengthen their absorptive capacity, they may not successfully build up their own innovative capabilities and transform themselves from imitators to innovators (Li et al. 2010).

Major channels for emerging market firms to access external knowledge are through intentional knowledge transfers such as in strategic alliances and acquisitions (Awate et al. 2015; Kumaraswamy et al. 2012; Luo and Child 2015), or through unintentional knowledge spillovers such as in innovation clusters (Lamin and Livanis 2013). As the market liberalization in the home country begins, most of these firms catch up through inward internationalization. They are mostly contract manufacturers such as OEM or ODM for foreign companies. Through these alliances, many firms access advanced knowledge and invest in internal R&D or marketing efforts to successfully build up their own innovation and brand marketing capability (Kittilaksanawong 2015a). Technology collaborations, customer relationship development, and internal R&D investments are all critical elements for the successful catch-up strategies of domestic firms in emerging markets (Kumaraswamy et al. 2012).

Location choices for such inward internationalization in emerging economies play an important role in the catch-up opportunity. Co-location provides learning opportunities through unintentional knowledge spillovers from diverse sources (Lamin and Livanis 2013). It is an attractive catch-up strategy because almost all domestic firms can relocate their operational facilities to be close to those of foreign or established domestic firms. However, only some firms with sufficient resources can pursue other formal mechanisms such as joint ventures or cross-border acquisitions. Besides, these firms are usually already more skillful in combining outside technologies with their own resources instead of creating an original novel technology for product offerings (Luo et al. 2011).

The knowledge available through spillovers in agglomerations is often non-proprietary since high-value knowledge is likely to be codified (Mudambi and Swift 2012). However, given that domestic firms in emerging markets are mostly technologically and managerially backward, this type of knowledge would be an important foundation for them to initially engage in the catching up (Meyer and Sinani 2009). Co-location is thus a strategy for these firms to initially imitate observable technologies and managerial practices to narrow down their competence gaps. Indeed, catch-up processes of emerging market firms in the beginning typically involve a high level of imitation of existing technologies and practices. However, as these firms keep investing in internal R&D, such duplication may evolve into innovative imitation and eventually novel innovation (Luo et al. 2011; Luo and Child 2015).

Firms in both advanced and emerging economies have increasingly relocated their value creation activities across geographical locations. To reduce costs, firms in advanced economies outsource standardized high-value activities to local firms in emerging economies. These outsourced activities are rapidly transferred to suppliers in different locations (Mudambi 2008). This process tends to result in knowledge spillovers, which provide an opportunity for local firms to catch up. As the catch-up process progresses, through such supply networks, these local firms often continue to seek more advanced competences by further investing R&D in advanced economies (Awate et al. 2015). Over time, local firms in the network have built up their capabilities and become competitors against their MNE partners (Kittilaksanawong 2015a).

The knowledge-backward status and the dependency on accessing external knowledge rather than investing to build internal knowledge are catalysts for domestic firms in emerging markets to become better aware of their weaknesses, which in turn, prompt them to devise novel competitive strategies. Due to the lack of technological history, these firms are less confined to technological path dependence. They possess high flexibility to search for resources more widely across locations and combine them with existing resources in novel ways (McGaughey 2002). These initial conditions significantly contribute to the successful implementation of compositional strategies often used by emerging market firms.

Compositional strategies allow domestic firms to create higher-quality and higher-value products to compete against competitors from advanced economies and to capture more growth opportunities (Luo and Child 2015). These strategies fit well with the current competitive environment where many resources are available for purchase in the open market. Emerging market firms without distinctive resources can become highly competitive through the innovative composition of these generic resources. However, compositional strategies, depending largely on external resources, may not offset internal competitive weaknesses and create sustained competitive advantage in the long run. This strategy is appropriate particularly for SMEs in the early stages of the catching up. After domestic firms have gone through such imitative catch-up stages, they are required to invest in internal R&D to develop their own distinct organizational resources.

An initiative to develop such distinct organizational resources is to acquire geographically dispersed knowledge by internationalizing R&D activities (Awate et al. 2015). Many emerging market firms have rapidly become the market leader due to their ability to access established knowledge (Luo and Tung 2007). Particularly, their overseas subsidiaries upgrade or create advanced R&D capabilities and the headquarters replicates them throughout the MNE's network for the overall organizational innovation. Such reverse flows of knowledge require that the headquarters tactfully negotiate with the subsidiary to transfer the knowledge (Awate et al. 2015). The catching up within emerging market MNEs is thus more difficult and time consuming. Managers of emerging market firms pursuing R&D internationalization for such purpose should be more careful in devising mechanisms for the reverse knowledge transfers.

Capability building for firms in emerging markets is a time-consuming process because these markets lack competent suppliers, distribution networks, and qualified talents (Jullens 2013). Companies have to move quickly in the early stage of market liberalization through their existing capabilities. Once they are up and running, they should focus on getting the business model right for profitability. Many companies only emphasize efficient manufacturing to rapidly scale up to meet the market growth. They neglect developing the innovation capabilities in product design and engineering and quality management, which are necessary when the market becomes mature.

One way to attain such capabilities is to learn through contract manufacturing. Having developed such capabilities, the companies should focus on scaling up such as by acquiring competitors to consolidate their position and be leading players in the home market. The open innovation strategy that seeks technologies from external sources alone may not be sufficient. Importantly, they need to change their organizational structures and processes and invest in internal R&D to strengthen absorptive capacity, which is a critical element for them to move from imitative-driven to innovative-driven catch-up strategy. However, they should not over-stretch their internal resources. They should keep product lines and markets relatively narrow, while filling competence gaps through greater investments in R&D, partnerships, or acquisitions (Jullens 2013). Over time, they should expand into higher-value customer segments and markets. They should integrate a portfolio of strong brands, innovation capabilities, and sophisticated marketing capabilities to build their distinct competitive advantage.

To preempt the emerging market competitors, firms from advanced economies can use the drivers of their strategic intent for catching up including awareness, motivation, and capability (Chen et al. 2007) to identify and assess potential challengers from these markets, and implement upfront strategies to prevent them from turning into the rivals. Governments in emerging economies can also use these drivers to identify and support the potential domestic candidates to successfully catch up to be on par with the global competitors. They should also support the development of innovation clusters to facilitate the catching up of domestic firms that do not have sufficient resources in pursuing joint ventures or acquisitions.

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Best Strategic Decisions in Management of Complex Operations

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Abstract This paper explores practice and presents further development on typologies for strategic integrative capability development. The study includes an inductive investigation comprising seven different cases exploring specific aspects of the operations in five competing engineer to order companies. The focal companies use the same best practice framework for integration of operations in their contract with the same customer. I describe how the case companies configure their operations and develop strategies and practices for their integrative capabilities. The paper expands the domain of integration research within operations management by providing a contextual description based on multiple case studies investigated by the use of focus group interviews in combination with conceptual development of ideal types based in the strategic configurational theory and concepts from supply chain integration. The empirical evidence is not used for theory testing, but exploration of industrial practice. The paper discuss and propose typologies for strategic decisions in management of complex operations with special attention to turbulent environments for engineer to order supply chains.

Keywords Configurational approach · Turbulent environment · Supply chain integration

1 Introduction

Research on integration is not new to operations management. Integration as phenomenon is a typical ingredient in supply chain management. The study of integration is related to the impact on the operational performance. Studies of the effect from integrative practices on operational and business performance are producing conflicting conclusions (van Donk and van der Vaart 2005). The evolution of integration in the field has been progressing from the integration of operations

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vertically between operations and business strategy of the 1980s, to the horizontal focus with process integration in the 1990s, moving towards supply chain integration with delivery integration from supplier to customer and information integration from customer to supplier at the turn of the millennium (Frohlich and Westbrook 2001).

The main theme in the empirical part of this study is related to various forms of integration, and the context of the operational systems in place to handle maintenance and modification contracts on offshore assets for oil and gas production. These are long term contracts and a production system is set up to provide the services and deliveries required for the asset at any given time. Their assignments are solved as projects, and there are numerous assignments being processed simultaneously. We recognize this practice within the definitions of engineer to order supply chains (Hicks et al. 2001). In the empirical part of this study, I am interested in studying is how development of integrative practice is handled as a part of their continuous improvement program. They have a contractual obligation to have such a program in place. This is a part of an industry developed best practice for development of integrative capabilities. Use of best practices is a paradigm in operations management. The assumption is that adaption of best practice leads to superior capabilities and performance (Voss 1995). A critical review of the integration research concluded that the phenomenon has been defined too limited, without sufficient concern to contextual factors, with too much emphasis on integration as an organizational concept (instead of dyadic or as a network phenomenon) and the methods used are not sufficiently explorative (van Donk and van der Vaart 2005).

The objective of this study is to explore practice and present an empirically grounded description of integrative practices within the offshore oil and gas industry. As a starting point for the exploration, I look at current practices for development of integrative capabilities. What are the variables, what and who is in the domain and how do these variables connect in this specific domain. To address these questions we ask how the operations are organized, where do they see the best potential from improvement of integrative capabilities, what are the current issues within the specific aspect of the operations and which initiatives can they propose for future improvements of the aspect? What are the best strategies for management of complex operations?

The multiple case study gives opportunities to explore practice. I use an industry grown best practice in the fieldwork. The data is collected through focus group interviews, and the research design for the data collection and multiple case studies is presented after presentation of the conceptual framework in next section. The case study is the basis for the initial report on empirical findings. After the initial findings, I will present a theoretical background and perspectives for further discussion of the cases. The last section contains discussion of the cases related to literature and conclusions with implications for practice, theory and methodology.

2 Conceptual Framework "Best Practice at Work"

The research presented in this paper is related to a conceptual framework of integrated operations as a tool for continuous improvement of operational performance. The concept has emerged in the oil and gas industry the last two decades (Lilleng and Sagatun 2010). The industry definition of this framework is (IO Center): "Integrated Operations (IO) is the integration of people, organisations, work processes and information technology to make smarter and faster decisions. It is enabled by global access to real time information, collaborative technology and integration of multiple expertises across disciplines, organisations and geographical locations." The key variables in the framework are the level of integration within and between people, organisations, work processes and information technology. The concept argues causality between the level of integration, and smarter and better decisions, which in turn will result in a better operational performance.

The seven success criteria for integrated operations are listed in Table 1: Success Criteria of Integrated Operations (Lilleng et al. 2012; Lilleng and Sagatun 2010). The last five address technology and infrastructure, while the two first address

Table 1 Success criteria of integrated operations; elaboration from (Lilleng et al. 2012; Lilleng and Sagatun 2010)

No.	Success criteria	Capabilities for best practice
7	Mindset, leadership and training	Transparent leadership, utilize new ways of working, integration competence, sustainable change, continuous improvement, learning organization (active training)
6	Organization, roles and responsibilities (governance)	Harmonized and documented work processes, clear competence requirements, mandates and decision authority, clear and standardized roles, responsibilities and relational links, clearly stated requirements for information needs, best practices etc. for describes tasks within work processes, collaborative work processes (between disciplines/skills and locations)
5	Collaboration functionalities and work arenas	Technology and physical space for access to information and connection between team members independent of location
4	Information visualization and workspaces	Enable cross-disciplinary and proactive use of relevant information, where workspaces that are adapted, presented and visualized with the work process context in mind, information can come from various sources and must be aggregated to fit the decisions relevant for the specific work processes
3	Information access, integration layer	Users must have access to appropriate applications and information must be available across applications

(continued)

Table 1 (continued)

No.	Success criteria	Capabilities for best practice
2	Communication infrastructure and data transmission	Capacity for large data quantities without latency and with sufficient uptime and security, handle multiple technologies
1	Data capture and data basis	Use of advanced sensors and automated data capture, rich data sources, capacity to handle and store large datasets

organizational structure and human factors. These are used for elicitation when conceptualizing improvement initiatives within integrative capabilities. These capabilities are developed in parallel to harvest the full benefits of integration. For instance is it not a sufficient condition for success if only the technology is in place, while the roles and responsibilities are poorly defined, and vice versa. The framework is expected to have a normative character, providing a prescription for improved operational performance. The foundation for it is developed in the empirical world. There is a lack of studies questioning the validity of the framework. For instance, are the success criterions sufficient conditions for success and are they sufficiently operationalized into measurable scales?

3 Research Design

This paper presents an inductive exploration of integrative practice. The starting point is in the empirical world. What is going on in the organization? There are issues related to who holds the truth in relation to organizational behavior (March and Sutton 1997). There are several work processes within one organization. Each consisting of activities to produce the deliverables needed to serve the organization's purpose. To make an organization work, the people need to interact, serving different roles and responsibilities. However, it is not clear that a single conception of purpose is shared among participants in an organization (March and Sutton 1997). To understand an organization one will need insight into many variables. Another property of organizations is the constant change, the organization evolve over time.

Data Collection March and Sutton (1997) points out the complex task of identifying causal structures in organizational performance from historical archives, as performance is influenced by external factors, feedback loops are ignored and reconstructed records can be influenced by subsequent performance results. To get a shared account of reality we use several sources. Both governing documents and focus group interviews are used. The documents contain statements on how the organization intends to operate. The interviews give an account for the current practice and their collective believes about what the future holds. "The focus group employs guided, interactional discussions as a means of generating the rich details of complex experiences and the reasoning behind [an individual's] actions, beliefs, perceptions and attitudes" (Powell and Single 1996). The term focus imply the engagement in a collective activity over a presented subject (Kitzinger 1994), In this study we call the subject an aspect. Interaction between participants highlights their view of the world and is the crucial feature of focus groups. The production of data happens in the interaction between informants and with the researcher. Focus groups are especially useful when existing knowledge is inadequate, the subject under investigation is complex, have a number of variables and needs triangulated evidence (Powell and Single 1996), which is the situation we are facing when seeking empirical evidence from an organization (March and Sutton 1997).

Multiple Case Study An appropriate research method when studying contemporary practices is case study research (Yin 2014). The empirical evidence is handled as case studies and the analysis is handled as a multiple case study (Yin 2014). The investigation into an aspect of the operations at a focal organization is the unit of analysis. The aspect forms the boundary of the cases. To emphasize an exploratory research design as a part of theory generation we did not base the inquiry on existing literature (Ketokivi and Choi 2014), but used the industry developed best practice framework presented above as starting point. This is to avoid limiting the findings to the usual variables already discussed in literature. However, several concepts from literature has been included in the discussion and sense making of the case findings.

Sampling Logic The sample for collection of data in this study is based on an analytic sampling logic due to the contractors' similar conditions. In addition the sampling is based on convenient access to the organizations. The sample constitutes all the five contractors providing maintenance and modification services to offshore assets for one oil company. All the contracts are with this same customer. Each of the contractors supports more than one asset, but no asset is supported by more than one contractor for maintenance and modifications. The contracts was awarded in 2010 and lasts for 7 years. The contracts include requirements related to integrative capabilities, which make these contractors suitable for research in integrative behaviour within or between organizations.

Case Boundary The basis of our inquiry is a series of focus group interviews. The aspect is selected by the focal company for each case. The main criterion for selection is based on where they believe there are the most benefits to be expected by development of integrative capabilities. The cases are all a result of a process where each case consist of information from preparatory discussions with contractor liaison and management, documentation in forms of organization charts, procedures and role descriptions. Two focus group interviews per case were conducted. Seven cases studies were described.

Informants The organizations provided personnel with knowledge of each case, with a mixture of personnel with functional responsibilities and related managers such as process owners and support function managers. These informants where all involved in the processes under investigations, being capable to raise issues and propose solutions.

Record Keeping and Data Verification The minutes from the meetings represent the discussion as it proceeded. The researcher, a representative from the customer and a liaison form the contractor were facilitating the interviews mainly by open-ended questions and evoking dialogue between the participants. The minutes of both interviews were merged into a synthesis of the themes discussed. Selected participants then validated the content. The liaison and process owner typically contributed to this, but they could involve the participants of their choice. The synthesized minutes contained issues and solutions based on the framework for integrated operations. A research protocol was made and utilized for the case studies. The case descriptions were developed in addition to and based on the interview report as well as observations from the process for each case.

4 Empirical Findings

The focal companies of the case descriptions are all competing contractors supplying modifications and maintenance services to assets situated at sea (offshore). The contract activities can be divided in an engineering, procurement, construction and installation-contract logic (EPCI). The assets are facilities related to production of oil. The general project activities are:

1. Assignment issued
2. Project is created, with project responsible person and initial timeframe
3. Early phase engineering and project planning
4. Project delivery
   a. Detail engineering—multiple disciplines
   b. Procurement—multiple suppliers
   c. Construction/sub-assemblies—multiple sites
5. Transport to supply base
6. Transport offshore—material and personnel
7. Installation offshore
8. Finalize documentation

This project flow is associated to the activities related to fulfilling the EPCI-contract for the focal companies. This is however just a subset of the business that the different contractors are conducting. Hence, it does not reflect a complete firm. For instance, the focal firm's contract bidding process is not studied.

The products delivered within this structure vary from simple maintenance work to more complex modification projects. However, even simple maintenance work are complex tasks in respect to information requirements, planning and coordination.

The space offshore is limited and the transportation capacity is constrained both for personnel and materials. In addition the access to the work sites are dependent on other activities, such as erection of scaffolding, blocking of physical space or processing outage at the asset.

When the assignments are issued, there is often limited information of the requirements for fulfilling the scope of work. Databases are often not up to date with the latest changes. The sites are far from where the engineers do their design work, and access to the knowledge might require a site visit. A maintenance job might include change of pumps and electrical motors. The customer specify the requirements for the replacements, and have frame agreements with subcontractors. The contractor does the procurement and planning of the work using multiple disciplines of engineers, as well as multiple disciplines of installation workers. Sometimes subcontractors are used throughout the process, both on detail engineering, construction and installation, but managed by the contractor.

The planning and coordination for all installation activities are handled by dedicated land based project control centres. They coordinate with the overall plan and activity at the offshore facility, however, the main planning and coordination is done by the customer's land based control centre. Both customer and contractors have dedicated control centres for each oilfield.

During the time period for the case studies the oil price dropped significantly. The first case conducted was selected because previous observations had pointed out that several employees in the onshore operations centre had multiple roles. At that time that was seen as a problem, due to a fear of reduced quality when people divided their attention. However, when it was time for interviews, this issue had been addressed. They were in compliance to the described model. At the same time they brought to our attention that when there was low activity, they could not justify this organization. Was the design wrong?

As time went by and more cases were studied we met organizations in change. As the assumptions changed, the organization designs changed. For instance we had cases where we got organization charts that were made during the last few months, or weeks. When we had our interviews the changes had been communicated to the organization. After we left and as we discussed the case study text, even new organization charts designed and launched.

Out of the seven cases four had an orientation towards the organization of their operations. For these cases the issues and proposed solutions were focused on how the contractor could configure their operation internally in addition to integration to the customer's operations. They mainly addressed how the project delivery system could be improved. For the remaining three cases the focus was on the interface with the subcontractors. All these cases also addressed both internal measures and measures related to the customer. This is because the subcontractors are selected through the customer's approved vendor list. The supplies are procured within the subcontractors' frame agreements with the customer. Some figures from the focus group interviews are collected in Table 2.

We see the average number of informants were eight, but since there were two focus group interviews per case this averages four informants per focus group

Table 2 Focus group interview statistics

Case no.	Aspect explored	Number of informants	Issues raised	Proposed initiatives	Responsible internally	Responsible at customer
1	Organizing operations	8	20	7	4	3
2	Organizing operations	8	22	5	5	0
3	Organizing operations	13	20	7	6	1
4	Organizing operations	6	20	9	6	3
5	Subcontractor handling	8	21	7	3	4
6	Subcontractor handling	4	40	5	2	3
7	Subcontractor handling	6	10	6	4	2
	Average per case	8	22	6.6	4.3	2.3

interview. The liaison from the contractor, a customer representative and the researcher are in addition, setting the average number of participants at seven per interview. Each case provided in average 22 issues where on average 30 % were proposed as improvement initiatives to be implemented. 65 % of the initiatives were issues that the contractor could address internally. The rest require the customer to take the lead. Within the table above we can also observe that the distribution over who is responsible to resolve the issues is different between the two classes of aspects explored. Out of the 18 proposed initiatives addressing subcontractor handling, 50 % are addressed to the customer, while the number is 25 % for top four cases.

When classifying the proposed improvement initiatives in accordance with the IO framework we observe that all the success criterions have been addressed. Below we see a synthesis of the typical issues across the cases. The descriptions are made general to contain all the issues that was addressed in the proposed improvement initiatives for all the cases (Table 3).

Is Flux the New Normal? The current development in the oil price has affected the activity level in the oil and gas industry. There is a cost reduction focus and a reduction of activity. Through the case studies we have witnessed different behaviour in relation to the reality for the focal companies. The number and scope of the assignments are reduced. As the revenue is based on project deliveries, the contractors have been forced to go through with dramatic cost cutting initiatives. This has provided insight into the issues of variability in activity level, the inherent complexity and need for flexibility of the delivery system. The industry experts states that when and if the oil price rise, it will be a new normal. The operations

Table 3 Cross case issues categorized by success criteria

No.	Success criteria	Typical issues across cases
7	Mindset, leadership and training	• Lack of policy and culture for coordination, information sharing, common understanding of goals between organizational units, both internally, between organizations and at external organizations • New strategies, structures and processes not implemented, lack of plans for transitions except the occasional new organization chart • No attention to organizational learning processes and training of basic collaboration practices
6	Organization, roles and responsibilities (governance)	• Gap between actual operations and formal procedures and work instructions • Unclear roles, responsibilities, work processes and decision points • Not established clear communication lines and division of authority in interfaces between organization units and between disciplines
5	Collaboration functionalities and work arenas	• Collaboration infrastructure does not support work processes and decision points (or not defined) • Collaboration technology not used to its potential • Collaboration technology not compatible or is not available
4	Information visualization and workspaces	• Workspaces/information visualisation does not support work processes and decision points (or not defined)
3	Information access, integration layer	• Manual interfaces or lack of information sharing across applications • Lack of access to applications at information point of origin • Application catering the right information does not exist
2	Communication infrastructure and data transmission	Communication infrastructure does not exist with sufficient capacity
1	Data capture and data basis	• Data is not updated • Data is not sufficiently structured • No data source exist to support work process and decision point

cannot return to the old way of doing things, the industry must remain profitable independent of the oil price (Statoil 2015). At the end of the day, the central question is how to maintain and improve effectiveness and efficiency in the delivery system. The structure as described in these cases does not appear to be aligned with the new context in a way that serve the requirement for effective and efficient operations. The question coming out of the empirical study is; what would the best configuration of this type of delivery system be? Are the conditions right for solving the issues with an integration strategy?

5 Theoretical Background

Development of strategies that propose the best performance as possible have been discussed conceptually and empirically in many streams of literature. In the framework presented above, we have focused on different factors related to integration. We assume that the grater the integration, the better performance can be achieved. But what configuration of these factors provide the best possible performance. What are typical for the best performers? These questions are closely related to the purpose configurational theory where use of typologies to build a strategy that fits the environment. To utilize an opportunity would require to create a structure that supports the strategy (Chandler 1962).

Configurational Theory and Change Starting with the framework for organizational change in industry, where the interdependency of task, people (actor), technology and structure demonstrated the locus of various approaches to organizational change (Leavitt 1965). It is often the task variable in this model that is the dependant variable and the target for change initiatives. Alignment is made by focusing change on one or more of the other three variables, but the people variables are especially important. What we learn from Leavitt is that one have to consider change holistically in design efforts. This is the notion of fit and alignment between variables discussed in the configurational theory (Doty and Glick 1994; Miller 1986, 1996). It is the alignment between dominant themes that defines what first order constructs that are relevant (Miller 1996). A well-developed typology is the one introduced by Miles and Snow (1978) where they focused on aliment between environment, strategy, structure and process and introduces the four ideal types prospector, analyser, defender, and reactor (Doty et al. 1993). Each ideal type represent a specific configuration of multiple unidimensional constructs.

Configurations in Supply Chain Management In the supply chain management literature there is a string of studies presenting supply chain management using approximations to configurational approaches (Neher 2005). The motivation for configurational approaches is to see the supply chain in a holistic perspective, as it can be assumed that the parts of a system must be understood as a whole and not in isolation (Meyer et al. 1993). Fisher (1997) discussed what might be the right supply chain based on type of products in terms of predictability of demand. Predictable demand of functional products promote a configuration of efficient processes with focus on cost, asset utilization and quality, and unpredictable demand of innovative products promote a configuration of market-responsive processes with buffers of stock and capacity as well as focus on reduction of lead times, speed flexibility, and quality. Tan et al. (2000) proposed to divide the market-responsive configuration in two different categories. One for customizable products with semi-unpredictable demand and medium life-cycles promoting demand planning processes, assembly-to-order, mass customization and postponement strategies, and one for innovative products with unpredictable demand and short life-cycles promoting a make-to-order strategy. The predictable demand products was suggested to have a make-to-stock strategy. More production oriented supply chain configurations are discussed by Christopher (2000). He proposed the configurations of agile supply chains for situations with high product variety low volume and unpredictable demand with high variability, while lean supply chain was proposed for situations with low product variety, high volume and predictable demand. Christopher also suggest that as environment and markets are becoming increasingly more turbulent and volatile, the agile supply chains are increasingly more relevant. Hybrid configurations between lean and agile labelled leagile are also discussed in literature (Mason-Jones et al. 2000). This configuration is related to the postponement strategy and introduces the concept of a decoupling point between the marked responsive side of the agile supply chain, and a predictable material supply side where the lean supply chain configuration is applied. Lee (2002) introduced framework of demand- and supply uncertainty. In the dimension of demand uncertainty he differentiate between functional products (low) and innovative products (high) inspired by Fisher (1997). The dimension of supply uncertainty he differentiate between stable processes (low) and evolving processes (high). On the low/low uncertainty on both dimensions, he propose an efficient supply chain configuration, while on the high/high uncertainty dimensions he propose an agile supply chain configuration. In situations where uncertainty is high on the demand side and low on the supply side is labelled responsive supply chain, while the opposite position is labelled risk-hedging supply chain. Klaas (2003) is a thorough attempt by explicitly using the configurational theory for creating a typology for supply chain configurations utilizing most of the dimensions of the configuration-oriented studies reported above (Neher 2005). His configuration follows the notion of clustering dimensions of context, strategy, structure, and processes (Miller 1986). The following is a summarized of the dimensions and elements used (Klaas 2003): (1) mechanisms of coordination; push or pull, tightness between (internal) supply chain elements, (2) logistics processes and infrastructure; postponement/speculation, bundling of material's flow, centralization/decentralization, (3) formal organizational structure; specialization, standardization, delegation, etc., and (4) logistics context; demand predictability, service level, product attributes, production technology (flexibility, economy of scale) and competitive strategy. The configurational typologies promoted by Klaas are presented in the main dimension of strategic goals; divided in cost oriented versus flexibility-oriented goals, and coordination mechanisms; divided between forecast driven versus demand driven mechanisms. With the strategic goal being flexibility, Klaas promote the typology "aglile logistics segment" when the coordination mechanism is forecast driven "anticipative pull-controlling" for innovative standard products, and "individual logistics segment" when the coordination mechanism is demand driven "reactive push-controlling" for individual single products. When the strategic goal is to minimize cost, Klaas promote the typology "tight logistics segment" when the coordination mechanism is forecast driven "anticipative push-controlling" for functional standard products, and "modular logistics segment" when the coordination mechanism is demand driven "reactive pull-controlling" for modular system products.

Supply Networks The research in supply chain management can be viewed at several levels; (1) the internal chain, (2) dyadic relationships, (3) external chain, and (4) on a network level (Harland 1996). Empirical research on supply networks show that the network properties vary substantially, but networks can be classified in accordance to level of product complexity and products types (Lamming et al. 2000).

Definitions of Supply Chain Integration The literature on supply chain integration has evolved over the last two decades, and in particular after the study of supply chain strategies by Frohlich and Westbrook (2001). The propositions that strategic integration in the supply chain has a performance improving effect has been also been debated in literature well before the 2000's (Armistead and Mapes 1993; Lambert et al. 1978). The definitions and conceptualisations have evolved and there has been produced inconsistent findings of the relationship between supply chain integration and performance. Clarity has been obstructed by the inability to compare results between different studies, since different conceptualizations has been operationalized into conflicting measures and scales (Germain and Lyer 2006). In agreement by recent contributions in the supply chain integration domain this study utilize a definition of the concept divided in the three dimensions of supplier, internal and customer integration (Schoenherr and Swink 2012; Wong et al. 2011; Zhao et al. 2011). The integrative capability is related to the degree the focal organization "strategically collaborates with its supply chain partners and collaboratively manages intra- and inter-organizational processes" (Flynn et al. 2010). Intra-organizational integrations is related to the internal integration, while inter-organizational integration is related to external partners such as customers and suppliers. Integrative capabilities facilitate coordination and the effective and efficient flows of information, material, money and decisions, with the ultimate objective to maximize customer value (Flynn et al. 2010; Schoenherr and Swink 2012; Zhao et al. 2011).

Integration Strategies Five distinct strategies for external integrations was empirically investigated by Frohlich and Westbrook (2001). This study appears to set off a series of studies in supply chain integration. Their major findings was the identification and empirical exploration of the five strategies of direction and degree of integration (the arcs of integration), and that higher degree of integration yield higher performance. In order of increased degree of integration and performance the strategies where identified as inward-, periphery-, supplier-, customer-, and outward facing integration. Critics has been on not considering internal integration. This has been included in the cross validation study by Schoenherr and Swink (2012) who also summarized some of the major findings from representative studies on supply chain integration. I have selected some relevant studies to paraphrase as a short introduction to recent literature. All of these are survey-based.

Configurations in Supply Chain Integration The benefits of being strategically interconnected and aligned with the supply chain partners are confirmed empirically in several studies (Frohlich and Westbrook 2001; Schoenherr and Swink 2012). Internal integration is a moderator for the relationship between external integration and both delivery and flexibility performance while the same moderating effect was not found in the cost and quality performance, and external integration internalize external resources (Schoenherr and Swink 2012). Evidence of internal integration as a moderator in the relationship between downstream integration and logistics performance has also been presented (Germain and Lyer 2006). In a study of specific configurations of internal and external supplier integration practices an optimal set, forming an ideal strategic position and the concept of misfit as deviation from the ideal position was confirmed to be related to performance (Das et al. 2006). Increased misfit result in decreased performance. A study of relationship between dimensions and patterns of integration and performance, produced evidence that integration is related to both operational and business performance, as well as the customer integration has a stronger relationship to performance than supplier integration (Flynn et al. 2010). Wong et al. (2011) investigated the moderation effect of environmental uncertainty in the relationship between the three dimensions of integration and four performance measures. Evidence of environmental uncertainty as a moderator was identified in the relation between internal integration and cost and quality performance, between supplier integration and delivery and flexibility performance, and between customer integration and flexibility performance. The effect of integrative practices such as information sharing, product co-development and organizational coordination on product performance and product modularity performance was investigated in a sample of manufacturers in Hong Kong (Lau et al. 2010). Product co-development influenced both performance measures, and organization coordination influences product modularity, however, they could not confirm other links. In this times of flux we also site a study examining the effects of three dimensions of integration (supplier, internal and customer) on performance measures related to external flexibility and supply chain agility (Braunscheidel and Suresh 2009). Evidence confirmed both the internal and the external integration influence supply chain agility, and internal integration influences external integration. They also examined impact of two organizational orientations (market and learning) on integration, and found evidence of influence on both internal and external integration from market orientation, while learning orientation only influenced internal integration. The constructs used for market orientation was defined as customer orientation, competitor orientation, inter-functional coordination (Narver and Slater 1990), while the learning orientation was defined as commitment to learning, shared vision and open-mindedness (Sinkula et al. 1997). Swink et al. (2007) investigated how three strategic integration dimensions (corporate, customer and supplier) and one internal product-process technology integration impacted two business performance measures (market performance and customer satisfaction) and five manufacturing competitive capabilities (cost efficiency, quality, delivery, process flexibility and new product flexibility). Narver and Slater (1990) research set out to answer the question "Does manufacturing competitive capabilities have a mediating effect on business performance?" Corporate strategy and product-process integration show greater impact on the manufacturing competitive capabilities than strategic customer and supplier integration, but all the integration types show benefits. The authors also makes a note to the investment cost of the different integration strategies, and argue that corporate strategy integration has the lowest implementation cost.

Configurations in Engineer-to-Order Supply Chains So far, I have presented definitions of supply chain integration and some supply chain management configurations. As the industry presented in the empirical data of this study can be classified as an engineer-to-order type industry, the literature on traditional manufacturing focused supply chain management might not apply directly. Research on engineer-to-order supply chains has been neglected, but there are however some strings of literature in engineer-to-order context (Gosling and Naim 2009; Hicks et al. 2001). Continuing on our configurational journey, Hicks et al. (2001) developed a typology for four ideal types to classify the different forms of engineer-to-order companies. Ideal type is a construct in typologies used in the configurational approach. “Ideal types are complex constructs that can be used to represent holistic configurations of multiple unidimensional constructs” (Doty and Glick 1994). Ideal types for the engineer-to-order industry can according to Hicks et al. (2001) be (1) vertical integrated, (2) design and assembly, (3) design and contract, and (4) project management. These types are all presented in the dimensions (1) core competencies, (2) competitive advantage, (3) vertical integration (4) supplier relationships (5) environment, (6) type of risks. On a methodical note the use of typology and ideal type might be semantically wrong in the study, as it might be a classification scheme that is presented (Doty and Glick 1994). However, the insight from the classifications are useful in many aspects. They build the classifications on three types of company depending on what are internal and external processes when it comes to component manufacturing, subassemblies and end products, where components are expected to have the most shallow product structure and end products will have a deep product structure. The different process types can be in the range of flow-, batch- and job shop. Subassembly and assembly of end products typically use the job shop type process. Type I companies have all processes internal (vertically integrated) fits a stable environment, type II outsource component manufacturing (design and assembly) fits uncertain environment, and type III outsource all physical activities (design and contract + project management) fits a dynamic environment. The classifications might not be mutually exclusive.

Engineer-to-Order Strategy Even though the literature is limited, there are identified several definitions of engineer-to-order supply chains. Typical definitions found in several streams of literature on engineer-to-order supply chains can be as follows (Gosling and Naim 2009): (1) have customized production dimensions with the decoupling point located at the design stage, (2) offer customized product where existing designs are modified to order (3) offer customized products where completely new designs are developed to order, and (4) operate in an project environment with project specific demand/one-of-a kind products. Gosling and Naim

(2009) divided the literature relevant to developing engineer-to-order supply chains in seven strategic themes; (1) shift between supply chain structure to suit marketplace/standardisation/reduce complexity, (2) supply chain integration, (3) information management, (4) business systems engineering/business process re-engineering, (5) flexibility, (6) time compression, and (7) new product development process improvement.

Resources Based View The literature presented here has been related to different configurations that might be beneficial in a supply chain context. Initially I have stated that the strategy had been to develop integrative capabilities. The concept of capabilities is within the core of the resource-based view of the organization. The body of literature related to the resource based view establish resources and capabilities as important for understanding the sources for sustainable competitive advantage for firms (Barney et al. 2011). In the resource-based paradigm a sustained competitive advantage is created through bundling strategic resources in a way competitors find difficult to imitate or substitute without great effort (Barney 1986, 1991, 2001; Teece et al. 1997). These resources must be controlled by the firm, and they enable the firm to conceive and implement strategies that improves its efficiency and effectiveness. The firm's resources can be assets (physical, human, organizational), capabilities, firm attributes, information and knowledge, etc. (Barney 1991). The strategic resources are the ones that are scarce [not readily available in a factor market (Barney 1986)], imperfectly imitable and imperfectly substitutable. The resource-based paradigm is often classified as resource picking strategies based on the neo classical micro economics school by exploiting the strategic resources to capture returns in excess to normal limits or economic rent as it is referred to in the theory (Makadok 2001). Economic rent is viewed as the value captured by the firm, and the theory provides several subsets of this.

External Resources Many researchers have limited resource-based view within the boundaries of the firm, however, an extended resource-based view point out that ownership of resources is not critical (Lavie 2006; Lewis 2000). Gaining access to external resources through building collaboration, exploiting knowledge and enhancing relationships outside the boundaries of the firm can also contribute to a bundle of resources difficult to imitate or substitute by competitors (Napier and Nilsson 2006). The extended view provides us with a holistic perspective (Lewis et al. 2010). Rent accumulating behaviour can be seen in business alliances and other forms of interconnected firms. In a resource view of an alliance we can define a composition of rents extracted by the focal firm (Lavie 2006). First of all internal rent is harvested from the internal resource bundle. Some resources are by contract or agreement defined as shared between partners. They are originally owned by one of the alliance partners, but made available for exploitation in the alliance. This can be classified as appropriated relational rent. In addition there are some unintended rents both from harvesting from unshared partner resources and leakage of firm rents to partners from unshared firm resources. In alliances there should be a balance between exploration and exploitation. This is influencing the performance of each firm in the alliance (Lavie et al. 2011). However, these capabilities of participating in alliances through strategic purchasing and supply chain management can also be argued to be sources of sustained competitive advantage in the perspective of resource based view (Barney 2012).

Dynamic Capabilities These resource based views of strategic management of the firm is complimented by the theory of dynamic capabilities (Teece et al. 1997). The resource-based view and dynamic capabilities as paradigms within strategic management are economizing strategies focusing on the firm performance and share most of the assumptions. While the resource-based view focus on configuration of resources, the dynamic capability view is oriented towards developing capabilities based on evolutionary economic theory (Makadok 2001). Teece et al. (1997) define dynamic capabilities as the firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments. Competence is an important construct in the dynamic capability view. Competence is the origin of the firm's products, and the determining factor for the performance. The core competencies define the firm's fundamental business and are based on bundles of resources that enable activities and processes, enhanced by combining complementary assets. Resources are defined as firm specific assets that are difficult to imitate (strategic resources), while other undifferentiated inputs tradable in factor markets are called factors of production. Factors of production cannot be the origin of sustainable competitive advantage. The dynamic capability is about ability to adapt to the environment. We can link this to a concept introduces by Miles and Snow (1978), called the adaptive cycle. Constant to the strategic choice approach to the study of organizations (Chandler 1962) they presented adaptive problems managers continuously where working on; (1) the entrepreneurial problem (choice of product-marked domain), (2) the engineering problem (choice of technologies for production and distribution), and (3) the administrative problem (choice of exploring areas for future innovation and/or exploiting existing business). This also links back to the configurational theory.

Inside Out or Outside in Perspectives The relevance of resource based view and dynamic capabilities in this study is related to the strategizing in an inside out perspective of how to compete through resource picking which represents the flipside of the coin of the configurational theory for developing a strategy for an organization. The configurational approaches looks at organizations (or other social units) from a holistic point of view, hence an outside in perspective (Meyer et al. 1993; Neher 2005). Existing literature on supply chain integration as summarized above, is survey-based empirical work, but the concepts and factors derived from various definitions of supply chain management has been operationalized into inconsistent measurement scales (van der Vaart and van Donk 2008). It is then difficult to see clearly recognisable clusters of constructs making up dominant themes or configurations. The initial empirical findings from the case study in this paper set the context for the discussions of the questions stated.

6 Discussion and Conclusion

The multiple case study demonstrates use of the seven success criteria in the IO framework in the conceptualization of improvement initiatives. They are used in a prescriptive manner, meaning if the organization improves these variables, performance will follow. The variables focused on for this study is then the mind-set, leadership, training, organization, networking, work process framework, collaboration work arenas, information visualization, work spaces, information access, communication infrastructure, data capture and remote access. To design integrative capabilities within these dimensions and comply with the design, is prescribing a higher performance. It is not possible to say if the measures affect the performance neither if they are viable improvement measures. The data available for these cases does not provide information on those issues. Further longitudinal studies of the empirical world can identify the effects.

We have observed that when the externalities have changed dramatically the organizations are searching for alternative designs. Using a framework for continuous improvement might not sufficiently meet their challenges. They need a tool for rapid redesign of their operations and their organizations. The organizations struggles with organizational change, and it might be the capability to change we need to address.

There is identified that the way organization changes are practiced and what is described in literature deviates (Bartunek et al. 2011). In terms of the proposed improvements, they might not be implemented, as it is easier to conceive a best practice than to comply with it. What prescription they need may not found directly by visiting the empirical world through single cases.

The success criteria framework contains variables on man, technology and structure. There is not a connection to the task variable (Leavitt 1965) that specifies what is the purpose of the organization, what creates value. The framework does not have an explicit strategic dimension where the alignment to external conditions and design organizational structure and processes is addressed. The framework does not differentiate between types of integrative capabilities, but is explicitly defines that all the success criteria must be developed in parallel.

From the literature of the arcs of integration we can learn that performance benefits increase with scope of integration and internal integration has a positive effect on getting greater benefits from external integration. An advice in this respect would be to always have a focus on internal integration. One issue for the changes that the contractors face in the turbulent time is if they can afford to invest in external integration when both the supplier and customer side of the operations have significant fluctuations and uncertainty. When looking for optimal strategies the literature point out strategies that are beneficial for a variety of contexts.

The situation described here is certainly one of uncertainty in demand and supply, even when the external links are partly integrated. The products might fall into the category of innovative products, at least in the respect that the supply chain must be designed with focus on responsiveness, prescribing agile supply chain strategies. Although the industry is under a hard cost pressure, which indicates some hybrid strategy being more suitable. As an engineer-to-order situation where manufacturing is handled as one-of-a-kind projects, the theory is not concluding what strategies, structures, processes that fits the context. There is a research opportunity using configurational theory to create ideal types that prescribe improved performance. Typologies are actionable theory, and will have great benefit for supply chain and organization designers.

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ICT and International Manufacturing Strategy

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Abstract Nowadays several manufacturing principles are applied to Information and Communication Technology (ICT) and the ones who went lean (or agile if you will) are improving their capability to deliver and execute. Still, is doing things right enough today? The real challenge is actually being able to do the right things. In a time of great challenges the capability to provide an ICT strategy model, totally aligned with International Manufacturing Strategy it is going to be a key success factor to bridge business value requirements and ICT world in order to deliver higher performances focusing on right priorities. The International factor brings into the picture a higher level of complexity in order to overcome global technical hurdles as well as cultural barriers. Managing complexity can be facilitated if the ICT systems are implementing balanced, centralized or decentralized, solutions. The ICT road map should be able to answers several needs at different levels of the organisation: from operational tasks, to management control up to strategic planning and, at the same time, support the decision making process where information characteristics requirements differs (in terms of time horizon, level of details, data source, degree of certainty and frequency). Manufacturing and ICT need to face the challenge together and find the right balance on several factors, where the threshold of automation is definitely a key one; together with the hard balance between the opportunity to leverage best-practices or protect own-practices that are considered competitive advantages. As a result robust processes will be embedded in (rightly) automated work-flow procedures which will be available across the company. Although often neglected, people management and people development is recognised as a foundation of a Manufacturing System, even to this extend ICT has the power to contribute and become a strong enabler. Knowledge Management Systems are not supposed to replace coaching and mentoring, but they will help, more and more, in creating a knowledge repository and facilitating communication and interactions.

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1 Introduction

In the last years ICT is dramatically impacting and changing the way of running business with a greater and greater impact on manufacturing as well. Although the role of ICT is quickly evolving from a traditional technical approach to a much wider business approach, there is still today a lack of a comprehensive experience and understanding to make ICT a real enabler for manufacturing; particularly in an international setting. Purpose of this work is to provide a frame, collecting what is available in literature from both ICT and Manufacturing point of view and propose a holistic approach, which can help in closing the gap.

The reasons why ICT implementations are suffering a tremendous failure rate are rooted on multiple causes. This study will illustrate which could be the key dimensions, to be focused on, in order to improve the success of ICT, together with Manufacturing, for higher system performances. Amongst others, the attention will be on ICT strategic approach, ICT technical execution, and people development (supported by knowledge management).

The framework provided could be useful both to ICT and Manufacturing managers, which are interested in understanding the other side and improve the ability to manage their functions in an international situation.

In order to accomplish this framework, the following sessions will illustrate, firstly through a systematic literature review, the role of ICT (defining the way to aim for the right solutions, implementing them with knowledgeable people in an international context) and then the field findings to support the research proposition.

2 Literature Review

2.1 Mission of ICT

ICT has been rapidly changing in the last decades following an incredible technical journey which is providing more and more possibility to help manufacturing, and business in general, to support all the steps from the operational level, through the management level up to the executive and strategic level. Early years (from 1980) of ICT were simply focused on the technical side (hardware and software management), slowly (from 1990) evolving into a production focus (execution and service level of standard products), and, only relatively recently (from 2000), ICT is trying to make a shift to a 'business needs' focus.

A simple and effective way to describe this journey is provided by the Business Capability Maturity Model (ICT Standard Forum, www.ictstandards.com), which helps to define the necessary steps to have ICT organisation fully supporting business.

Manufacturing management has been following the concept of value creation (Womack et al. 1990; Womack and Jones 1996) for several decades, following the model proposed by the Toyota Production System which is the base of the Lean movement (Liker 2004).

A similar evolution is required for the ICT organisation and its leadership. Value thinking (Huovine and Makkonen 2004) is the necessary skill for today ICT leadership, which has to complete an evolution from the technical paradigm of the early stages to a higher process and strategic thinking, which can lead to actual value delivery taking best advantage of the IT portfolio.

2.2 Context of ICT

Framing ICT context in a given company is a preliminary necessary task to make sure right focus is given to ICT. The model, which is weighting infusion and diffusion (Sullivan 1985), can be a good starting point. On one hand, it should be considered the degree of dependency of the firm from the information systems for execution, which is the so-called infusion dimension. On the other hand, the diffusion dimension is assessing to which degree information systems are actually available on the company and how strategic are the decisions taken about its usage (Table 1).

What will be discussed in this study will help defining the ICT positioning where the struggle would be to find the right balance between infusion and diffusion from

Table 1 Dimensions and factors to set ICT context and ICT strategy (adapted from Sullivan 1985)

ICT strategy	Infusion–diffusion	Scenario
Traditional	Low–low	Typically when ICT is not critical for business execution, ICT is strongly centralized. Focus on efficiency improvement with low degree of ICT integration
Opportunistic	Low–high	ICT tends to be decentralized; ICT development is left to a sort of federal approach without a centralisation. ICT is locally optimized maintain a silos approach
Backbone	High–low	ICT is centralized and critical for business execution. Failure of ICT would result on business disruption
Complex	High–high	ICT is decentralized and, however, it is critical for business execution. Search for innovation, typically slowed down by central control, has to be balanced by the need to control company execution, which is typically compromised by a decentralized approach

the internal point of view of the firm. It is a fact that, in the last decades, external competitive pressure are increasingly putting ICT on the critical path of the business, forcing infusion to become a constantly high dimension. At the same time an International Manufacturing strategy will increment internal forces to have distributed control of ICT, for the sake of speed and local optimization, which will lead to high also the diffusion dimension.

As a result International Manufacturing is placing ICT strategy on the complex scenario requiring enormous skills for right strategy and right execution.

2.3 Role of ICT

Information Systems is facing a technological drastic evolution combined with the need to adopt and evolve in terms of organisation. Trying to identify the key aspects of ICT supporting international manufacturing strategy we can summarise key business deliverables to be met (Rugiadini 1970): *operations, decision making and knowledge management*.

Enterprise Operational Support through robust ERP (*Enterprise Resource Planning*) covering (Doane 2012) Financial Accounting, Sales and Distribution, Material Management, Production Planning, Human Capital Management and Controlling. To support an international manufacturing strategy, there is a need to support capabilities to handle extended Supply Chains through the use of SCM (*Supply Management Systems*) to connect global Customers, handle Distribution, manage Plants, and link Suppliers optimizing overall supply chain costs. Focus on Customer relationship is achieved from CRM (*Customer Relationship Management*) systems, which can support manufacturing alignment by handling sales and marketing, creating a unique repository for customer management.

Supporting *Decision Making* (Curtis and Cobahm 2008) process is definitely one of the biggest roles of ICT. Different needs must be addressed, with different level of information (often supported by Business Intelligence solutions) that technically can span from decision support systems, through digital dashboards to data warehouse and data mining; regardless the technique ICT hat to be able to support a fast and reliable process to make decisions (Table 2).

Following the focus on operations and decision-making, the remainder key business deliverable to be met by ICT is KMS (*Knowledge Management Systems*), which needs to be able (Hawryszkiewycz 2010) to merge Activities, Knowledge and People enabling culture and knowledge sharing.

The success of KMS will be recognized once best practices diffusion is a reality that can help firms developing high performance networks.

The role of ICT has been introduced in this research describing the main areas supported by ICT implementation (in terms of operations, decision making and knowledge management) like they were different deliverables. Nevertheless, it has to be borne in mind that those roles, from a technical stand point, are more and more delivered by means of fully integrated systems.

Table 2 Information characteristics and factors for decision making (adapted from Curtis and Cobahm 2008)

Organisational level	Time horizon	Level of details	Source	Degree of certainty	Frequency
Strategic planning	Long term (several months, years)	Maximum level of aggregation	Aggregation of internal and external sources	Higher level of uncertainty	Infrequent
Management control	Medium term (weeks and months)	Segmented reports by significant dimensions	Mainly Internal		Regular use
Operational tasks	Short (hours and days)	Detailed, supporting daily transactions	Internal	Maximum certainty of information	Very frequent use

2.4 *ICT Portfolio*

The complete architecture of ICT, defined as portfolio ICT (Morabito et al. 2010) is the combination of systems and IT capabilities to collect, store and retrieve data in such a way to provide information at the right time to the right people. Given the overall ICT strategy, and the ability to monitor through performances measurements, the portfolio can be summarized in three major subjects: *technical portfolio, capabilities* and *people*.

Technical portfolio is the actual system hardware architecture (networks, machines, layout) and software (applications) portfolio. The ability to provide flexibility, i.e. to provide the right degree of freedom to support a company business plan, is strictly connected with the technical portfolio design and maintenance.

Capabilities are the actual processes in place to use available resources; it's the organisation in place resulting from the combination explicit (known and available) knowledge and implicit (tacit) knowledge. Capabilities are making the difference between right or wrong execution.

People are the foundation of both ICT and Manufacturing organisation, it has been observed (Louis 2007) how easily non value added activities are impacting daily work; thinking of having an organisation of people evolving from, the currently most common, task oriented (highly non value added) to strategic oriented (highly value added) will result in a faster and leaner organisation at all level. People are a relevant variable to ICT portfolio both from the internal side of IT (actual technical competences) and from the external side (the users), they all need to be able to share a common approach in order to bridge (Curtis and Cobahm 2008) from physical analysis of business model (particularly manufacturing) to ICT logical and technical solutions.

2.5 International Approach

A manufacturer is going to internationalize its operations for many reasons (market, labour cost, and technology amongst other), however we are going to focus on what is making the ICT international viable. Several dimensions need to be crossed in order to actually get to the technological core. Following the proposed scheme by Laudon and Laudon (2015) a comprehensive journey should be taken from global environment, through global corporate, organisation, business processes down to the actual technology.

A global environment is introducing a number of challenges that are conditioning ICT due to the social–cultural side, the actual business factors and the physical technical barriers. The cultural challenges, on top of the strictly technical one, as Hofsted and Hofsted (2005) are suggesting, are impacting with several aspects: relation to authority, concept of self, concept of masculinity and femininity, uncertainty avoidance and time orientation. A part from the legal political differences, although extremely relevant, global business factors are implying the fact that a company is playing in a *global market*, leveraging *global workforce* to organize a *global production*, led by *global coordination*. The ICT organisation has to answer all of these global context aspects, which is complex enough, but which becomes a tremendous challenge once one is adding also the actual technical side. The international playground is facing different technical aspects (standards, reliability, speed, skills) which are summarized in Table 3.

To provide an initial frame for ICT, in order to match global corporate model, Laudon and Laudon (2015) are suggesting that the structure has to cope and adapt with the chosen model by the international manufacturing strategy. Focusing on production (mind that a similar discussion can be done for all relevant business functions), the chosen approach can be *dispersed* (in the case of a *multinational* type) or *centralized* (if the model applied is the one of an *exporter*, a *franchiser* or a *transnational* company). The response of ICT has then to fit accordingly and, depending on the positioning on the Sullivan model, this response can be (Laudon

Table 3 Factors describing the technical international environmental barrier (adapted from Laudon and Laudon 2015)

Factor	Impact
Standard	Need of coordination of actual different standard for Electronic Data Interchange. Particularly data flow regulation (think of privacy rules for instance) can significantly vary from country to country
Reliability	Availability of telecommunication network as well as reliability, uptime, is impacting the architecture and the depth of the ICT systems. Particularly affecting the possibility to work on line or off line
Speed	Capability to quickly exchange data, access data update them concurrently across the globe can be an important contributor
People	This become a technical factor being strictly related to the level of education, subsequently the possible lack of know how in different regions

and Laudon 2015) *centralised, duplicated, decentralized* or *networked*. If we omit simplified models required for exporters and franchiser (where, respectively, a centralized and duplicated approach would be the natural fit) we are left with the *complex options*; which are the decentralized and networked ones. As a conclusion it is observed that the more complex scenarios are the ones of multinational (with local production and sales that are centrally coordinated in terms of financial and management control) and the emerging transnational model (where also strategy and financial control are approached as a sort of federal model).

Already Roche (1993) has indicated a guideline collecting right principles to approach ICT to decide what should be centralized (the core of the company) or decentralized (the local manufacturing sites). This guideline can be summarized by three principles: (a) global company processes matched by global systems; (b) regional company processes handled by decentralised and coordinated systems; (c) local business processes with local systems.

2.6 Building and Managing Information Systems

Building and managing ICT infrastructure it's about the ability to develop new products that fit and follow the business development. Also in this field a paradigm shift has been happening in the last decades in a similar fashion to what has been happening in manufacturing going from traditional mass production approach to the more advanced technique of lean management. Already Takeuchi and Nokana (1986) where challenging the approach of a traditional waterfall (strictly sequential) approach in product development versus the all-at-once approach of companies trying to have a faster and more reliable process. From that moment a lot has been done and discussed to end up with the birth of the so-called agile movement (Schawber and Beedle 2001), which transformed the way of developing and build software. The commonality of the principles applied to ICT development techniques and manufacturing lean principles are really strong and the two world can share a lot in terms of approach and philosophy. The five principle suggested by Womack and Jones (1996)—Define Value, Map Value, Establish Flow, Pull, Seek Perfection—are well part of the agile movement. The approach called scrum (Schawber and Beedle 2001) is fundamentally linking the concept of customer value and flow (Rubin 2012). It is beyond the scope of this study to discuss the actual working details of the software development techniques, however it is relevant to add this element in the general context with the purpose of clarifying, later on, how the execution part of ICT can, and should, be an important pillar for the international manufacturing strategy. ICT organisations that are able to deliver, with agile systems, can achieve terrific improvements, as it typically happens in manufacturing during lean transformations. As Rubin (2012) is pointing out, speed of development could improved by a factor of 7, effort reduced by 10, and providing —at the same time—an excellent service to Customers, which were used to poor levels of customer satisfaction.

2.7 Knowledge Management

In this research an important pillar of the ICT role on international manufacturing strategy hits the (lack) of knowledge management. Today environment is facing an emerging nature of knowledge-based processes (Hawryszkiewycz 2010). The most common terms used in knowledge management are the explicit (codified) knowledge and the implicit (owned by people, and not codified) knowledge. Using the water metaphor (Andriessen et al. 2009) can be useful to depict how knowledge is impacting organisations. Andriessen is referring to knowledge as if it were water: water should flow through organization and feed it; canals are needed to distribute knowledge, dripping taps fixed to avoid leakages (knowledge loss). ICT has then the role to keep moving from simple data gathering, to information management, then to knowledge management, which will evolve into wisdom when people develop the capability to use knowledge to solve problems. In order to achieve this, ICT systems can contribute by making available explicit knowledge via business applications and business database (capturing and storing knowledge). This will have then knowledge embedded into applications that can make that knowledge available (by creating systems often linked to workflow frameworks). Eventually, explicit knowledge will be built and exchanged, starting from tacit by means of networking people through social software. Typical ICT systems to manage create, store and distribute knowledge are summarized into three types as per the Table 4.

2.8 People Management

It could sound awkward to write a session of literature review about people, however the proposition of this work, as later explained, is positioning people on the very critical path for ICT right development, particularly to support international manufacturing. As Rother (2010) is describing, the foundation for a long sustainable long-term development it's hidden: it is not what one can see (visible) in terms of tools, principles and practice, but what is hidden (invisible) in terms of thinking and mind set. Toyota, leading example of continuous improvement mind-set, is

Table 4 Role of different KMS (adapted from Laudon and Laudon 2015)

Type	Focus
General purpose systems	Systems that are helping managing general purpose content (knowledge) and often helping collaboration through social application software (e.g. blog, wiki-like)
Specialized systems	Typical technical knowledge repository systems to help work systems (e.g. CAD station for engineers, virtualisation platforms)
Intelligent systems	In this case from stored data and knowledge advanced (semi)-automatic techniques are used also with relation to the decision making process (e.g. data mining, fuzzy logic, neural network, etc.)

achieving the invisible part through Kata approach (word originating from martial arts indicating the process of teaching combat moves) (Rother 2010): the combination of learning routine empowered by scientific approach is what, in the long run, is creating a different people mind set and problem solving capability. The logical steps (Rother 2010) to achieve that are cycling from: setting direction, understand current condition, define next target condition, and then iterate to move toward the set direction.

Already Monden (2011) explained how system thinking is extremely relevant at Toyota both for manufacturing, and in general for all company functions. Starting on the early 1990, Toyota was one of the first to focus on technical personnel development adopting the so call T-type model (Monden) where people development is occurring on two dimensions: the vertical bar representing the development of specific technical skills on the given field, and the horizontal bar which represents the wider area of general skills required; namely system thinking skills (problem solving) and people development skills.

This system thinking approach is often criticised and considered not globally viable because it is, supposedly, considered strongly dependent on cultural approach and environment. However one should consider how the foundation of people development, which is today naturally inside the 'Toyota Production System', can be rooted back to the Training Within Industry program (Dinero 2005). TWI program was launched from the American government during WWII to support industries to face productivity challenges during wartime. The program, which slowly went forgotten in western countries, was in reality duly studied and practiced in Japan leaving an indelible fingerprint to TPS. As Dinero (2005) is recalling in his study of TWI, even John Shook (2010) (one of the world leading expert of Lean practices, who worked initially at NUMMI—first American joint venture GM-Toyota Plant) was surprised how 'culturally impossible' Toyota people practices were actually rooted in the now long forgotten American TWI program. Cultural bias, although clearly present for reason already introduced, and well explained by Hofsted and Hofsted (2005), can also be largely influenced by stereotypes.

3 Methodology

In order to achieve the goal of proposing a clear framework for ICT successful support to International Manufacturing the literature background has been challenged against the experience of several projects in multiple countries both on the ICT side and on the Manufacturing side. The possibility of the writer to work on several international ICT and Manufacturing projects ensured the possibility to access broad experience and empirical evidence of successful and unsuccessful factors. The experiences used to support the proposed model span through Western and Eastern Europe, USA, South America and China, but they are not disclosed for confidentiality reasons.

In order to make a comprehensive study the main areas used to compare and test hypotheses took into considerations ICT organisation, ICT knowledge, manufacturing style, knowledge management and people management. The conclusions of this work are also based on many interactions and discussions with several people from various firms from operational level (factory operators, manufacturing engineers, ICT programmers, ICT analysts) to executive level (COOs, CIOs, and CEOs).

Table 5 Main problems with manufacturing using ICT solutions

Area	Symptom	Problems
Level of ICT automation	Dual systems in place (manual and ICT), double data entry. Lack of accuracy and real time information ICT systems cumbersome and not in line with production real time needs	ICT is not meeting manufacturing requirements in terms of data collection, data accuracy and data retrieval No understanding of processes, and subsequently no sound decisions on what should be automated and what should be left manual is possible. Lack of system thinking
Production control	Production control is inaccurate; access to data is cumbersome and not visual on the floor	ICT system not meeting manufacturing day-to-day floor management requirements Lack of ICT visual management (hidden on computer not supporting lean practices)
Short term capacity management	Production scheduling is run with non-ICT common systems	ICT system not meeting manufacturing day-to-day floor management requirements. ICT maturity on lean practices
Medium term capacity management	Capacity management is handled with multiple systems, information not available to every body	ICT systems working in silos (such as sales, demand planning, production planning, material management, etc.) failing to provide a consistent extended solution
Flow and pull	Orders (production, material) fail to be addressed by ERP solutions, manual systems present and not integrated into ICT. Supply Chain disruption	Manufacturing improvement is slowed down by lack of adequate ICT solutions. Supply Chain Management fails to be seen as a complete flow, and push logics still disrupt value creation
People	Local optimization, poor problem solving performances	People development is not taken in due consideration, systematic thinking is not a priority which keep manufacturing away from ICT and the other way round

4 An Overview of the ICT Internationalisation Projects—Key Factors

During the research it has emerged that several problems related to ICT implementation, focusing on impact on manufacturing, are recurring and basically contributing to the failure of achieving effective ICT deployment. While some of the problems can be traced down to the specific international factors some are less dependent on it.

With the purpose of providing a comprehensive framework the main problems are classified on three main categories: Manufacturing ICT solutions, ICT Management, International.

The research is willing to show that Internationalisation is an additional factor of complexity, which builds on the typical lack of pre-requisite (not) being met by the normal interaction of ICT and Manufacturing.

Tables 5, 6, and 7 are collecting the main findings on the three categories identified.

Table 6 Main problems with ICT management

Area	Symptom	Problems
Business alignment	ICT perceived as a tool, resulting in fragmented solutions. ICT is a cost	Maturity level of ICT organisation is not addressed, as a result a strong focus on technical solutions is maintained without supporting real business value
Portfolio management	Fragmented solutions without holistic approach, data inaccuracy and redundancy	Portfolio management, without right business alignment, is tactically approaching individual needs not only loosing effectiveness but increasing total cost of ownership (lower efficiency)
Analysis	Analysis is not documented, requirements not clear	ICT approach still on the 'waterfall' model is not able to achieve fast, reliable execution. The inadequacy of ICT execution capabilities compromise manufacturing performances
Development	Solutions are not meeting requirements, are late and over budget	
People	Technical approach and lack of understanding of business need	People development is not taken in due consideration, systematic thinking is not a priority which keep ICT away from manufacturing and the other way round

Table 7 Main problems with ICT international dimension

Area	Symptom	Problems
Global differences	ICT systems are not integrated, communication is not fast, data are redundant and inaccurate	Technical international barriers are not taken in due account resulting in fragmented ICT solution which are not supporting international manufacturing
Global supply chain	Overall value optimization opportunity are not seen and not pursued. Customer and supplier communication breaks down. Inventory sub-optimized	Operational support, particularly vital on SCM, is not provided at international level. Right strategy in terms of management (both operational and strategic level) become cumbersome
Decision making (business intelligence)	Decision making process is slow. Available data are not used	The lack of managing data across the various countries, deciding properly what should be centralized and what decentralized is limiting BI solution for everybody
Knowledge management	Manufacturing sites are isolated, best practices are not shared. Multiple effort to solve same problems	When KMS is not a central part of ICT strategy most likely, not only, there is a huge loss of tacit knowledge, but also, explicit knowledge becomes virtually inaccessible
People	Communication breakdown, lack of skills	Broad international organisations are adding cultural bias which slows down improvement and understanding (adding to the lack of system thinking and educational gaps)
Cost model	Simplified models based on standard cost approach, difficult to access and inaccurate	ICT and Manufacturing management are failing to work with Finance to build adequate cost model to properly reflect complexity (Wilson and Perumal 2010) to manage properly manufacturing footprint
Level of ICT automation	Simple non-value added tasks run manually. Fundamental business practices wrongly run with ICT systems	Failing to balance the centralized/decentralized model make the manual/automatic decision on ICT solutions virtually impossible. Result is an exponential increase on waste

5 Solving the Equation of ICT and International Manufacturing

In order to overcome the wide problems that are present in the scenario described the research is proposing the following approach: *in order to meet manufacturing local expectations for execution and, at the same time, central coordination of* *manufacturing for strategic planning, one should leverage people knowledge to find the optimum compromise to balance two fundamental dimensions: (a) central and local systems; (b) automation and manual systems.*

In order to pursue this goal key points to address will be working on the following: people development, ICT business alignment, and portfolio management.

5.1 People Development

In the experience of this research it has been extremely rare to find companies able to develop the right mind set to support real sustainable value creation and continuous improvement. This aspect is already very challenging if one only considers strictly the manufacturing environment, it becomes particularly difficult once wide cross-functional (i.e. including ICT) competencies are expected.

Having introduced the T model (Monden) described earlier, people development should concurrently work on the general skills dimension and on the technical side. In this research we are taking the technical skills for granted (however it has been observed that it is not necessarily the case), and put more emphasis on the so-called general skills, since evidence proved that these are the ones hardest to develop. Hence in order to sustain the international environment, the major skills where there should be a constant focus are in the area of general skills, and specifically: the ability to handle *cultural difference* and the *system thinking* approach (which is at the basis of a continuous improvement mind-set constantly driven by value orientation).

Developing teams able to work on the cultural side can trigger an international team that will improve communication and understating, subsequently leveraging the best of all players; this will lead to deliver central and local solutions more and more consistent. People, having systems thinking embedded in their way of acting, will be able to make the challenging hard calls required to select the right ICT solution, to develop them smoothly and continuously as a normal way of doing business (not taking ICT as a mere set of tools).

As Rother (2010) is suggesting, this cultural change can be achieved through a systematic iteration of an approach where regular practices of new behaviour can influence people and, overtime, can affects—and change—organisational culture.

What has been observed is that the proposed holistic approach is rarely present in companies and, as a result, people lack the necessary skills to support the international complexity. Before moving on the next topics, it is worth mentioning that to work consistently on the area of people development a long journey should be undertaken starting from the most senior manager, and cascading to middle management till working engineers and technicians.

The approach recommended would address the people problems previously described, contributing to avoid communication breakdown, to facilitate understanding of business needs, to properly balance local or global optimization and to raise adequate technical skills.

5.2 ICT Business Alignment

Moving to the actual ICT management style, it has been observed that in most cases ICT is failing to support the complex (as per Sullivan definition) environment related to the international manufacturing. Recognising that ICT can become a competitive advantage (Hovineen and Makkonen) for international manufacturing success it means recognising that ICT can be a high business contributor with a very cost efficient system. In the cases observed ICT solution have rarely been connected to the actual business value, being stuck in the technological management approach. ICT has to be managed as a fundamental strategy function together with all other function in such a way that business alignment can be guaranteed. This ICT management approach can be achieved balancing three main areas: business *value*, ICT *execution*, *portfolio*.

Addressing the first area (business value) means the capability to understand context, critical success factors and actual ICT contribution factors in order to have a clear leading strategy from central level to local level. Woking on the second area (ICT execution) is creating an ICT operational environment where guiding principles, processes and indicators can help to make (and control) the actual strategy execution. Last but not least, the third area (portfolio) is actually working on the technical (hardware and software) architecture coping with the different international requirements. This approach can effectively solve the main problems with ICT and international dimension identified. A solid ICT (value driven) management will be able to correctly place central or decentralized systems and it will better distinguish where to put the threshold between needed automatic systems and manual system.

5.3 Portfolio Management

Delivering the actual technical Portfolio is the capability of ICT to support manufacturing both effectively and efficiently. It is the end result of ICT strategy managed with the right approach, driven and delivered by the right people. One of the first drivers is to have a portfolio intimate with the leading company value is understanding and following the company value focus. A company has typically three major value strategies: customer intimacy, product leadership and operational excellence. Understanding the leading one (with respect to international manufacturing, operational excellence is most likely the best candidate) is important to harmonize the portfolio.

As anticipated, the technical portfolio becomes a tool to deliver the ultimate ICT goal that is the capability: to support operating level, to enable decision making process, and to create a repository for company knowledge.

When ICT is intimate with business requirements the delivered portfolio can handle the problems encountered during the study, both strictly in terms of relation with manufacturing and in terms of internationalisation. Predominantly ICT solution for manufacturing should match the company 'real' processes. As Monden (2011) is describing the Supply Chain Management system, developed by Toyota in the last 40 years, is an unique system that has been able to include the right operational processes within the system and, at the same time, to connect an international networks of dealers, plants and suppliers. This sort of accomplishment can be achieved not only if manufacturing systems are clear, defined and reliable, but also when ICT can make them available with thorough technical solutions. Supporting international manufacturing means (Iyver et al. 2009) building enterprise systems able to handle variety (of market demand), velocity (steady material flow), variability (due to inconsistencies), and visibility (to enable system improvements).

The most common lesson learned is the fact that the portfolio is a rigid solution (often unbalanced on the centralization side), which slowly looses contact with the local manufacturing sites resulting in disaggregate island working 'out of the system'; starting, unavoidably, a dangerous vicious cycle. If the solutions are, on the contrary, able to follow and adapt to the business what will follow then, not only it will result in operations properly running, but it will also make a reliable decision making process possible. Specifically when ICT strategy is clearing allocating at the right level of (de)centralisation consistent data and information, this will eventually result in the possibility to make sound business decision.

6 Conclusions

In the project war room visual planning is up and running, kanban boards are under control no abnormal situation asks for support; this morning the gemba walk is a smooth one. It sounds like a manufacturing incipit but it could easily be a comment from an ICT organisation.

The ability do deliver ICT solutions should be a given; what ICT is supposed to do in an international environment is not just doing things right, but it's really being able to do the right thing.

This can be achieved if both ICT and Manufacturing *leadership* are able to take a quantum leap in terms of capabilities from the more traditional technological and cost efficiency approach to a *business oriented* (value driven) model with the capability to talk and understand each other.

Working in the international environment is adding *complexity* not only on the *technical* side but on the *cultural* side as well.

What has been presented as highlighted how critical for ICT is to provide (at the right global or local level) accessible, fast and reliable systems. Such a challenging goal can be achieved working with people, being able to develop a mind set to cope at the same time with process thinking, lean manufacturing, information systems and people management. Process thinking is difficult to teach and learn, the lesson of Toyota and its Kata approach, is there to be learned and exploited by everybody. The additional effort to have people able to cope with cultural bias overcoming communication barrier will make the difference between success and failure.

ICT has a big opportunity to wire a portion of this soft tacit knowledge into hard systems of Knowledge Management going beyond the, ideally, simple task to deliver integrate 'enterprise solutions' such as ERP and Business Intelligence. This will guarantee (continuously improving) robust processes embedded in (rightly) automated work flow procedures. The international manufacturing environment is setting the arena for ICT on the complex quadrant of Sullivan model and only the approach described can reach the right balance between central versus local and automatic versus manual.

Lean Manufacturing is delivering Value to the Customers; ICT has to join the same chase for value.

Value alignment, properly scaled at the right level of the organisation (machine, department, value stream, plant, region, corporate), will support a timely decision-making process ensuring continuous improvement.

This research has highlighted how global environment is introducing both cultural and technical obstacles; it has confirmed, as in previous study, a reality of global disorganisation of ICT implementation. It has been observed how critical can be the role of people in overcoming these issues, particularly to help creating a system thinking culture, which will make international integration less disruptive.

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Do Improvement Programs Complement Each Other?

Phillip J. Lederer

Abstract Improvement programs of various types have been adopted by many corporations and other organizations. In some cases, multiple programs have been implemented. An important question is whether such programs are complements to each other? In other words, is the value added of a pair of programs larger than value generated by the sum of each instituted separately. This chapter studies that question for some common improvement programs. Complementarity is studied for three program types: uncertainty reduction about customers' values for service, accounting programs like ABC that eliminate biased cost estimates, and operations efforts. Three kinds of operations improvements are considered: reducing variable cost, reducing capacity cost and reducing non-value added time. Research by Milgrom and Roberts (Am Econ Rev 80(3):511–528, 1990) argue that many modern improvement programs are complementary. But in this theoretical work the conclusion is a direct result of the technical assumptions made. Specifically, their assumption of supermodularity properties directly leads to the results. Missing from this analysis, but explored here, is whether realistic, well understood cost functions lead to complementary properties. Initially we assume that cost is driven by queuing-like production technology. Because batching/lot sizing and fixed charge problems have costs like queuing, the results apply broadly. In this case, the first two programs can be either complements or substitutes. But they are *both* complementary to direct cost savings and capacity cost reduction. The situation with reduction of cost estimate bias is more complex: it is complementary to direct cost savings and the reduction in non-value added time but is a substitute to reducing capacity cost. Complementarity properties are also studied for general demand and cost functions, with sufficient conditions presented. The managerial conclusion is that care must be taken in assuming the complementarity of real programs, and that more central oversight of improvement efforts probably is warranted to better estimate the value of programs.

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1 Introduction

During the past two decades firms have adopted many types of functional improvement programs. To give only a few examples: operations programs such as Total Quality Management (TQM), Materials Resource Planning II (MRP-II), and Just-in-Time (JIT) have been adopted to reduce cost, increase quality and enhance customer service. In marketing, ServQual and customer satisfaction programs have been instituted. In accounting, Activity Based Costing (ABC), and other product costing programs have been implemented. The net impact on the firm of these programs is complex but can result in more desirable products, better service to customers, lower cost, better pricing, and higher margins.

Milgrom and Roberts (1990) and researchers thereafter have applied ideas of complementarity to model interactions of improvement programs. That is, the total benefit of the two activities performed together is greater than the sum of benefits when each activity is performed alone. Complementarity of activities X and Y holds if: when activity X is performed alone firm value increases by ΔV_X, and when activity Y is performed alone firm value increases by ΔV_Y, then when activity X and Y are performed together the firm value increases by ΔV_{X+Y} with the property that $\Delta V_{X+Y} \geq \Delta V_X + \Delta V_Y$.

The important managerial issue is that a firm benefits most by coordinating adoption of complementary activities because the valuation of each program separately undervalues joint adoption. On the other hand, two programs are substitutes when doing two activities together causes a gain that is less than the gain from doing each separately, thus the independently valued activities have less value than the independent valuations suggest. The upshot is that a well managed enterprise ought to engage in complementary activities and take care with substitute activities because the gain may be less than anticipated. This paper gives some direction as to which sets of improvement programs gain the most from coordinated decision making by studying the complementary/substitutability of several types of programs.

In order to guarantee complementarity, the modern literature has assumed supermodularity[1] which is mathematical condition which implies complementarity of, say, two activities. In the above cited research, the cost function is most often *assumed* to be supermodular. That is, supermodularity properties are not derived

[1]The definition of supermodularity for a real valued function $f(x,y)$ on $\mathbb{R}^2$ is: given any $x_1 \leq x_2;\ y_1 \leq y_2$ then $f(x_2,y_1) - f(x_1,y_1) \leq f(x_2,y_2) - f(x_1,y_2)$, and an identical property if x and y are switched. (This is often called the "increasing differences property").

from fundamental principles of a general operations process. An unresearched question is whether *realistically* modeled cost and demand functions cause commonly adopted programs to be complements or substitutes. By “realistic” cost models I mean those most often recognized and used by operations management researchers, which include queuing technology and or inventory control processes. Next, I describe the types of programs I model.

Marketing research is sometimes used to better estimate parameters of consumer preferences, such as demand elasticity with respect to price and service levels. I refer to this type of program as “uncertainty reduction”. The value added of such a program is better decision-making through reduced uncertainty. If uncertainty reduction is interpreted as “learning”, then these results are important as they show the effect of “learning” on other improvement programs.

Aside from uncertainty reduction, I explore two other types of improvement programs. The second type studied is removing bias in cost estimates and the other is improving operations. Bias elimination programs occur in accounting systems when cost estimates are biased due to misallocation of fixed costs. For example, ABC accounting systems improve product costing by more carefully allocating fixed cost to their drivers. Kaplan and Cooper (1997) explain that many cost accounting systems over-allocate costs to high volume simple products and under-cost more complex lower-volume products. Zimmerman (1979) explains that cost allocation is a “second-best” process that helps an accountant to estimate marginal costs. The fact that the process is second-best and is often applied to all products mechanically reinforces the argument that errors in cost estimation do occur. A bias reduction program begins with the intellectual understanding that some cost allocations are biased and the direction of the bias often can be inferred ex-ante. One of the programs I study involves removing such bias.

The third type of improvement program studied is an improvement program in operations. This might focus on many aspects such as higher conformance to technical specifications, reduced lead-time, and reduced product cost. In this study the focus is on reducing direct cost, reducing non-value added lead-time and reducing capacity costs. I study several types of operations improvement programs and show that they are mutually complementary but not necessarily to other programs. This suggests that simultaneous operations improvement programs are generally more valuable than “stand-alone” economic assessments would imply.

In this analysis, common, but specific types of operations, marketing and accounting improvement programs are studied. Specificity is required because the structure of each program type affects the value function differently, and thus generates different basic sufficient conditions. Although our results are not generic for all programs, the approach to establishing sufficient conditions is generic.

I show that many improvement programs are not necessarily complementary but are instead substitutes or independently behaved. Table 1 describes the results of Sect. 2 where the demand function is assumed convex in price and the cost function concave in production quantity. The latter is an important case as our results apply to cost and service environments driven by queuing. I show that a program that adds value by reducing uncertainty about some decision-affecting-parameters can be a complement or

Table 1 Complementarity of improvement programs studied in Sect. 2

	Reduce uncertainty about value of early schedule delivery (ξ_a)	Reduce uncertainty about cost of late delivery (ξ_T)	Remove cost bias (r)	Reduce variable cost (c)	Reduce short term capacity cost (γ)	Reduce non value added time (t_a)
Reduce uncertainty about customers value of early scheduled delivery (ξ_a)		+	±	+	+	+
Reduce uncertainty about cost to the customer of late delivery(ξ_T)			–	Additive	Additive	+
Remove cost bias (r)				+	–	+
Reduce variable cost (c)					+	+
Reduce short term capacity cost (γ)						+
Reduce non value added time (t_a)						

The differing complementary properties of programs related to operations (cost related), accounting (removing cost bias) and marketing (uncertainty reduction of customer demand parameters). *Key* + complement, − substitute, ± either, *additive* independent

a substitute to other programs. Reducing uncertainty about the customers value of early delivery promises is complementary to reducing uncertainity about the value of late delivery and to cost related operations programs, but could be either complementary or a substitute for removing cost estimate bias. Reducing uncertainty about the customer's non-pecuniary cost of late delivery is a substitute for the cost bias program, a complement to reducing non-value added time but independent to other operations improvements such as reducing variable cost or short term capacity cost. A program to reduce bias in cost estimates is complementary to variable cost reduction or a non-value added time reduction program but is a substitute to reducing short-term capacity cost! Finally, programs that reduce variable cost, short-term capacity cost and non-value added time are mutual complements.

One of the contributions of this paper is studying complementarity in a queuing environment. The operations management literature has often adopted queuing as one of the key processes to model services as well as manufacturing. This is because queuing processes enable mapping production decisions into resulting service and inventory levels. Thus, how production decisions affects service levels and inventory costs can be modeled. It also is observed that other prominent operations processes share the cost behavior of queuing where total cost displays increasing returns to scale with respect to production volume. The most prominent of these are production processes with setup cost. These include the economic-order-quantity (EOQ) model and any other model with a fixed charge, such as location siting (see Francis et al. 1992). Thus, results about queuing processes apply more commonly than might first be suspected.

Section 3 explores more general cost and demand situations than are explored in Sect. 2. Here sufficient conditions that imply complementarity or substitutability of improvement programs when the demand and cost functions are non-linear are presented. Demand is assumed to be a convex decreasing function of service quality. The cost function can be convex, concave or neither as a function of production quantity. Several examples are used to demonstrate the power of the sufficient conditions are presented.

In the analysis of this paper, I ignore the significant cost of implementing an improvement program. This is because my focus is on the complementarity of improvement program *benefits*. For a specific project, the cost of implementation may be significant, but often can be assumed to be independent of the implementation of other programs. Thus, I focus on the value of an improvement program and not its value net of implementation cost. Next, I survey the literature on complementarity focused on improvement.

1.1 Literature Review

A recent overview of the use of supermodularity and complementarity in economics and game theory is found in Amir (2005). Milgrom and Roberts (1990, 1995) present models of a profit maximizing firm making operations and process choice decisions. The goal is to analyze comparative statics of the firm under optimal decisions about pricing, process choice, product innovation, lead-time to delivery, etc. Their modeling assumptions concerning supermodularity of functions leads to the result that the programs studied are complementary. Similarly, Bagwell and Ramey (1994) study the complementary relationship between processes, discount buying and falling consumer prices. In these papers, the authors seek to understand conditions that guarantee complementarity of decision variables, and monotone changes in optimal solutions with respect to exogenous variables. Also along these lines, Topkis (1995) generalizes the cited papers by Milgrom and Roberts and demonstrates necessary and sufficient assumptions to assure complementarity and monotonicity of optimal solutions. In order to get their results in all of these papers, assumptions are made that state that demand and cost functions are supermodular in decision variables. Complementarity of decision variables is shown by the property that maximization of a supermodular function with respect to some of the decision variables yields a function that is again supermodular in the remaining variables (Topkis 1998, Theorem 2.7.6). Monotonicity of optimal solutions with respect to non-decision variables is assured when the objective function is supermodular in the decision variable and the non-decision variables (Topkis 1998, Theorem 2.8.2). In short, assumptions about supermodularity, demand and cost lead directly to the results. The assumed cost functions are treated as "black boxes" meaning that the physics of the inherent processes is neither modeled nor developed. An unanswered question is if typical operations technologies (such as queuing, inventory management, fixed charge problems, etc.) lead to cost functions that are consistent with supermodularity, and when paired with a reasonable demand function, will total profit be supermodular in decision variables? Thus, a gap exists between the assumptions made in existing literature on complementarity and properties of important real operations technologies.

As previously stated, this paper analyzes the complementarity of uncertainty reduction and other improvement programs. Several papers have been written on the interaction of risk and supermodularity. An important paper is Athey (2002) that studies the monotonicity of the solution to an expected utility problem with respect to parameters that shift the utility function and the associated probability distribution. The question asked is what restrictions are necessary so that an arbitrary parameterized objective function from a restricted class of functions and an arbitrary parameterized probability distribution from a restricted class of probability distributions yields an expected value function that is supermodular in the decision variables and parameters. This question is important because it sets conditions for optimal decisions to be monotone in the common parameters. This question is quite unlike that of this paper that studies the complementarity of decisions to adopt different improvement programs, and not how parameters affect solutions.

Particularly important is the work of Siggelkow (2002) which demonstrates the cost of misperceiving complementarity or substitutability of programs. He shows that generally incorrectly assuming complementary effects are more costly than incorrectly assuming substitution effects. Siggelkow's work underscores the value of knowing when improvement programs possess either (or neither) of these properties. My research helps to better understand when complementarity or substitutability is likely to be present through analytical modeling of demand and processes.

The rest of the paper is organized as follows. Section 2 demonstrates analysis of a queuing process in a market with constant demand elasticity. The analysis studies whether direct cost savings, uncertainty reduction, and cost bias elimination are complements or substitutes. Section 3 generalizes conditions of Sect. 2 to other cost and demand functions. Section 4 presents a summary of results and some suggestions for further research.

2 A Study in Complementarity: The Three Improvement Programs in a System with Queuing

In this section I model a profit maximizing firm and its production system. The firm uses one of the basic operations processes: queuing. What is interesting about the queuing process is that if direct cost and delay dependent costs (e.g., work-in-process inventory, delay costs to customers) are considered there is a nonlinear production relationship between inputs and output cost. I assume that the firm wishes to improve its profitability by engaging in improvement programs. Consistent with the discussion so far, the firm is uncertain about some parameters that affect customers' demand. One possible improvement program is reduction in this uncertainty, which can be interpreted as a marketing-related program. In addition to uncertainty reduction, I study two other types of improvement programs: (1) cost bias elimination (which is accounting system related), and (2) direct cost savings (which is production related). Cost bias elimination improves profit by recognizing that often firms make production decisions based upon biased cost estimates. In a real firm, many productivity improvement programs are possible, such as direct cost savings, defect elimination, yield enhancement, shortening production lead time, decreasing process variability, and shortening cycle times, etc. In modeling, I need to be specific and focus primarily on direct cost savings and, secondarily, on reduction in non-value added lead time, and capacity costs.

Consider a one-stage, one-product system that produces to customer order. For simplicity, it is assumed that the manager seeks to maximize profit and is risk neutral. The manager's decisions are: production rate, what delivery date to promise, and how much short-term capacity (such as direct labor) to employ. The time to produce an order can be reduced by adding short-term capacity to speed up the production rate, but at some expense. The promised delivery date is the date when the delivery to the customer is supposed to be made: however due to production problems the delivery date may be missed and the order may be tardy. We assume that the price that a customer is willing to pay is a function of the market's demand rate, the time to delivery and the tardiness of such the order. The firm's costs are the sum of direct cost and capacity related cost. To formally describe the problem, the following notation is used:

p	the \$ price for the product/unit (a function of sales rate)
P	the "full" price is the \$ sum of the unit sales price, p, plus the sum of the costs of delivery delay, and expected tardiness
q	the steady state sales rate in each period for the product (units/period) (decision variable)
δ_a	promised delivery date (periods in the future) (decision variable)
δ_K	the short-term capacity for cost center (rate of production/period) (decision variable)
$C(\delta_K)$	the total \$ cost of short-term capacity at cost center. We assume $C(\delta_K) = \gamma\delta_K$ (\$/rate of production in units/period)
$L = L(q, \delta_K)$	the total production lead time for production rate q per period with capacity
δ_K	Lead time is itself divided into two components: non-value added lead time, and process time (periods)
$L_N = t_o$	non-value added lead time (periods)

$$L_P = \frac{1}{\delta_K - q} = \text{process lead time (periods)} \tag{2.1}$$

T the expected tardiness of the order (expected difference between the actual delivery date and the promised delivery date (periods)

c the direct production \$ cost per unit of the product

ξ_a customers' cost per period for planned delivery wait (\$/period)

ξ_T customers' cost per period of delay beyond the promised delivery date (\$/period)

As is traditional, random variables will be indicated by a tilde above the character and mean value will be indicated by a bar over the random variable.

Customers value fast planned delivery and adherence to the schedule. We assume that customers' cost per period for a planned delivery horizon is ξ_a. We also assume that the customer's cost of delay per period in actual delivery beyond the "promised" date δ_a is ξ_T. Once delivery date has been promised, then customers find no value to delivery before that date. The cost structure is very much like that of a customer running a project. The project is complex and activities must be coordinated. Once an item (off the critical path) has been scheduled for delivery, earlier arrival is valueless. However, tardiness (late arrival) causes disruptions and additional project cost.

For analytic tractability, the customers demand function is assumed to be of a simple constant elastic form:

$$P(q) = \sqrt{\frac{\alpha}{q}}, \quad \text{thus,} \quad p + \xi_T T + \xi_a \delta_a = \sqrt{\frac{\alpha}{q}}. \tag{2.2}$$

In Sect. 3, I show that this assumption can be generalized to a broad range of demand functions.

The firm is uncertain about a customer's taste for quick delivery and tardiness, but has an unbiased estimate of cost parameters $\tilde{\xi}_a$ and $\tilde{\xi}_T$. Customers may more highly value quick delivery than reduced tardiness ($\xi_a > \xi_T$), or may view early delivery more valuable than an earlier promised delivery date ($\xi_T > \xi_a$). The PDF's for these two random variables are: f_a and f_T. A notation we will often use is to write the expected value of these two random variables as, respectively, $\bar{\xi}_a$ and $\bar{\xi}_T$.

Lead-time consists of two components: non-value added time and process-related time queuing time, $L = L_N + L_P$. Non-value added time captures the time in which an item is neither in production nor in queue for production. Non-value added time is an important component of total lead-time, and has been a major focus of waste reduction in total quality management.

To calculate process-related queuing time we assume an M/M/1 queuing process which implies that the arrival of orders is given by a Poisson process and the service times are exponentially distributed with rate δ_K. Thus, the actual queuing time is a function of production capacity and manager's capacity-related effort, and expected waiting time is given by the M/M/1 formula $L_P = \frac{1}{\delta_K - q}$. Using the M/M/1 assumption, process time due to congestion is stochastic with an exponential distribution and the actual completion time t has a distribution function

$$h(t \mid \delta_K, q) = \frac{1}{\delta_K - q} e^{-(\delta_K - q)(t - t_o)}. \tag{2.3}$$

If a is the promised delivery date, the expected tardiness has a value of

$$T(\delta_a, q, \delta_K) = \frac{1}{\delta_K - q} e^{-(\delta_K - q)(\delta_a - t_o)}. \tag{2.4}$$

The firm's objective is to choose a production rate for the product and short-term capacity to maximize its profit.

$$\underset{q,\delta_a,\delta_K}{\text{Max}} \quad \Pi = pq - cq - \gamma\delta_K \tag{2.5}$$

$$\text{subject to} \quad p = \sqrt{\frac{\alpha}{q}} - \xi_a\delta_a - \xi_T T \tag{2.6}$$

$$q \geq 0, \;\; \delta_a \geq 0, \;\; \delta_K \geq 0. \tag{2.7}$$

This problem can be written separating the inner problem that minimizes cost with respect to decision variables:

$$\underset{q}{\text{Max}} \;\; \underset{\delta_a,\delta_K}{\text{Min}} \;\; \left[\sqrt{\alpha q} - [(\xi_a\delta_a + c + \xi_T T)q + \gamma\delta_K]\right],$$

$$\text{or,} \quad \underset{q}{\text{Max}} \;\; \left[\sqrt{\alpha q} - \underset{\delta_a,\delta_K}{\text{Min}} \;\; \left[(\xi_a\delta_a + c + \xi_T \frac{1}{\delta_K - q} e^{-(\delta_K - q)(\delta_a - t_o)})q + \gamma\delta_K\right]\right] \tag{2.8}$$

subject to (2.7).

It will be useful to define the cost function

$$\begin{aligned} C(q, \delta_a, \delta_K, \xi_a, \xi_T) &= (\xi_a\delta_a + c + \xi_T T)q + \gamma\delta_K \\ &= \left(\xi_a\delta_a + c + \xi_T \frac{1}{\delta_K - q} e^{-(\delta_K - q)(\delta_a - t_o)}\right)q + \gamma\delta_K \end{aligned} \tag{2.9}$$

thus the objective can be written $\underset{q}{\text{Max}} \;\; \left[\sqrt{\alpha q} - \underset{\delta_a,\delta_K}{\text{Min}} \;\; C(q, \delta_a, \delta_K, \xi_a, \xi_T)\right]$.

We next derive optimal values of the decision variables.

2.1 Optimization of Decisions

Proposition 2.1 *For fixed q, the values of δ_K, and δ_a, that solve the inner problem are:*

$$\delta_a^*(q) = \begin{cases} t_o & if \quad \xi_a \geq \xi_T \\ t_o + \sqrt{\frac{\gamma}{\xi_a\left(1-\log(\frac{\xi_a}{\xi_T})\right)q}}\log\left(\frac{\xi_T}{\xi_a}\right) & if \quad \xi_a < \xi_T \end{cases} \tag{2.10}$$

$$\delta_K^*(q) = \begin{cases} q + \sqrt{\frac{\xi q}{\gamma}} & if \quad \xi_a \geq \xi_T \\ q + \sqrt{\frac{\xi_a\left(1-\log(\frac{\xi_a}{\xi_T})\right)q}{\gamma}} & if \quad \xi_a < \xi_T \end{cases}, \tag{2.11}$$

with associated tardiness

$$T^*(q) = \begin{cases} \frac{1}{\delta_K^*-q} = \sqrt{\frac{\gamma}{\xi_T q}} & if \quad \xi_a \geq \xi_T \\ \frac{1}{\xi_T}\sqrt{\frac{\gamma\xi_a}{\left(1-\log(\frac{\xi_a}{\xi_T})\right)q}} & if \quad \xi_a < \xi_T \end{cases}. \tag{2.12}$$

Optimal decisions are derived by differentiating by the appropriate variable and solving the first-order condition (and checking the second-order conditions). These routine computations are omitted.

To simplify notation for later expressions, I write:

$$\lambda(\xi_a, \xi_T) = \begin{cases} \xi_T & if\ \xi_T \leq \xi_a \\ \xi_a\left(1 - \log\left(\frac{\xi_a}{\xi_T}\right)\right) & if\ \xi_T \geq \xi_a \end{cases}. \tag{2.13}$$

If $\xi_T \leq \xi_a$, the firm prefers to announce its earliest possible delivery date (t_o). Then the expected tardiness is just the expected time in system for an order. If $\xi_a \leq \xi_T$, the firm will announce a date after t_o .

Substituting the results of Proposition 2.1, the firm's objective function is in the form:

$$\Pi(q, \xi) = \underset{q}{\text{Max}}\ \sqrt{\alpha q} - \left[(\xi_a t_o + c + \gamma)q + 2\sqrt{\gamma\lambda(\xi_a, \xi_T)q}\right]. \tag{2.14}$$

We proceed, and solve explicitly for an optimal sales rate:

$$q(\xi) = \left(\frac{\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma\lambda(\xi_a, \xi_T)}}{\xi_a t_o + c + \gamma}\right)^2, \tag{2.15}$$

in which case the firm's profit function is:

$$\Pi(q(\xi), \xi) = \frac{\left(\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma\lambda(\xi_a, \xi_T)}\right)^2}{\xi_a t_o + c + \gamma} = (\xi_a t_o + c + \gamma)q(\xi). \tag{2.16}$$

Interestingly, profit is directly proportional to the sales rate. If $\xi_a \leq \xi_T$, the Hessian of the profit function with respect to (ξ_a, ξ_T) can be shown to be positive definite, so that this function is strictly convex in (ξ_a, ξ_T). Likewise if $\xi_a \geq \xi_T$, the same conclusion holds and I will show in the next section that information about ξ_a is valuable even though choice of delivery date is fixed at t_o.

We next explicitly compute the value of marketing research, cost estimation, and process improvement programs.

2.2 Value of an Uncertainty Reduction Program

If there is uncertainty in the value of the demand parameters $\tilde{\xi}_a$ and $\tilde{\xi}_T$ when its decisions are made, the firm's problem is:

$$\underset{q}{\text{Max}} \ \underset{\delta_a, \delta_K}{\text{Max}} \ E_f[\sqrt{\alpha q} - \tilde{\xi}_a \delta_a q - cq - \tilde{\xi}_T T q - \gamma \delta_K] \text{ subject to (2.7).}$$

Computing the expectation, the optimization problem becomes:

$$\underset{q}{\text{Max}} \ \underset{\delta_a, \delta_K}{\text{Max}} \ \sqrt{\alpha q} - \bar{\xi}_a \delta_a q - cq - \bar{\xi}_T T q - \gamma \delta_K, \text{ subject to (2.7).}$$

(Recall, a bar over a random variable indicates its mean). The firm's problem is:

$$\Pi(q, \bar{\xi}) = \underset{q}{\text{Max}} \ \sqrt{\alpha} q - \left[\left(\bar{\xi}_a t_o + c + \gamma\right) q + 2\sqrt{\lambda(\bar{\xi}_a, \bar{\xi}_T)}\sqrt{\gamma q}\right].$$

Now, the decisions the manager makes are exactly those specified in (2.10) and (2.11) but with $\bar{\xi}_a$ and $\bar{\xi}_T$ used instead of ξ_a and ξ_T. The profit functions will be:

$$\Pi(q, (\bar{\xi}_a, \bar{\xi}_T)) = \underset{q}{\text{Max}} \ \sqrt{\alpha q} - \left[\left(\bar{\xi}_a t_o + c + \gamma\right) q + 2\sqrt{\lambda(\bar{\xi}_a, \bar{\xi}_T)}\sqrt{\gamma q}\right].$$

The optimal sales rate and profit are:

$$q(\bar{\xi}_a, \bar{\xi}_T) = \left(\frac{\frac{\sqrt{\alpha}}{2} - \sqrt{\lambda(\bar{\xi}_a, \bar{\xi}_T)}}{(\bar{\xi}_a + h)t_o + c + \gamma} \right)^2 \tag{2.17}$$

$$\Pi(q(\bar{\xi}_a, \bar{\xi}_T), (\bar{\xi}_a, \bar{\xi}_T)) = \frac{\left(\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma}\sqrt{\lambda(\bar{\xi}_a, \bar{\xi}_T)} \right)^2}{\bar{\xi}_a t_o + c + \gamma}. \tag{2.18}$$

The profit in absolute terms is just $q(\bar{\xi})\left(\bar{\xi}_a t_o + c + \gamma\right)$. Note that as before, profit is linear in the sales rate, and directly proportional to the unit direct cost, $\xi_a t_o + c + \gamma$.

The expected gain from instituting an *uncertainty reduction program* is

$$\begin{aligned} &E\Pi(q(\tilde{\xi}_a, \tilde{\xi}_T)), (\tilde{\xi}_a, \tilde{\xi}_T)) - \Pi(q(\bar{\xi}_a, \bar{\xi}_a), (\bar{\xi}_a, \bar{\xi}_a)) \\ &\quad = \frac{\sqrt{\alpha\gamma}\sqrt{\lambda(\bar{\xi}_a, \bar{\xi}_T)} + \gamma\lambda(\bar{\xi}_a, \bar{\xi}_T)}{\bar{\xi}_a t_o + c + \gamma} - E\frac{\sqrt{\alpha\gamma}\sqrt{\lambda(\tilde{\xi}_a, \tilde{\xi}_T)} + \gamma\lambda(\tilde{\xi}_a, \tilde{\xi}_T)}{\tilde{\xi}_a t_o + c + \gamma} > 0. \end{aligned} \tag{2.19}$$

As in the last section, the Hessian of (2.18) is positive definite in (ξ_a, ξ_T), thus is a convex function of (ξ_a, ξ_T), which implies that (2.19) is strictly positive. But observing definition (2.13) it is seen that even if $\xi_a \geq \xi_T$, positive expected value-added occurs when uncertainty about ξ_a and ξ_T are reduced. Although the due date (δ_a) decision is not affected by reduced uncertainty about ξ_T, the optimal production rate is. We conclude that reduction in uncertainty for either, or both parameters is valuable.

2.3 Value of Bias Reduction

In this section I introduce bias into cost estimates. I assume a common accounting procedure and heuristic: the firm uses *average* operating cost to estimate a component, or the whole of *marginal* cost. We consider distortion of the non-linear cost of production $\gamma q + \sqrt{\lambda\gamma q}$ by use of its average cost. Using average cost has the effect of *reducing* marginal cost by 50 %. If the firm uses (2.9) and (2.10) to set δ_a and δ_K, then at any volume level, q':

$$\text{Average } \textit{real} \text{ operating cost} = \xi_a t_o + c + \gamma + \sqrt{\frac{\lambda\gamma}{q'}}, \tag{2.20}$$

where q' is output used to set the average cost. Now the firm's profit as a function of production (assuming the other components are estimated correctly) is:

$$\hat{\Pi}(q,\xi) = \sqrt{\alpha q} - (\xi_a t_o + c + \gamma)q - \sqrt{\lambda\gamma q} - \sqrt{\frac{\lambda\gamma}{q'}}q. \tag{2.21}$$

The derivative of profit with respect to demand is now

$$\frac{\partial\hat{\Pi}(q,\xi)}{\partial q} = \frac{\sqrt{\alpha}}{\sqrt{q}} - (\xi_a t_o + c + \gamma) - \frac{1}{2}\frac{\sqrt{\lambda\gamma}}{\sqrt{q}} - \frac{\sqrt{\lambda\gamma}}{\sqrt{q'}}.$$

When $q = q'$, we find the optimal production level is just

$$\hat{q}(\xi) = \left(\frac{\frac{\sqrt{\alpha}}{2} - \frac{3}{2}\sqrt{\lambda\gamma}}{\xi_a t_o + c + \gamma}\right)^2. \tag{2.22}$$

Using biased cost, $\hat{q}$ is the perceived "optimal q". I write $\hat{\Pi}$ and $\hat{C}$ for respectively, the profit and cost functions computed with biased cost. The biased cost function is $\hat{C}(q,\hat{\delta}^*) = (\xi_a t_o + c + \gamma)q + \frac{3}{2}\sqrt{\gamma\lambda(\xi_a,\xi_T)q}$ instead of the true cost function: $C(q,\delta^*) = (\xi_a t_o + c + \gamma)q + 2\sqrt{\gamma\lambda(\xi_a,\xi_T)q}$ (2 is the *proper* weighting on the non-linear term in q, but when misestimating, the *improper* weighting is 3/4 of the *proper* value. This tells us that one component of marginal cost is misestimated by a factor of ¾, that is marginal cost is 25 % too low). With misestimated marginal cost, true profit is:

$$\Pi(\hat{q}(\xi),\xi) = \frac{\left(\frac{\sqrt{\alpha}}{2} - \frac{3}{4}\sqrt{\lambda\gamma}\right)\left(\frac{\sqrt{\alpha}}{2} - \frac{5}{4}\sqrt{\lambda\gamma}\right)}{\xi_a t_o + c + \gamma}. \tag{2.23}$$

It can be shown that (2.22) is strictly convex in (ξ_a,ξ_T), so that uncertainty reduction is valuable even with distorted production decisions through cost misestimate. By subtracting (2.16) from (2.23), the value of a bias elimination program is:

$$\Pi(q(\xi),\xi) - \Pi(\hat{q}(\xi),\xi) = \frac{\gamma\lambda(\xi_a,\xi_T)}{16(\xi_a t_o + c + \gamma)} \tag{2.24}$$

In this example, the bias causes one component of marginal cost to be taken at $r = 3/4$ of its real value. In general, if that component of marginal cost is distorted by a factor of r, the value added by removing bias can be shown to be

$$\Pi(q(\xi),\xi) - \Pi(\hat{q}(r,\xi),\xi) = \frac{(1-r)^2\gamma\lambda(\xi_a,\xi_T)}{(\xi_a t_o + c + \gamma)}. \tag{2.25}$$

This fact will be useful in the next section in analyzing complementarity when marginal cost is *over*estimated, that is, $r > 1$.

2.4 The Value of Direct Cost Savings

In this section, I explicitly compute the value of reduction in variable production cost (c). Suppose that all parameters are known with certainty. If the linear cost can be reduced to zero ($c = 0$), the optimal production and profit become

$$q(\xi, 0) = \left(\frac{\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma\lambda}}{\xi_a t_o + \gamma}\right)^2, \text{ and} \tag{2.26}$$

$$\Pi(q(\xi, 0), \xi) = \frac{\left(\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma\lambda}\right)^2}{\xi_a t_o + \gamma} = (\xi_a t_o + \gamma) q(\xi, 0). \tag{2.27}$$

Profit increases by

$$\Pi(q(\xi, 0), \xi) - \Pi(q(\xi, c), \xi) = \Pi(q(\xi, c), \xi)\left(\frac{(\xi_a t_o + c + \gamma)}{\xi_a t_o + \gamma} - 1\right) \tag{2.28}$$

which is clearly positive.

2.5 Complementary/Substitute Improvement Programs

By explicit computation, the complementarity or substitutability between the three improvements is demonstrated. I show that complementarity or substitutability cannot be universally assumed for all parameter values. Thus, care must be taken in assuming complementarity of improvement programs.

Suppose the firm is using an *average costing system* and has uncertainty about demand parameters that cannot be resolved before production begins.

If the firm engages in a cost bias elimination program, the gain has been shown via (2.24) to be $\frac{\gamma\lambda(\bar{\xi}_a, \bar{\xi}_T)}{16(\bar{\xi}_a t_o + c + \gamma)}$. If the firm also implements an uncertainty reduction program, the additional benefit is now, $E_{\tilde{\xi}} \frac{\gamma\lambda(\tilde{\xi}_a, \tilde{\xi}_T)}{16(\tilde{\xi}_a t_o + c + \gamma)} - \frac{\gamma\lambda(\bar{\xi}_a, \bar{\xi}_T)}{16(\bar{\xi}_a t_o + c + \gamma)}$.

If uncertainty in ξ_T *but not* ξ_a has been eliminated, the value added is $E_{\tilde{\xi}_T} \frac{\gamma\lambda(\bar{\xi}_a, \tilde{\xi}_T)}{16(\bar{\xi}_a t_o + c + \gamma)} - \frac{\gamma\lambda(\bar{\xi}_a, \bar{\xi}_T)}{16(\bar{\xi}_a t_o + c + \gamma)}$. This is negative as the value added by cost bias elimination, (2.24), is concave in ξ_T : $\frac{d}{d\xi_T^2}\left[\frac{\gamma\lambda(\xi_a, \xi_T)}{16(\xi_a t_o + c + \gamma)}\right] = -\frac{\gamma}{16(c + \gamma + t_o\xi_a)\xi_a^2} < 0.$

Thus, cost bias reduction is a *substitute* for uncertainty reduction in ξ_T. This surprising result contrasts with the complementarity properties of uncertainty reduction in ξ_a which we show next.

If uncertainty in ξ_a *but not* ξ_T has been eliminated complementarity properties are ascertained by convexity properties of the value added and there are two cases. This is a bit complicated because, as remarked earlier, if $\bar{\xi}_T \leq \xi_a$, then the promised delivery date will be t_o. If $\tilde{\xi}_T \leq \tilde{\xi}_a$ holds with probability 1, the expected value added is convex independent of the other parameters, thus cost bias elimination and uncertainty reduction are complements.

If $\tilde{\xi}_T \geq \tilde{\xi}_a$ holds with probability 1, the expected value added is neither concave nor convex: $\frac{d^2}{d\xi_a^2}\left[\frac{\gamma\lambda(\xi_a,\bar{\xi}_T)}{16(\bar{\xi}_a t_o + c+\gamma)}\right] = \frac{-\gamma(c+\gamma)^2 - t_o^2\xi_a^2 + 2(c+\gamma)t_o\lambda(\xi_a,\bar{\xi}_T)}{16\xi_a(c+\gamma+t_o\xi_a)^3}$. Unfortunately, the sign is ambiguous. However some sufficient conditions for convexity can be derived. There are two sub-cases related to the relative ratio of $\tilde{\xi}_a$ and $\bar{\xi}_T$. If $\bar{\xi}_T/\tilde{\xi}_a > \mathrm{e}^{\frac{1}{2}\left(-2+\frac{c+\gamma}{t_o\tilde{\xi}_a}+\frac{t_o\tilde{\xi}_a}{c+\gamma}\right)}$ with probability 1, then the second-order derivative is negative and *substitutability* is implied; if $\bar{\xi}_T/\tilde{\xi}_a < \mathrm{e}^{\frac{1}{2}\left(-2+\frac{c+\gamma}{t_o\tilde{\xi}_a}+\frac{t_o\tilde{\xi}_a}{c+\gamma}\right)}$ with probability 1, then the *second-order derivative is positive*, and *complementarity* is implied. Thus, the complementarity of bias elimination and uncertainty reduction cannot be taken as a given, and must be considered carefully.

Do these results depend on the fact that our model assumes that one component of marginal cost is underestimated? What happens when that component is *over*estimated? By observing the general case for marginal cost bias as expressed in (2.25), it can be seen that the above conclusions about complementarity hold when bias results in *over* or *under*estimates of marginal cost.

Next, I show that direct cost savings and uncertainty reduction are complements. When cost c is reduced to zero but there is uncertainty about parameters, then the expected value added by direct cost savings is $\Pi(q(\bar{\xi},c),\bar{\xi})\left(\frac{\bar{\xi}_a t_o + c+\gamma}{\bar{\xi}_a t_o+\gamma} - 1\right)$. If uncertainty about parameters has been resolved, then the value added by direct cost savings is $E_{\tilde{\xi}}\left[\Pi(q(\tilde{\xi},c),\tilde{\xi})\left(\frac{\tilde{\xi}_a t_o + c+\gamma}{\tilde{\xi}_a t_o+\gamma} - 1\right)\right]$. Note that as Π and $\left(\frac{\xi_a t_o + c+\gamma}{\xi_a t_o+\gamma} - 1\right)$ are both positive, convex in ξ_a and monotone decreasing in ξ_a, it follows that the product of Π and $\left(\frac{\xi_a t_o + c+\gamma}{\xi_a t_o+\gamma} - 1\right)$ is also convex in ξ_a. Thus, $E_{\tilde{\xi}}\left[\Pi(q(\tilde{\xi},c),\tilde{\xi})\left(\frac{\tilde{\xi}_a t_o + c+\gamma}{\tilde{\xi}_a t_o+\gamma} - 1\right)\right] > \Pi(q(\bar{\xi},c),\bar{\xi})\left(\frac{\bar{\xi}_a t_o + c+\gamma}{\bar{\xi}_a t_o+\gamma} - 1\right)$: direct cost savings is unambiguously complementary to uncertainty reduction in ξ_a. By an identical argument, reducing the value of γ or t_o are seen to be complements to bias elimination.

Because the second term in the product is not a function of ξ_T, uncertainty reduction in ξ_T does not increase or decrease the value added by direct cost savings: these programs have *additive values*. Again, the same conclusion can be made about γ or t_o: reducing these has no effect on the value added by reducing uncertainty in ξ_T.

The relationship between bias reduction and direct cost savings is easily inferred from (2.23). The increase in value due to bias reduction is complementary to c and t_o, but is a substitute to reduction in γ.

Is uncertainty reduction in ξ_T complementary to uncertainty reduction in ξ_a? The answer is yes. This is shown via the following proposition:

Proposition 2.2 *Consider two random variables, $\tilde{\xi}_a$ and $\tilde{\xi}_T$ with respective means $\tilde{\xi}_a$ and $\tilde{\xi}_T$. Also assume three continuous functions defined on a compact set G denoted $F_a(x)$, $F_T(x)$ and $J(x)$ with $x \in G$. Now define $x(\xi_a, \xi_T) = \underset{x}{ArgMax}[J(x) - \xi_a F_a(x) - \xi_T F_T(x)]$ then*

$$\begin{aligned}
&E_{\tilde{\xi}_a \tilde{\xi}_T}\left[J(x(\tilde{\xi}_a, \tilde{\xi}_T)) - \tilde{\xi}_a F_a(x(\tilde{\xi}_a, \tilde{\xi}_T)) - \tilde{\xi}_T F_T(x(\tilde{\xi}_a, \tilde{\xi}_T))\right] \\
&- E_{\tilde{\xi}_T}\left[J(x(\bar{\xi}_a, \tilde{\xi}_T)) - \bar{\xi}_a F_a(x(\bar{\xi}_a, \tilde{\xi}_T)) - \tilde{\xi}_T F_T(x(\bar{\xi}_a, \tilde{\xi}_T))\right] \\
&\quad \geq E_{\tilde{\xi}_a}\left[J(x(\tilde{\xi}_a, \bar{\xi}_T)) - \tilde{\xi}_a F_a(x(\tilde{\xi}_a, \bar{\xi}_T)) - \bar{\xi}_T F_T(x(\tilde{\xi}_a, \bar{\xi}_T))\right] \\
&- \left[J(x(\bar{\xi}_a, \bar{\xi}_T)) - \bar{\xi}_a F_a(x(\bar{\xi}_a, \bar{\xi}_T)) + \bar{\xi} F_T(x(\bar{\xi}_a, \bar{\xi}))\right]
\end{aligned}$$

.

Proof *Let* $H(x(\xi_a, \xi_T)) = [J(x(\xi_a, \xi_T)) - \xi_a F_a(x(\xi_a, \xi_T)) - \xi_T F_T(x(\xi_a, \xi_T))]$. H is a convex function of $(\xi_a, \xi_T) \in G$. This implies by Jensen's inequality

$$\begin{aligned}
&E_{\tilde{\xi}_a \tilde{\xi}_T}\left[J(x(\tilde{\xi}_a, \tilde{\xi}_T)) - \tilde{\xi}_a F_a(x(\tilde{\xi}_a, \tilde{\xi}_T)) - \tilde{\xi}_T F_T(x(\tilde{\xi}_a, \tilde{\xi}_T))\right] \\
&\geq E_{\tilde{\xi}_a}\left[J(x(\tilde{\xi}_a, \bar{\xi}_T)) - \tilde{\xi}_a F_a(x(\tilde{\xi}_a, \bar{\xi}_T)) - \bar{\xi}_T F_T(x(\tilde{\xi}_a, \bar{\xi}_T))\right].
\end{aligned}$$

and,

$$\begin{aligned}
&E_{\tilde{\xi}_T}\left[J(x(\bar{\xi}_a, \tilde{\xi}_T)) - \bar{\xi}_a F_a(x(\bar{\xi}_a, \tilde{\xi}_T)) - \tilde{\xi}_T F_T(x(\bar{\xi}_a, \tilde{\xi}_T))\right] \geq J(\bar{\xi}_a, \bar{\xi}_T) \\
&\quad - \bar{\xi}_a F_a(x(\bar{\xi}_a, \bar{\xi}_T)) - \bar{\xi}_T F_T(x(\bar{\xi}_a, \bar{\xi})).
\end{aligned}$$

Thus the conclusion is justified. QED

Consider the original profit function defined by (2.8). Letting $x = (\delta_a, \delta_K)$ puts (2.8) in the same general form as H. Then the conclusion of the proposition holds for the profit function. Thus, uncertainty reduction in one parameter is complementary to uncertainty reduction in another.

2.6 Complementarity of Other Operations Improvement Programs

Other observations are possible from this model by exploiting different, important parameters. The formula for optimal profit, (2.15), can be used to study complementarity of direct cost savings with two other operations improvement actions. These two actions are: reducing non-value added lead-time (t_o) and reducing the cost per unit of capacity (γ). Note that these are the only other operations-related parameters in the model aside from c. Computing the appropriate cross partials:

$$\frac{\partial^2\Pi}{\partial c\partial\gamma} = \frac{\sqrt{\alpha\gamma} + \sqrt{\lambda/\gamma}(-2\gamma + (c+\gamma+\xi_a t_o)^2}{2\sqrt{\gamma}(c+\gamma+\xi_a t_o)} > 0 \text{ if } c > 0,$$

$$\frac{\partial^2\Pi}{\partial c\partial t_o} = 2\xi_a \frac{\left(\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma\lambda}\right)^2}{(c+\gamma+\xi_a t_o)} > 0,$$

$$\frac{\partial^2\Pi}{\partial\gamma\partial t_o} = \lambda\xi_a^2 \frac{\left(\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma\lambda}\right)}{\sqrt{\gamma\lambda}(c+\gamma+\xi_a t_o)^2} + 2\xi \frac{\left(\frac{\sqrt{\alpha}}{2} - \sqrt{\gamma\lambda}\right)^2}{(c+\gamma+\xi_a t_o)^2} > 0.$$

Thus, these three improvement programs are complementary. Further, on the lattice defined on the positive orthant of three-space for (c, γ, t_o), the profit function is supermodular. It is significant to note that all three operations improvements are complementary to each other.

To summarize, in this section in the context of a queuing process, I have shown that although uncertainty reduction programs are not supermodular, it may be possible to make definitive statements of complementarity or substitutability. Direct cost reduction is complementary to uncertainty reduction. When average costing causes marginal cost to be biased, I have shown that cost reduction and bias elimination are complements. However, ambiguity enters in other cases. Depending on parameter values, cost bias elimination and uncertainty reduction may be complements or substitutes. Care must be taken not to make a priori assumptions that all improvement programs are complements.

The next section generalizes these results by presenting sufficient conditions for these three programs to be complements and substitutes. The sufficient conditions are presented in the context of more general demand and cost functions.

3 General Results

Complementarity of the three programs under more general demand and cost functions are analyzed in this section. Sufficient conditions for complementarity are developed for any demand and cost functions.

Consider a market with an inverse demand function, $P = P(q)$, where P is the *full price* per unit. Full price is the sum of the price charged plus service quality associated costs borne by the customer. Customers are sensitive to characteristics of service quality, such as product quality, lead time, reliability of delivery, etc. Without loss of generality, we assume a single attribute for customer service quality, s, that is weighted by a positive constant ξ. The service level is a negative attribute (higher s implies longer wait, more unreliability, poorer service, etc.). If the service level is s and the customer's sensitivity to inconvenience is parameter ξ, the *real* price paid by the customer is $p = P(q) - \vartheta(\xi)s$. In this section function $\vartheta()$ is not necessarily linear in ξ. Instead we assume the function is concave in ξ.

Making concave $\vartheta(\xi)$ assures that the expected value of additional information about ξ is non-negative. However, if $\vartheta(\xi)$ is *convex*, then the value of information has an expected value that is *non-positive*. Thus, this concavity condition is necessary for information to add value.

Given a scalar decision parameter δ and production volume q, the service level is given by the function $s(q, \delta)$. The cost of producing output q with quality $s(q, \delta)$ is $\mathcal{C}(q, \delta)$. Firm profit is

$$\Pi(q, \delta, \xi) = (P(q) - \vartheta(\xi)s(q, \delta))q - \mathcal{C}(q, \delta). \tag{3.1}$$

Here we interpret parameter ξ as affecting demand through "*Full Price*" but a slight re-interpretation of the model could have it affect the cost function. To do this, the cost $s(q, \delta)q$ would be part of the cost function, not the *Full Price*. As in Sect. 2, with a certain value of ξ, the profit maximizing choice of δ is denoted $\delta^*(q, \xi)$.

The following three assumptions insure that a local optimal production rate is a continuous function of other model parameters..

Assumptions 3.1

(a) $P(q)$ is twice continuously differentiable, down-sloping for all $q \geq 0$.

(b) $\vartheta(\xi)s(q, \delta)q + \mathcal{C}(q, \delta)$ is four-times continuously differentiable in δ and is concave in δ for all δ within the set $(q, \delta) \in \Gamma \subset \mathbb{R}^2_+$ where Γ is a closed convex set.

(c) $(q, \delta^*(q, \xi)) = (q, \underset{\{\delta|(q,\delta)\in\Gamma\}}{\text{ArgMin}}[\vartheta(\xi)s(q, \delta) + C(q, \delta)])$ is in the interior of Γ for all q. Further $\frac{d^2[\vartheta(\xi)s(q,\delta)q + \mathcal{C}(q,\delta)]}{d\delta^2}|_{(q,\delta)=(q,\delta^*(q,\xi))} < 0$

(d) Let $q^* = \underset{q \geq 0}{\text{ArgMax}}\, P(q) - \vartheta(\xi)s(q, \delta^*(q, \xi))q - \mathcal{C}(q, \delta^*(q, \xi))$ then, $(q^*, \delta^*(q, \xi)) \in \text{int}\,\Gamma$ and $\frac{d^2[P(q) - \vartheta(\xi)s(q,\delta^*(q,\xi))q - \mathcal{C}(q,\delta^*(q,\xi))]}{dq^2}|_{(q,\delta)=(q*,\delta^*(q,\xi))} < 0$

These assumptions generalize requirements of Sect. 2. and admit a far wider set of demand and cost functions than was previously assumed. Assumptions about continuous differentiability are not very restrictive. The differentiability assumptions are made to assure continuity of higher order derivatives derived by the inverse function theorem. If a function is not sufficiently differentiable, it may be replaced by an analytic function that is arbitrarily close to the original. With this approximation, the tools of the following pages can be used to predict complementarity properties.

Assumption 3.1.a is a standard requirement for a demand function. Assumption 3.1.b states that the optimum capacity choice will be in a closed convex set, which implies that the K-T conditions are sufficient to guarantee optimality in capacity choice. Assumption 3.1.c strengthens the latter in that given a value of q the optimum capacity choice will be global maximum within the set Γ so first order conditions are sufficient to guarantee an optimum capacity choice. Further, it guarantees that this optimum is locally continuous in other model parameters, by the inverse function theorem. Assumption 3.1.d states that the optimum choice of capacity and production rate when restricted to set Γ is in the interior of Γ. By the inverse function theorem, this assumption implies that this optimum is a continuous function of other model parameters.

These assumptions guarantee that within a set Γ, the optimum capacity choice-production volume is a continuous function of other parameters such as a, b, ξ, or K within some neighborhood of the original parameter values. Although Assumptions 3.1 only generate local properties, in the examples we present, they are in fact global properties. Finally, note that there are no formal assumptions of complementarity between functions.

For the reminder of the paper, when optimal $\delta^*(q, \xi)$ is used, we will drop the optimal decision δ^* from the notation as we assume optimal decision have been made. We write:

$$\begin{aligned} s(q,\xi) &= s(q,\delta^*(q,\xi),\xi) \\ \mathcal{C}(q,\xi) &= \mathcal{C}(q,\delta^*(q,\xi)), \\ \Pi(q,\xi) &= \Pi(q,\delta^*(q,\xi),\xi) \text{ and} \\ \Pi(\xi) &= \operatorname*{Max}_q \Pi(q,\delta^*(q,\xi),\xi). \end{aligned}$$

The next section defines the improvement programs.

3.1 Uncertainty Reduction, Cost Bias Elimination and Direct Cost Reduction Programs

As in Sect. 2, three improvement programs are studied. First, a program to reduce uncertainty about parameter ξ is shown. As before, uncertainty reduction adds profit, because $\vartheta(\xi)$ is concave in ξ.

Proposition 3.2 *The value of uncertainty reduction about ξ is positive: $E_\xi \Pi(q, \tilde{\xi}) \geq \Pi(q, \overline{\xi})$.*

Proof Suppose ξ is uncertain. Then $\Pi(q,\xi,\delta) = (P(q) - \vartheta(\xi)s(q,\delta))q - \mathcal{C}(q,\delta)$ is a convex function of ξ, and thus, when optimizing with respect to δ will be a convex function of ξ. Thus, the function $\Pi(q,\xi) = P(q) - \vartheta(\xi)s(q,\delta^*(q,\xi))q - \mathcal{C}(q,\delta^*(q,\xi))$ is convex in ξ. QED

The second improvement program is one where a manager misestimates a parameter used to set the service or the production level, and the improvement program corrects bias in parameter estimates so that better decisions can be made. An assumption of the form of the cost function and the nature of the bias must be assumed. The cost function of Sect. 2 is generalized as partitioned between components linear in q and non-linear in q. That is, we rewrite $\xi s(q,\xi)q + \mathcal{C}(q,\xi)$ as the sum of all its linear terms $(\gamma + c + \xi)q$ plus its nonlinear terms in $q, C(q,\xi)$.

$$(\gamma + c + \xi)q + C(q,\xi) \triangleq \xi s(q,\xi)q + \mathcal{C}(q,\xi). \tag{3.2}$$

I will assume that a manager uses inaccurate non-linear product cost $rC(q,\xi)$ with $r > 0$, when choosing "optimal" q. This cost-form is generalized at the end of this section.

Distorted cost causes a suboptimal production decision to be made, and it is that distortion which reduces real profit. If the firm uses an inaccurate cost function, the firm's profit is *ex-ante forecasted* to be

$$\Pi(q,\xi,r) = P(q)q - (\gamma + c + \xi)q - rC(q,\xi), \tag{3.3}$$

where $\Pi(q,\xi,r)$ is the perceived, but inaccurate profit. The optimum q under biased cost yields

$$q(\xi,r) = \operatorname*{Arg\,Max}_{q}\,(P(q) - \gamma + c + \xi)q - rC(q,\xi) \tag{3.4}$$

with real profits

$$\Pi(\xi,r) = P(q(\xi,r))q(\xi,r) - (\gamma + c + \xi)q(\xi,r) - C(q(\xi,r),\xi). \tag{3.5}$$

The value added by eliminating cost estimating bias is equal to $\Pi(\xi) - \Pi(\xi,r)$.
The third improvement program reduces cost. It is a reduction in unit cost c.
The next three sections study the complementarity of these programs.

3.2 Complementarity of Uncertainty Reduction and Cost Bias Elimination Programs

We now can state sufficient conditions for the uncertainty reduction and cost bias elimination improvement programs to be complements or substitutes.

Proposition 3.3

(i) *A cost bias elimination program and uncertainty reduction program are complements if* $\Pi(\xi) - \Pi(\xi, r)$ *is convex in* ξ.
(ii) *A cost bias elimination program and uncertainty reduction program are substitutes if* $\Pi(\xi) - \Pi(\xi, r)$ *is concave in* ξ.

Proof Case i: If $\Pi(\xi) - \Pi(\xi, r)$ is convex in ξ, then $E_{\tilde{\xi}}\Pi(\xi) - E_{\tilde{\xi}}\Pi(\xi, r) \geq \Pi(\bar{\xi}, r) - \Pi(\bar{\xi})$. This implies the result. Case ii is similarly proved. QED

Discussion: One way to establish the concavity/convexity of $\Pi(\xi) - \Pi(\xi, r)$ is to study the function $\frac{d\Pi^{k+1}(\xi,q(\xi,r))}{d\xi^k dr}$. Information about the sign of this derivative when $r = 1$ will establish local convexity/concavity properties near $r = 1$. The definition of $q(\xi, r)$ requires that $\frac{d\Pi(\xi,q)}{dq}|_{q=q(1,\xi)} = 0$, for all ξ. Thus,

$$\frac{d\Pi(\xi, q(\xi, r))}{dr}|_{r=1} = \frac{d\Pi(\xi, q)}{dq}|_{q=q(\xi,1)} \frac{dq(\xi, r)}{dr}|_{r=1} = 0 \text{ for all } \xi. \tag{3.6}$$

That is, no matter how ξ may change, $\frac{d\Pi(\xi,q(\xi,r))}{dr}|_{q=q(\xi,1)} = 0$. This implies by differentiation by ξ that $\frac{d\Pi^2(\xi,q(\xi,r))}{d\xi dr}|_{r=1} \triangleq 0$ for all ξ, and in general, $\frac{d\Pi^{k+1}(\xi,q(\xi,r))}{d\xi^k dr}|_{r=1} \triangleq 0$ for any ξ and any $k \geq 1$. We might conclude that $\frac{d\Pi^3(\xi,q(\xi,r))}{drd\xi^2}|_{r=1}$ cannot be used to predict local complementarity properties based upon profit derivatives when $r = 1$.

However this assertion is false: local behavior of a properly defined function at $r = 1$ is sufficient to determine local complementarity. This is shown next. To do so I define the mixed derivative of profit ignoring the non-linear in q cost function *C:*

$$\textit{Condition A}: \; g(r, \xi) = \frac{d^3(P(q(\xi, r) - (a_1\gamma + a_2 c + a_3\xi))q(\xi, r))}{drd\xi^2} > 0.$$

$$\textit{Condition B}: \; g(r, \xi) = \frac{d^3(P(q(\xi, r) - (a_1\gamma + a_2 c + a_3\xi))q(\xi, r))}{drd\xi^2} < 0$$

Proposition 3.4 *Suppose Condition A holds in an open neighborhood of* ξ *for* $r = 1$. *Then there exists a neighborhood of* $r = 1$, *with* $\underline{r} < 1 < \bar{r}$, *where uncertainty reduction and cost bias elimination are complements for any distribution function on* ξ *with support within the open neighborhood. Likewise, if Condition B holds in an open neighborhood of* ξ *for* $r = 1$ *then there exists a neighborhood of* $r = 1$, *with* $\underline{r} < 0 < \bar{r}$ *where uncertainty reduction and bias elimination are substitutes for any distribution function on* ξ *with support within a neighborhood of* ξ.

A proof is found in the "Appendix".

Although it is true that $\frac{d^3\Pi(q,\xi,r)}{drd\xi^2}|_{r=1,q=q(\xi,1)} = 0$, complementarity can be characterized in the neighborhood of $r = 1$ *by* studying the mixed-partial derivative of revenue minus undistorted cost. I will say that "*Condition A holds for interval* $(\underline{R}, \bar{R})$," with $0 \leq \underline{R} < 1 < \bar{R}$ if Condition A holds for all $r \in (\underline{R}, \bar{R})$ on this interval. Given an interval $[\underline{\xi}, \bar{\xi}]$ with $\underline{\xi} > 0$, I will say that "*Condition A holds on* $[\underline{\xi}, \bar{\xi}]$ *for* $(\underline{R}, \bar{R})$," if Condition A holds for all $\xi \in [\underline{\xi}, \bar{\xi}]$ and $r \in (\underline{R}, \bar{R})$. All of these definitions can be restated in terms of equivalent relations for Condition B.

Next global conditions for complementarity of uncertainty reduction and cost bias elimination are presented:

Corollary 3.1 *If Condition A holds on* $[\underline{\xi}, \bar{\xi}]$ *for* $(\underline{R}, \bar{R})$ *then for any* $\xi \in [\underline{\xi}, \bar{\xi}]$, $\Pi(q(s, \xi), \xi) - \Pi(q(1, \xi), \xi)$, *is convex for all* $s \in (\underline{R}, \bar{R})$.

If Condition B holds on $[\underline{\xi}, \bar{\xi}]$ *for* $(\underline{R}, \bar{R})$ *then for any* $\xi \in [\underline{\xi}, \bar{\xi}]$, $\Pi(q(s, \xi), \xi) - \Pi(q(1, \xi), \xi)$, *is concave for all* $s \in (\underline{R}, \bar{R})$.

If the hypotheses of the corollary hold, then, Proposition 3.2 predicts complementarity or substitutability of uncertainty reduction and bias elimination.

The above results hold when cost bias is of a more general form. The proof of Proposition 3.3 shows the validity of the following formulation of cost bias.

Lemma 3.1 *If total cost is* $C_1(q, \xi) + C_2(q, \xi) \triangleq \xi s(q, \xi)q + \mathcal{C}(q, \xi)$ *and cost bias is of the form:* $C_1(q, \xi) + rC_2(q, \xi)$, *then the preceding Proposition 3.2, and Corollary 3.1 hold with* $sign[\frac{d^3(P(q(r,\xi)) - (a_1\gamma + a_2c + a_3\xi))q(r,\xi)}{drd\xi^2}|_{r=1,q=q(\xi,1)}]$ *replaced by* $sign[\frac{d^3P(q(r,\xi)q(r,\xi) - C_1(q,\xi))}{drd\xi^2}|_{r=1,q=q(\xi,1)}]$.

I close this subsection with two examples that demonstrate the usefulness of Conditions A and B.

Example 3.1 Consider the model of Sect. 2. Recall that $\Pi(q, \xi) = \sqrt{\alpha q} - \{(\xi_a t_o + c + \gamma)q + 2\sqrt{\gamma\lambda(\xi_a, \xi_T)q}\}$ therefore "misestimated" profit is $\Pi^r(r, q, \xi) = \underset{q}{\text{Max}}\ \sqrt{\alpha q} - (\xi_a t_o + c + \gamma)q + 2r\sqrt{\gamma\lambda(\xi_a, \xi_T)q}$. By optimizing this later equation with respect to q, one obtains the general solution: $q(r, \xi) = \left(\frac{\frac{\sqrt{\alpha}}{2} - r\sqrt{\gamma\lambda(\xi_a,\xi_T)}}{(\xi_a t_o + c + \gamma)}\right)^2$.

If we study uncertainty in parameter ξ_T, then we are interested in properties of $\frac{d^3(P(q(r,\xi_T),\xi_T) - (c + \gamma + \xi_a t_0))q(r,\xi_T)}{d\xi_T^2 dr} = \frac{2r\xi_a}{(c + \gamma + t_o\xi_a)\xi_T^2} > 0$. Thus, Condition A holds and uncertainty reduction and bias elimination programs are substitutes. Note that this condition holds for all ξ and all *r:* so we know this is a global property for all distribution functions and any degree of bias.

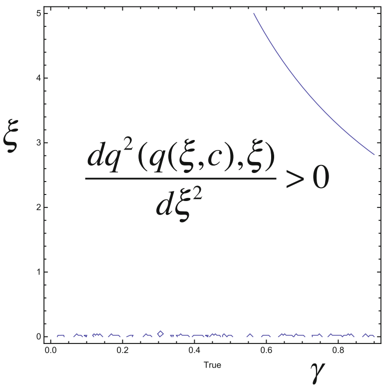
If we study uncertainty in parameter ξ_a, then we are interested in properties of $\frac{d^3(P(q(r,\xi_T),\xi_T) - (c + \gamma + \xi_a t_0))q(r,\xi_T)}{d\xi_a^2 dr} = \frac{2\gamma(r-1)^2\left((c + \gamma)(c + \gamma + 2_o\xi_a) - t_o^2\xi_a^2\right)}{(c + \gamma + t_o\xi_a)^3\xi_a}$. The sign of this expression is independent of r and depends on the sign of $(c+\gamma)(c+\gamma+2_o\xi_a)-t_o^2\xi_a^2$. Complementarity properties are the same if $r < 1$, or $r > 1$: if bias is positive or negative!

Example 3.2 In this example I assume demand function in a different form than before, and a cost function that is convex. Let $P(q) = a - bq$ be the inverse demand function, where q is the production rate. Let the sum of linear and non linear production cost and capacity cost be $cq+q^2+\delta\gamma$ where δ is the capacity decision and γ is the unit cost of capacity, If the customer's delay is $\frac{1}{\delta-q}$ then the cost of delay is: $\xi s(\delta,q)=\frac{\xi}{\delta-q}$. The cost function is thus $Cost=\left(c+\frac{\xi}{\delta-q}\right)q+q^2+\gamma q$ and the profit function is $\pi(\delta,q)=\left(a-bq-c-\frac{\xi}{\delta-q}\right)q-q^2-\gamma q$, where q is the production rate decision and δ is the capacity decision. First, I check the Assumptions 3.1: (a) holds as inverse demand is twice continuously differentiable in *q;* (b) The cost function is concave in δ for all $q \geq 0$ as the second derivative of cost with respect to δ is $=\frac{2\gamma^{3/2}}{\sqrt{q\xi}}>0$. The optimal solution is $\delta^*(q,\xi)=\frac{\sqrt{\gamma}q+\sqrt{q\xi}}{\sqrt{\gamma}}$; (c) Using the optimal choice of δ, profit is a concave function of q if $q \geq \left(\frac{1}{2^2}\frac{\sqrt{\gamma\xi}}{1+b}\right)^{2/3}$. The profit function is $\pi(\delta^*,q)=(a+q-bq+\gamma)q-2\sqrt{\gamma q\xi}$, with properties $\pi(0,\delta^*)=0$, $\frac{d^2\pi(\delta^*,0)}{dq^2}>0$, $\lim_{q\to\infty}\pi(q,\delta^*)=-\infty$, $\lim_{q\to\infty}\pi\frac{d^2\pi(q,\delta^*)}{dq^2}<0$, and with 3 (complex and real) roots to the equation $\frac{d\pi(\delta^*,q)}{dq}=0$. The profit function can change direction at most twice when $q \geq 0$ (3 changes are impossible given the last listed properties and four changes leads to 4 real roots to the first derivative of profit on $q \geq 0$). This shows that the optimal value of q *is* either $q = 0$ *or* $q > 0$. Defining $\Gamma=\{(\delta,q)\in\mathbb{R}_+\times[\left(\frac{1}{2^2}\frac{\sqrt{\gamma\xi}}{1+b}\right)^{2/3},\infty]\}$, the condition $\frac{d\pi(q,\delta^*)}{dq}|_{q=\left(\frac{1}{2^2}\frac{\sqrt{\gamma\xi}}{1+b}\right)^{2/3}}>0$ can be guaranteed by examining the left hand side which is a polynomial in ξ in the form $-(e(1+b))^3\gamma+f\left((a-\gamma)-g\gamma^{1/3}\right)^3\xi$, with *e, f* and $g > 0$. It is seen that for fixed value of ξ, with sufficiently small values of b, and γ, or sufficiently large values of a, the inequality will hold. When it does, the global maximum production rate is in the interior of Γ and satisfied the first order equations, and assumption 3.1d holds. Thus, all assumptions hold.

Computing the "modified" profit function with non-linear cost terms dropped and the optimum production rate for cost function π^r generates the function $\pi^m(\delta^*,q(r))=(a-b^mq-c-\gamma)q(r)$. The function $\frac{d^3\pi^m}{drd\xi^2}|_{r=1,q^r}$ is shown in Fig. 1 and has a positive value in the region shown. Thus bias and uncertainty reduction are complements.

I next study the *direct cost savings program* and its complementarity to uncertainty reduction.

Fig. 1 For Example 3.1, the derivative $\frac{d^3\Pi(q,\xi,r)}{drd\xi^2}|_{r=1,q=q(\xi,1)}$ is positive, and the objective function is non-negative for all values of γ and ξ within the contour. For that region, uncertainty reduction and cost bias elimination are complements. Here a = 10, b = 3, c = 0



3.3 *Complementarity of Direct Cost Savings and Uncertainty Reduction Programs*

We write firm profit with a production rate q, parameter ξ, and unit production cost c as $\Pi(q,\xi,c)$. Let optimal production levels be $q(\xi,c)$. Production rates chosen using biased cost is denoted $q(\xi,c,r)$. First, a general condition for complementarity of cost savings and uncertainty reduction is presented:

Proposition 3.5

(i) *A direct cost savings and a uncertainty reduction program are complements if for any* c, c', $\Pi(\hat{q}(\xi,c,r),\xi,c) - \Pi(\hat{q}(\xi,c',r),\xi,c')$, *is concave in* ξ.
(ii) *A direct cost savings and a uncertainty reduction program are complements if for any* c, c', $\Pi(\hat{q}(\xi,c,r),\xi,c) - \Pi(\hat{q}(\xi,c',r),\xi,c')$, *is convex in* ξ.

Proof Case i: If $\Pi(\hat{q}(\xi,c,r),\xi,c) - \Pi(\hat{q}(\xi,c',r),\xi,c')$ is concave in ξ, then $E_{\tilde{\xi}}\Pi(\hat{q}(\xi,c,r),\xi,c) - \Pi(\hat{q}(\bar{\xi},c',r),\bar{\xi},c')$. This implies the result. Case ii is similarly proved. QED

If convexity or concavity of the above functions cannot be established, the following is an easy to compute sufficient condition for local complementarity or substitutability of cost saving and uncertainty reduction.

Proposition 3.6 *Assume the profit function has the form:*

$$\Pi(q,\xi,c) = P(q)q - cq - C(q,\xi).$$

Suppose that $q(\xi,c)$ *corresponds to the optimal production level. Then if* $\frac{d^2q(\xi,r),\xi,c)}{d\xi^2} > 0$, *direct cost savings is complementary to uncertainty reduction for all*

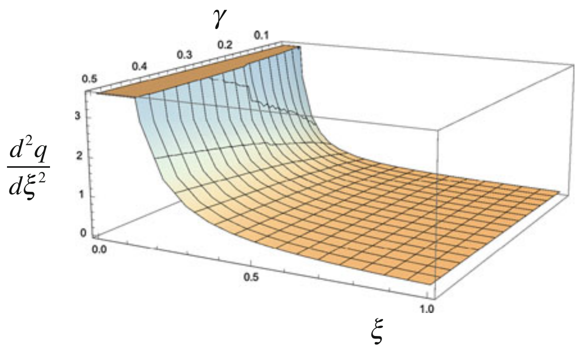


Fig. 2 For Example 3.2, the value of $\frac{dq^2(q(\xi,c),\xi)}{d\xi^2}$ is positive for the indicated values of ξ and γ. This implies that direct cost savings and uncertainty reduction are complements in this region. Here $a = 10$, $b = 3$, $c = 0$

c' in an open neighborhood of c. Alternatively, if $\frac{d^2q(\xi,r),\xi,c)}{d\xi^2} < 0$, *direct cost savings is a substitute to uncertainty reduction for all c' in an open neighborhood of c.*

Proof Differentiate the profit function with respect to *c:* $\frac{d\Pi(q(\xi,r),\xi,c)}{dc} = -q + \frac{dq}{dc}\frac{d\Pi(q(\xi,r),\xi,c)}{dq} = -q.$

It is clear that $\frac{d^3\Pi(q(\xi,r),\xi,c)}{d\xi^2 dc} = -\frac{d^2q(\xi,r),\xi,c)}{d\xi^2}$. For complementarity to hold, as c *increases* the curvature of profit must decrease; similarly, as c *decreases* the curvature of profit must increase. Increasing curvature increases the value added by uncertainty reduction. QED.

Example 3.1 continued When computing: $\frac{d^2q(\xi,r),\xi,c)}{d\xi_a^2}$ and $\frac{d^2q(\xi,r),\xi,c)}{d\xi_T^2}$ yield algebraic expressions that are always positive if and only if profit is positive.

Example 3.2 continued In Fig. 2, $\frac{d^2q(\xi,r),\xi,c)}{d\xi_a^2}$ is plotted as a function of γ, and ξ. The figure shows that this expression is uniformly positive, so that we know direct cost saving is complementary to uncertainty reduction for this model.

3.4 Complementarity of Bias Elimination and Direct Cost Savings Programs

For completeness, I next study the complementarity of direct cost savings and cost bias elimination. Because of the difficulty to establish global requirements, the sufficient conditions I develop are local tests. Of course, if these local tests hold on the entire domain, the results are global.

Lemma 3.2

i. *If* $\frac{d^2C(q)}{dq^2}|_{q=q(c,r)} < 0$ *and* $\frac{d^3\Pi(q,c,r)}{dq^3}|_{q=q(c,r)} > 0$, *then cost reduction and bias reduction programs are complements in a neighborhood of r.*

ii. *If* $\frac{d^2C(q)}{dq^2}|_{q=q(c,r)} > 0$ *and* $\frac{d^3\Pi(q,c,r)}{dq^3}|_{q=q(c,r)} < 0$, *then cost reduction and bias reduction programs are substitutes programs in a neighborhood of r.*

Proof See the "Appendix". It is notable that in this result the derivatives do not include differentiation with respect to *r*. This is quite unlike typical supermodularity tests involving mixed partials of variables associated with the programs in question. The next example demonstrates the proposition.

Example 3.1 Given profit and cost functions from Sect. 2:

$$\frac{d^2C(q)}{dq^2} = \frac{d^2}{dq^2}\left[\left(\bar{\xi}_a t_o + c + \gamma\right)q + 2\sqrt{\lambda(\bar{\xi}_a, \bar{\xi}_T)}\sqrt{\gamma q}\right] = -\frac{1}{2}\frac{\sqrt{\gamma\lambda(\xi_a, \xi_T)}}{q^{3/2}} < 0$$

$$\frac{d^3\Pi(q,c,r)}{dq^3} = \frac{d^3}{dq^3}\left[\sqrt{\alpha q} - \left[\left(\bar{\xi}_a t_o + c + \gamma\right)q + 2\sqrt{\lambda(\bar{\xi}_a, \bar{\xi}_T)}\sqrt{\gamma q}\right]\right]$$

$$= \frac{3}{8}\frac{\sqrt{\alpha} - 2\sqrt{\gamma\lambda(\xi_a, \xi_T)}}{q^{5/2}} > 0$$

and both expressions hold for any q. Thus the conclusion is that bias elimination and direct cost savings are complements. As this holds for any *q*, it is a global property.

Example 3.2 continued Discussion earlier in this section showed that the cost function is concave in *q*. Computing: $\frac{d^3\Pi(q,c,r)}{dq^3} = \frac{3r}{4}\sqrt{\frac{\gamma\xi}{q^5}} > 0$, so we see that bias elimination and direct cost savings are also complements.

4 Conclusion

Milgrom and Roberts (1990) show that supermodularity assumptions imply the complementarity of improvement programs, But do realistic demand function and operations processes display the necessary properties for programs to be complementary? In this paper I show that complementarity does not hold for common programs, and that some kinds of programs are substitutes while simultaneously others are complements.

In an extended analysis, I have demonstrated these effects on a commonly assumed operations process, namely queuing. This is important because other prominent operations technologies share the cost characteristics of queuing: in the simplest models total cost is proportional to the square root of production volume. For example, the simplest versions of the economic-order-quantity (EOQ) model and many fixed-charge models have this characteristic. Thus, the results of Sect. 2 apply more commonly than suspected. In Sect. 3, I developed sufficient conditions for complementarity both locally and globally for more general demand and cost functions.

My results reinforce the value for decentralized organizations of coordinating adoption of programs across functional boundaries. As recognized by Milgrom and Roberts (1990), when complementarities exist, it is desirable for a central authority to coordinate adoption of programs even when programs are focused on decentralized subunits because more value may be created than each subunit realizes. As modeled in this paper, improvement programs might be proposed independently by the marketing, accounting, and operations organizations. However, in the examples of this paper, substitutability of programs is shown to arise. Thus, central coordination may be necessary because independently proposed projects may *not* be as valuable as "locally" estimated ones. For both reasons, positive and negative, adding or subtracting value, centralized review of projects helps maximize firm value.

Finally, empirical study of these issues is a very important research question. One way to test premises of complementarity is to study how firms organize the evaluation of proposed improvement projects. If complementary or substitute effects hold, it would be expected that firms involve players from other functions. One could ask if business functions outside of the proposer's are involved in the adoption decision of improvement projects, and what types of projects merit this scrutiny. Another way to determine if a type of improvement program is complementary to other programs is to ask if the firm's policies make it easier to adopt this program than other types of programs. For example, are cost reduction projects (which we show tend to be complementary to other programs) evaluated at a lower discount rate than other types of proposals.

Appendix

Proof of Proposition 3.4 Define $\Pi^r(q,\xi,r) = P(q)q - (a_1\gamma + a_2c + a_3\xi)q - rC(q,\xi)$, which we distinguish from $\Pi(q,\xi) = P(q)q - (a_1\gamma + a_2c + a_3\xi)q - C(q,\xi)$.

Let $q(\xi, r)$ be defined as the solution to the first-order equation,

$$\frac{d\Pi^r(q(\xi,r),\xi,r)}{dq} = \frac{dP(q)q}{dq}|_{q=q(r,\xi)} - (a_1\gamma + a_2c + a_3\xi) - r\frac{dC(q,\xi)}{dq}|_{q=q(r,\xi)} = 0. \tag{A.1}$$

This implies $\frac{dC(q,\xi)}{dq}|_{q=q(r,\xi)} = \frac{1}{r}\left(\frac{dP(q)q}{dq}|_{q=q(r,\xi)} - (a_1\gamma + a_2c + a_3\xi)\right)$. It follows that we can express the derivative of actual profit with respect to q as:

$$\frac{d\Pi(q,\xi)}{dq}|_{q=q(r,\xi)} = \left(\frac{dP(q)q}{dq}|_{q=q(r,\xi)} - (a_1\gamma + a_2c + a_3\xi)\right)\left(1-\frac{1}{r}\right). \quad \text{(A.2)}$$

The derivative of (actual) profit with respect to r under production decision $q(\xi, r)$ is

$$\frac{d\Pi(q(\xi,r),\xi)}{dr}|_{q=q(r,\xi)} = \frac{d\Pi(q,\xi)}{dq}\frac{dq(\xi,r)}{dr}|_{q=q(r,\xi)}.$$

Substituting (A.2) into this last equation yields:

$$\frac{d\Pi(q(\xi,r),\xi)}{dr}|_{q=q(r,\xi)} = \left(\frac{dP(q)q}{dq}|_{q=q(r,\xi)} - a_1\gamma + a_2c + a_3\xi\right)\frac{dq(r,\xi)}{dr}\left(1-\frac{1}{r}\right)|_{q=q(r,\xi)}. \quad \text{(A.3)}$$

My goal is to determine the sign of $\frac{d\Pi^3(q(\xi,r),\xi)}{drd\xi^2}|_{q=q(r,\xi)}$ near $r = 1$. To do this I need to show that $\frac{dq(r,\xi)}{dr}$ is C^2 in an open neighborhood of $(1,\xi)$. Differentiating (A.1) with respect to r, $\frac{d\Pi^{r^2}(q(\xi,r),\xi,r)}{drdq} = -\frac{\partial C(q(\xi,r),\xi)}{\partial\xi\partial q} + \frac{\partial\Pi^{r^2}(q(\xi,r),\xi)}{\partial q^2}\frac{dq(\xi,r)}{dr} = 0.$

If $\frac{\partial\Pi^{r^2}(q(\xi,r),\xi)}{\partial q^2}|_{q=q(r=1,\xi)} \neq 0$ the implicit function theorem states that $\frac{dq(\xi,r)}{dr} = \frac{\frac{\partial C(q(\xi,r),\xi)}{\partial q}}{\frac{\partial\Pi^{r^2}(q(\xi,r),\xi)}{\partial q^2}}$. Additionally, this derivative will be twice continuously differentiable in a neighborhood of $r = 1$.

Differentiating (A.3) with respect to ξ twice:

$$\frac{d^2\Pi(q,\xi,r)}{drd\xi}|_{q=q(r,\xi)} = \begin{pmatrix} \frac{d^2P(q)q}{dq^2}\frac{dq(r,\xi)}{d\xi}\frac{dq(r,\xi)}{dr} \\ +\left(\frac{dP(q)q}{dq} - (a_1\gamma + a_2c + a_3\xi)\right)\frac{d^2q(r,\xi)}{drd\xi} - a_3\frac{dq(r,\xi)}{dr} \end{pmatrix}|_{q=q(r,\xi)}\left(1-\frac{1}{r}\right)$$

$$\frac{d^3\Pi(q,\xi,r)}{drd\xi^2}|_{q=q(\xi,r)} = \begin{pmatrix} \left(\frac{d^3P(q)q}{dq^3}\right)\left(\frac{dq(\xi,r)}{d\xi}\right)^2\frac{dq(\xi,r)}{dr} + \left(\frac{d^2P(q)q}{dq^2}\right)\frac{d^2q(\xi,r)}{d\xi^2}\frac{dq(\xi,r)}{dr} \\ +2\left(\frac{d^2P(q)q}{dq^2}\frac{dq(\xi,r)}{d\xi} - a_3\right)\frac{d^2q(\xi,r)}{drd\xi} \\ +\left(\frac{dP(q)q}{dq} - (a_1\gamma + a_2c + a_3\xi)\right)\frac{d^3q(\xi,r)}{dr\xi^2} \end{pmatrix}|_{q=q(\xi,r)}\left(1-\frac{1}{r}\right). \quad \text{(A.4)}$$

Similar to the above argument that used the implicit function theorem, $\frac{dq(\xi,r)}{d\xi}, \frac{d^2q(\xi,r)}{d\xi dr}, \frac{d^3q(\xi,r)}{d\xi^2dr}, \frac{d^3q(\xi,r)}{d\xi dr^2}, \frac{d^3q(\xi,r)}{d\xi^3}$, can be derived and found to be continuously differentiable in (ξ, r) within a neighborhood of $r = 1$. All the terms in the large brackets within (A.4) are continuously differentiable in (ξ, r) within a neighborhood of $r = 1$. Thus, the sign of $\frac{d^3P(q(\xi,r)-(a_1\gamma+a_2c+a_3\xi))q(\xi,r)}{drd\xi^2}$ will determine if concavity with respect to ξ increases with r or decreases in r. I note that if the bias was underweighting cost, that is $r < 1$, *or* bias was over weighting cost, that is, $r > 1$, concavity with respect to ξ changes in the same direction.

Proof of Lemma 3.2 The profit function is written as $\Pi^r(q, c, r) = P(q)q - cq - rC(q, \xi)$.

q(c,r) maximizes Π^r, and can be found by solving $\frac{d\Pi^r(q(c,r),c,r)}{dq} = 0$. Differentiating with respect to cost yields $\frac{d}{dc}\frac{d\Pi(q(c,r),c,r)}{dq} = \frac{d^2\Pi(q(c,r),c,r)}{dq^2}\frac{dq(c,r)}{dc} - 1$. Differentiating with respect to r again yields:

$$\frac{d}{dr}\left[\frac{d^2\Pi(q(c,r),c,r)}{dq^2}\frac{dq(c,r)}{dc} - 1\right] = \frac{d^3\Pi(q(c,r),c,r)}{dq^3}\frac{dq(c,r)}{dc}\frac{dq(c,r)}{dr} - \frac{d^2C(q(c,r))}{dq^2}\frac{dq(c,r)}{dc} + \frac{d^2\Pi(q(c,r),c,r)}{dq^2}\frac{d^2q(c,r)}{dcdr}.$$

Thus, $\frac{d^2q(c,r)}{dcdr} = \frac{\frac{dq(c,r)}{dc}\left[\frac{d^2C(q(c,r))}{dq^2}\frac{dq(c,r)}{dc} - \frac{d^3\Pi(q(c,r),c,r)}{dq^3}\frac{dq(c,r)}{dr}\right]}{\frac{d^2\Pi(q(c,r),c,r)}{dq^2}}$. If the conditions of part i) hold, then $\frac{d^2q(c,r)}{dcdr} > 0$. Now consider $\Pi(q, c) = P(q)q - cq - C(q, \xi)$.

$$\frac{\partial^2\Pi(c,r)}{\partial c\partial r} = \frac{\partial}{\partial c}\left[\frac{d[P(q)q - cq - C(q)]}{dq}\bigg|_{q=q(c,r)}\right] + \frac{d[P(q)q - cq - C(q)]}{dq}\frac{\partial^2 q(c,r)}{\partial c\partial r}.$$

The first term is zero. If I assume r > 1, then *q(c,r)* is less than *q(c,1) and* $\frac{d[P(q)q-cq-C(q)]}{dq}|_{q=q(c,r)} > 0$. I conclude that $\frac{\partial^2\Pi(c,r)}{\partial c\partial r} > 0$ which implies that c and r are complements. Removing estimating bias (*decreasing* r from above $r = 1$) and *reducing* cost (reducing c) causes the cross partials of Π to be positive. If instead, $r < 1$, then $\frac{d[P(q)q-cq-C(q)]}{dq}|_{q=q(c,r)} < 0$ and thus $\frac{\partial^2\Pi(c,r)}{\partial c\partial r} < 0$. Increasing r and decreasing c causes the cross partials of Π again to be positive: direct cost savings and bias elimination are complements. If the conditions of part ii) hold, then $\frac{d^2q(c,r)}{dcdr} < 0$. Following the logic of the above proof, if $r > 1$, reducing r and decreasing c results in the cross partials of to be negative. Similarly, if $r < 1$, then increasing r and decreasing c causes the cross partials of Π to be negative. In short, under conditions in part ii), bias elimination and direct cost savings are substitutes. *QED*

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Practices and Performance in Constraints Management Production Planning and Control Systems

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Abstract This chapter provides first a literature review of the characteristics of production systems operating according to the principles of Theory of Constraints (TOC). The analysis is conducted by a comparison of these characteristics with those of three well-known production systems, namely Dispatching, Kanban and Daily Rate. The literature review highlights that the most significant differences are pertinent to the third level of the manufacturing planning and control system, the so-called production executive control or shop floor control sub-system. An interpretative framework for discussing the distinguishing characteristics of TOC in production management is finally proposed. The second part of the chapter is dedicated to study the relationship between TOC production and operational performance of manufacturing plants. The study is based on data collected from 61 manufacturing plants located in Europe through an extensive questionnaire survey. Analysis of variance technique and regression models have been employed to test the research hypotheses. The results detect many differences and similarities in adoption of TOC practices across the plants and suggest that manufacturing managers should consider adopting some TOC practices instead of others. In particular the drum–buffer–rope methodology, the development of a Master Production Schedule based on constraints and the use of Non-constraint resources with excess capacity are among the most important practices to enhance competitive performance of manufacturing plants.

Keywords Empirical research · International comparison · Manufacturing performance · Theory of Constraints · Manufacturing practices

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1 Introduction

Since the 1980s Theory of Constraints (TOC) has been a critical theme in operations management research. This theory suggests that improvement in the global performance of organizations may be obtained by focusing on a few leverage points of the system. According to Goldratt (1990a), the TOC approach recognizes that every organization must be understood as a system with a goal, and so, every action taken by any part of the system must be judged by its impact on the whole system goal. Nowadays TOC is viewed as "an overall theory for running an organisation". A constraint "is anything that limits a system from achieving higher performance versus its goal" (Goldratt 1988). The theory highlights that every system must have at least one constraint. If it were not true, then a real system such as a profit making organisation would make unlimited profit. The main constraints in most organizations may be not only physical but also managerial-policy. However, contrary to conventional thinking, TOC views constraints as positive, not negative as the existence of constraints represents opportunities for improvement. Constraints determine the performance of a system, a gradual elevation of the system's constraints will improve its performance.

When applied to production processes, TOC describes the idea of identifying and managing the bottlenecks in the manufacturing process and introduces a method of creating a finite production schedule for the bottleneck operations. In this perspective, the story of TOC is indissolubly tied to that of Optimized Production Technology (OPT), a production planning and control system which was initially formalized in 1980s by the Goldratt' writings. Even if the two terms, TOC and OPT, are used somewhat interchangeable in the literature, they refer to two different components, namely, a philosophy which underpins the working system and a software package that produces manufacturing schedules through the application of this philosophy to the manufacturing system.

More specifically, in 1979 a manufacturing planning and control system (MPCS) named OPT-Optimized Production Timetables was presented by Goldratt (1980). The system was later known under the commercial name of Optimized Production Technology and was introduced as a proprietary software product originally sold from Creative Output, Inc. to identify and manage the bottlenecks in the manufacturing process and introduce a method of creating a finite production schedule for the bottleneck operations (see the monumental work of Cox and Schleier 2010). The OPT software consists of four major software components: Buildnet, Serve, Split and Opt. Opt and Serve contain the algorithm for scheduling production while Buildnet and Split collect and arrange data in the required format. Throughout the 1980s, OPT underwent significant modification to became an entire production control philosophy, called Theory of Constraints (Rahman 1998; Blackstone 2001; Watson et al. 2007). In other words, from the initial phase, the overall concept gradually moved from the production floor to encompasses all the departments and processes of a company. As reported in the article of Watson et al. (2007), the evolution of TOC may be segmented into five eras:

- The Optimized Production Technology Era—the secret algorithm.
- The Goal Era—articulating drum–buffer–rope scheduling.
- The Haystack Syndrome Era—articulating the TOC measures.
- The It's Not Luck Era—thinking processes applied to various topics.
- The Critical Chain Era—TOC project management.

The distinguishing attribute of OPT system when compared with the MRPII system is the importance of recognising and managing resources as bottleneck (constraints) and non-bottleneck. Production planning and scheduling in the OPT system is structured around constraints: the organization of data is carried out to efficiently generate master production schedules for bottleneck resources and, based on this constraint schedule, the scheduling algorithm backwards schedules production at non-bottleneck resources and determines the release of non-constraint materials.

Nowadays the number of companies that manage the production according to the principles of TOC/OPT is growing around the world. If in the 80s and 90s of last century the attention of researchers and companies has been captured by the principles and methods of JIT/Lean Manufacturing, it seems increasingly clear that in production environments with high product variety and significant bottlenecks the OPT/TOC application can be of significant help in improving the performances of efficiency and effectiveness. While many scholars suggested that OPT/TOC production significantly impacts organizational performance, there is still little agreement on how to successfully implement TOC production in the manufacturing organization. In particular, it is not yet clear the link between the adoption of specific OPT/TOC practices for the management of production and the impact these can have on specific performance measures.

In order to shed more light on this issue, the rest of the chapter is organized as follows:

- next section provides a literature review of TOC/OPT characteristics by comparing them with MRP, JIT and Daily Rate production management approaches. The literature review highlights that the most significant differences are pertinent to the third level of the MPCS, the so-called production executive control or shop floor control sub-system. An interpretative framework for discussing the distinguishing characteristics of TOC in production management is proposed. The framework points out the distinguishing practices that characterized the TOC approach in production management.
- the second part of the chapter is dedicated to study the difference and similarity in the implementation of TOC production practices and their impact on different operational performances of a manufacturing plants. The study is based on data collected from 61 manufacturing plants located in Spain, United Kingdom, Germany, Italy and France through an extensive questionnaire survey which has been conducted in 2014.

2 Distinguishing Practices of Constraints Management Production Planning and Control Systems

Due to space limitations, in this paragraph it is assumed that the reader is familiar with the basic mechanisms of production-inventory systems.

Much literature has been dedicated to study the characteristics of production systems operating in accordance with a TOC/OPT approach. In order to detail such characteristics we refer to the well-known model of Vollmann et al. (1997). In this model the architecture of a MPCS is organized on three levels named respectively (1) Front End or Production Planning, (2) Engine or Production Programming and (3) Back End or Production Execution (see Fig. 1a).

As it will be shown shortly, OPT/TOC production requires significant changes in the general architecture of a MPCS. These changes occur at all the three levels previously mentioned even if the most significant changes are on the third level of a MPCS, which is focused on the executive control of the production plans or Shop Floor Control (SFC). Consequently, in order to better understand how the TOC/OPT systems operate and their differences with other production systems, the activities which traditionally concern the SFC sub-system are studied in greater detail. In doing this the Melnyk et al.'s (1985) model (see Fig. 1b) was chosen as a reference framework. As shown in Fig. 1b, this model provides a whole representation of the activities managed by the SFC. Specifically, five groups of

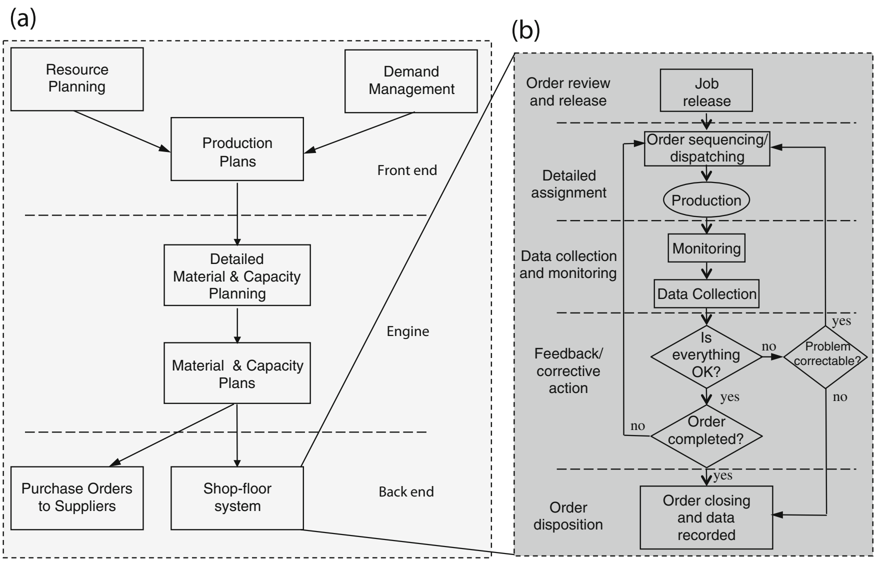

Fig. 1 The architecture of a manufacturing planning and control system (MPCS) (**a**) *Source* elaborated from Vollmann et al. (1997). **b** Shop floor control sub-system *Source* elaborated from Melnyk et al. (1985)

activities are recognized: Order review/release, Detailed assignment, Data collection/monitoring, Feedback/corrective action, Order disposition.

Order review/release includes those activities, which must take place before an order can be released to the shop floor. These activities are necessary firstly, to control the flow of information and orders passing from the planning system to the execution system and secondly, to ensure that the orders released have a reasonable chance of being completed by the expected time and the quantity. The detailed assignment refers to the activities supporting the precise assignment of resources. Traditionally, this defines for each work centre the sequence of operations to be carried out according to determined priorities. The third group of activities, i.e. data collection and monitoring, is essential for the accurate regulation of production, as it links the planning system with the execution system. The information pertaining to the actual progress of an order as it moves through the shop includes current location of the shop order; current state of completion; actual resources used at current and preceding operations; any unplanned delays encountered. The fourth group of activities is named feedback/corrective action. Corrective action is required by management any time the actual progress of a shop order exceeds some predefined margin of difference from its planned progress. In the presence of not conform orders the production plans corrective actions are taken in the very short term. The final set of activities included in Shop Floor Control is order disposition. The order has been completed (or is no longer usable because of scraps) and it goes out of the SFC sub-system. Order status is modified from open to close. In this last stage, information about the closed order is recorded. This information is crucial for cost accounting, cost planning and review of standard data used in planning of medium and long term capacities.

In order to study an OPT/TOC environment, the starting point are the five focusing steps developed by Goldratt (1990b) which can be summarised as follow:

1. *Identify the system's constraint(s)*. In the operations management area these may be materials, machines, people, demand level and so on.
2. *Decide how to exploit the system's constraint(s)*. Exploitation of the constraints seeks to achieve the highest rate of throughput possible. This requires to manage non-constraints resources so that they just provide what is needed to match the output of the constrained resources.
3. *Subordinate everything else to the above decision*. Since the constraints are keeping us from moving toward our goal, all the resources are applied that can assist in breaking them. This means that resource synchronisation with the constraint provides the most effective manner of resource utilisation. Moreover, non-constraint resources must contain productive capacity (capacity to support the constraint throughput) and idle capacity (capacity to protect against system disruptions and capacity not currently needed) (Grunwald et al. 1989).
4. *Elevate the system's constraint(s).* If we continue to work toward breaking a constraint (also called elevating a constraint) at some point the constraint will no longer be a constraint. The constraint will be broken.

5. *If in any of the previous steps a constraint is broken, go back to step 1. Do not let inertia become the next constraint*. This fifth step recommends to consider TOC a continuous process and remarks that no solution is or correct for all time or in every situation.

If the five steps are the working principle of TOC which provide a focus for a continuous improvement process, the base foundation of TOC's production is grounded on the following nine rules (Goldratt and Fox 1986):

- Balance flow, not capacity.
- Level of utilization of a non-bottleneck is determined not by its own potential but by some other constraint in the system.
- Utilization and activation of a resource are not synonymous.
- An hour lost at a bottleneck is an hour lost for the total system.
- An hour saved at a non-bottleneck is just a mirage.
- Bottlenecks govern both throughput and inventory in the system.
- A transfer batch may not, and many times should not, be equal to the process batch.
- The process batch should be variable, not fixed.
- Schedules should be established by looking at all of the constraints simultaneously. Lead times are a result of a schedule and cannot be predetermined.

The effective application of these nine rules is made possible by the DBR methodology and the use of time buffers (Goldratt and Cox 1984; Goldratt and Fox 1986; Lambrecht and Decaluwe 1988; Schragenheim and Ronen 1990; Gardiner et al. 1994; Bhardwaj et al. 2010). Drum–buffer–rope is a manufacturing *execution* methodology, named for its three components. The *drum* is the physical constraint of the plant: the work centre or machine or operation that limits the ability of the entire system to produce more. The rest of the plant follows the beat of the drum making sure that the drum has work and that anything the drum has processed does not get wasted.

The *buffer* protects the drum from the effects of disruptions at non-constraint resources. Buffers in DBR have time as their unit of measure, rather than quantity of material. This makes the priority system operate strictly based on the time an order is expected to be at the drum. Traditional DBR usually calls for buffers at several points in the system: the constraint (constraints buffers), synchronization points (assembly buffers) and at shipping (shipping buffers) (Lockamy and Cox 1991). The use of time buffers as an information system to effectively manage and improve throughput is referred to as buffer management.

The rope is the work release mechanism for the plant. Orders are released to the shop floor at one "buffer time" before they are due. Putting work into the system earlier than this buffer time is likely to generate too-high work-in-process and slow down the entire system.

The implementation of the DBR methodology requires significant changes in the general architecture of a MPCS (Umble and Srikanth 1990).

In particular, at the front-end level, master production scheduling (MPS) in a theory of constraints (TOC) environment requires a different focus and understanding than under classical material requirements planning (MRP) systems. Under TOC, the MPS is shifted to plan the constraint(s). This means that the development of the MPS consists of the following (Spencer and Cox 1995):

- determine the constraint(s) using capacity analysis
- determine which components are routed across the constraint(s)
- determine production priorities per constraint(s)
- use priorities to build up the MPS so that the constraint(s) is fully exploited
- schedule any items that do not contain components routed across the constraint (s) evenly in the MPS
- develop a material release schedule by back scheduling from the constraint(s) and create the constraint buffer
- develop the shipping schedule by forward scheduling from the constraint(s) and create the shipping buffer.

In summary, the MPS under TOC contains only components routed across the constraint; however, the MPS accounts for all end items in the shipping schedule. There is only one MPS under TOC but it drives a series of subordinate schedules for material release, final assembly and shipping to orchestrate production.

A second important change affects MRP which is located at the second level of the MPCS architecture. Swann (1986) in his conceptual contribution entitled "Using MRP for optimised schedules" compares specific components of the TOC and MRP and reports MRP shortcomings in a TOC production environment. While the main objective of TOC is to determine 'an optimised schedule', the main objective of MRP is to determine 'net requirements of the parts and components'. In other words, the MPS is fed into the MRP module for the material requirements calculations. The MRP is thus "reduced" to a simple calculation of requirements for raw materials or for components to be purchased; as a consequence, only purchasing orders, not production orders, are issued. The MRP system does not produce prioritised schedules which are instead generated by the DBR methodology. Thus, a case is made to view "little" MRP as an information system and DBR as a shop floor scheduler.

As regards the Capacity Requirements Planning (CRP) procedure, it is known that in a traditional MRPII environment, this can take place according to two different approaches: infinite capacity planning and finite capacity planning. The first approach is usually used to compare the capacity required to that available on a medium-term horizon while in the short term this is done with a finite capacity planning. In OPT/TOC production systems, the CRP procedure is used differently. Irrespective of the time horizon, as regards the bottlenecks, analysis of the feasibility of production plans is always made according to a finite capacity planning, while infinite capacity planning is used only for non-bottleneck resources.

Moreover, as pointed out by Panizzolo and Garengo (2013), the rope mechanism releases material in accordance with the finite schedule at the bottleneck and materials flow through the shop as required to support the bottleneck buffer. Thus, a first-come-first-serve priority often ensures that no orders are delayed. The input of materials into the shop based on usage by the control point assures that work in process inventories and lead times are controlled. In this manner, raw materials are pulled into the shop, not pushed. After being released, materials are processed in a first-come-first-served priority and are pushed between all operations. Consequently, in a TOC environment the material movement control system can be described as a combination of push/pull logic. More specifically, the downstream operations are finite forward loaded based upon the capacity of the CCR resource. The upstream operations are back scheduled from the CCR.

In order to better understand the characteristics of an MPCS operating in a OPT/TOC environment it was decided to carry out a comparative analysis of these characteristics with those of three well-known production systems, namely Dispatching, Kanban and Daily Rate.

Dispatching is a traditional production control method used in manufacturing systems characterized by generic production processes and able to generate a wide range of parts such as job-shops. Parts are produced in lots and the product bill of materials is generally multilevel. After the formulation of the production plans, the MRP procedure generates (using an infinite capacity algorithm) both job orders (work orders) and purchasing orders. As regards work orders, MRP issues daily dispatch reports to the manufacturing, which define the jobs that are present in each area and when each job should be completed or issued. According to a push logic, these dispatch lists specify which jobs should be completed (and when they should be completed) in order to ship manufactured goods on schedule. Lots move on operation completion and the production batch is equal to the transfer batch. As each required operations defined by the MRP dispatch reports is finished, personnel completing the action make entries into the MRP system. These entries inform the system about the status of all orders and allow a detailed control of material movement (for a complete review of shop floor control systems based on dispatching see the book of Bauer et al. 1994).

Kanban is well known as the celebrated scheduling system related to just-in-time (JIT) production developed at Toyota Motor Corporation to minimize inventory. Kanban uses the rate of demand to control the rate of production, passing demand from the end customer up through the chain of customer-store processes. Therefore, the supply or production is determined according to the actual demand of the customers. In detail, the production system is driven by a master production schedule released only to final assembly centres of the production process. No production orders are generated by the MRP procedure, which is used solely for the computation of purchasing requirements. Kanban control contains only local information flows. The cards (kanbans) circulate between a buffer and the immediate upstream machine. When a downstream machine picks up materials to perform an operation, it also detaches the card attached to the material. The card is then circulated back upstream to signal the next upstream machine do another operation (pull logic). Small inventories of semi-finished products are maintained at each work centre of the production process in standardized containers that are moved following strict rules of use. The number of kanban cards limits the flow of products so as kanban cards serve to ultimately control work-in-progress (WIP) and eliminate overproduction (for a complete review of shop floor control systems based on kanban see the book of Monden 1983).

Daily Rate is a repetitive planning control method typical of manufacturing systems characterized by very high level of production repetitiveness and stability (see for details the works of De Toni and Panizzolo 1993, 1997). In these situations, management is characterised by an overall vision of the production system, which leads to focusing on the entire process. Within this scenario, the fundamental objective of the shop floor control sub-system is to control the uninterrupted flow of materials that move through the machining centres according to a continuous flow, not in predefined lots. The high production volumes and low throughput times mean that the traditional control system typical of job-shops—the work order—is difficult to use in these situations: the focus of control is on resources rather than orders. Formulation of the production mix to be carried out, by day and by line, defines the so-called Production Daily Rate that is the true regulator of these repetitive manufacturing systems. This daily production programmes, which are defined taking into consideration the actual capacity of the lines, regulate the order release and materials movement given that the classic MRP procedure is reduced to a mere calculation of requirements with no formulation of production orders. Materials are issued to the plant according to the daily rate and move along the plant according to a first in–first out logic. Between the various stages, there are no decoupling stocks. Data collection and monitoring are carried out only in the most critical stages or milestone operations. If repetitive manufacturing is characterised by even more favourable operating conditions (product simplicity and reduced range) it is possible to have an even simpler data collection system, which only records the order opening and closing: auto-open/auto-close. Consumption of raw materials and components can be deduced from the output volume through the bill of materials. This technique allows ex-post construction of issues based on finished part receipts and it is known by the term backflushing or post-deducting.

A summarized description of the different characteristics of these four production systems (i.e. Dispatching, Kanban, Daily Rate and TOC) is shown in Table 1.

3 Toc Production and Manufacturing Performance

From the ‘80s, many books, dissertations, academic articles, magazine articles and conference proceedings had been written on TOC. This surge of interest in the TOC seems to stem from the potential benefits available from the implementation of TOC practices. A great deal of authors have investigated the relationships between TOC implementation and firm’s performance. In the beginning, these studies were mainly based on personal views rather than facts or research and put into evidence that TOC techniques could result in increased output while decreasing both inventory and cycle time. Subsequently, more accurate scholarly testing proved

Table 1 Distinguishing characteristics of TOC production in comparison with that of other production systems

Characteristics of manufacturing planning and control system (MPCS)	Dispatching	Kanban	Daily rate	TOC production
MPCS goal	Maximize efficiency	Minimize inventory	Ensure a regular production flow	Optimize bottleneck operations
Production planning	Production plans (MPS and FAS) with job orders	Levelled production plan (MPS and FAS)	Production plans (MPS and FAS) with job orders and flow orders	Production plans (MPS and FAS) optimized for constraint resources
Material requirements planning	• Multilevel bill of material • MRP with formulation of job-orders and purchasing orders	• Flat bill of material • Requirements calculation with formulation of purchasing orders	• Flat bill of material • Requirements calculation with formulation of purchasing orders	• Multilevel Bill of material • MRP for optimised schedules with formulation of purchasing orders
Capacity evaluation	• Infinite capacity requirements planning on the medium-term • Finite capacity planning in the short-term	Finite capacity requirements planning through Kanban cards	Finite capacity requirements planning of the whole line	• Finite capacity requirements planning for bottleneck operations • Infinite capacity requirements planning for non-bottleneck operations
Order release	Triggered by MRP schedules	On the basis of downstream consumption	On the basis of production programmes (Daily Rate)	Production in non-bottleneck work centres is triggered by a "rope" at the bottleneck that signals the release of raw materials from the beginning of production process
Priority assignment	• Dispatch List (Priority Rules) • PUSH scheduling	• Rack with Kanban production cards	• First In–First Out • PUSH scheduling	• Bottleneck work centres: Dispatch List with priority rules

(continued)

Table 1 (continued)

Characteristics of manufacturing planning and control system (MPCS)	Dispatching	Kanban	Daily rate	TOC production
		• PULL scheduling		• Non-bottleneck work centres: First In–First Out or on the basis of downstream consumption • PUSH/PULL scheduling
Work in progress	Queues of materials upstream of the work centres	In standard containers upstream and downstream of the work centres	In areas or deduction points along the line	Materials are placed: – in front of bottleneck work centres – at the intersection of non-bottleneck paths and the path from a bottleneck to its orders The are no or very little buffer inventory for non-bottleneck work centres
Production and transfer batches	• Lot movement on operation completion • Production batch = transfer batch	• Movement of standard containers on request of downstream centres by means of Kanban movement cards • The transfer batches are usually smaller than the process batches	Piece movement in a continuous flow	• Lot movement on operation completion • Production batch ≠ transfer batch • Large lots for bottleneck operations and small lots for non-bottleneck operations
Buffer type	Part buffer	Part buffer (Kanban containers)	• No buffer in rigid transfer lines	Time buffer

(continued)

Table 1 (continued)

Characteristics of manufacturing planning and control system (MPCS)	Dispatching	Kanban	Daily rate	TOC production
			• Part buffer in free-transfer lines	
Buffer size	Function of checks and balances system of MRP and physical storage capacity area	Based on size and number of Kanban cards	In free-transfer lines buffer size determined by physical storage capacity area	Number and value of parts vary while processing time is held constant
Work load control	• Variable WIP level • Workload is not controlled	• Almost constant WIP level • Workload controlled by Kanban cards	• Constant WIP level • Workload controlled by daily rate	• Constant WIP level • Workload controlled through the ROPE system
Issue and registration of materials	Picking list with simultaneous registration	Kanban cards from first centres with simultaneous registration	• Material issue on the basis of the daily rate schedule • Ex-post registration in backflush	Picking list with simultaneous registration
Data collection/monitoring	All work centres	All work centres	• Milestone work centres	Bottleneck work centres

those early findings revealing that manufacturing systems employing TOC techniques exceed the performance of those using Manufacturing Resource Planning (MRP-II). These studies showed that TOC systems produce greater levels of output while reducing inventory, manufacturing lead time, and the standard deviation of cycle time. More generally, in order to measure organisation's performance in achieving its main goal, the majority of these studies used the measures prescribed by Goldratt and Fox (1986):

- operational measurement: (1) Throughput (T), (2) Inventory (I), (3) Operating expense (OE)
- financial measurements: (1) Net profit (NP), (2) Return on investment (ROI), (3) Cash flow (CF)

The remainder of this section provides a pithy analysis of the major studies of the literature on the relationship between TOC implementation and manufacturing performance. As said, since 1980s, there had been several implementations of the

OPT software and TOC systems and many studies were being published in the literature. A number of these works focused on the characteristics of the OPT/TOC in comparison with other production control systems such as MRP and JIT (Aggarwall 1985; Johnson 1986; Koziol 1988).

With respect to the OPT–MRP comparison, some papers highlighted the shortcomings of MRP and the superiority of OPT (Swann 1986). Goldratt (1988) pointed out that the product–process structure of the OPT overcomes two key limitations of the MRP system, as it does not require the separation between product structure (bill of materials) and process structure (product routing). Some authors (Swann 1986; Reimer 1991; Spencer 1991) reported that a company may need both tools: MRP for net requirements and OPT for realistic shop schedules. In this perspective, OPT is viewed as a powerful shop floor control technique which may be considered as an enhancement to MRP. However, using a simulation, Duclos and Spencer (1995) pointed out that the scheduling procedure under theory of constrains, called drum–buffer–rope, produce significant better result than the MRP method used at the factory and they demonstrated that trying to combine the perceived strengths of two different production techniques may not yield satisfactory results.

As regards the relationship between TOC/OPT and just-in-time (JIT), Schonberger (2001) concluded that JIT is similar to OPT in many aspects because kanban is an effective approach to managing the constraints. Lambrecht and Decaluwe (1988) developed a simulation study to compare OPT with JIT. The results of their simulation indicated that both JIT and OPT offered useful insights as well as improvements over MRP. In addition, Atwater and Chakravorty (2002) used a simulation analysis, which showed TOC system performed best when station variability is high, but when station variability is low, JIT achieve best performances. Vollum and O’Malley (1989) discussed ways in which JIT would improve by using OPT. They concluded that there were no major problems with combining JIT and OPT methods where OPT scheduled the bottlenecks and JIT scheduled non-bottlenecks. Hansen (1989) also explored JIT and TOC compatibility and he concludes “JIT/TOC can form a natural evolutionary marriage that will enable us to not only compete in a world class manufacturing environment, but to literally leap from the competition”. Wheatly (1989) describes OPT software as “OPT is simply a JIT technique that is applicable to non-repetitive industrial environments where kanban flounders”.

Many studies in the literature have tried to make a simultaneous comparison of OPT, MRP and JIT (see the recent works of Gupta and Snyder 2009 and of Zhang et al. 2013). Most of these works underlines that manufacturing systems employing TOC technique exceed the performance of those using MRP and Just in Time, as TOC systems increase output while decreasing both inventory and cycle time (Ramsay et al. 1990; Fogarty et al. 1991; Cook 1994; Mabin and Balderstone 2000).

Everdell (1984) reviewed the three production planning and control systems (JIT, MRP and OPT) and underlined that JIT proceeds one step further than OPT and does synchronize operations and eliminates a lot of ‘Murphys’ that OPT recognizes as restraints. However, OPT, like JIT does not address all the planning support activities of MRP-II″. Aggarwall (1985) found that the three production systems can all operate effectively since all three incorporate the five production planning and control functions within them. Each system has its advantages and disadvantages.

Plenert and Best (1986) wrote that both JIT and OPT are more productive than MRP, and the OPT system is more complete than the JIT system. Sohal and Howard (1987) support the conclusions reached by Plenert and Best. Grunwald et al. (1989) highlighted different evidences. Based on a framework designed to compare different production planning and control systems, they conjectured that OPT operates best under conditions of high complexity and low uncertainty, MRP operates best under conditions of high complexity and high uncertain. Ramsay et al. (1990) carried out a simulation study and they conclude that the OPT approach appears to be most useful of the three.

More recently, Noreen et al. (1995) studied the implementation of TOC to a typical production environment and they stated its capability to quickly yield substantial improvements in operations and in profits. Finally, one of the most interesting work about the relationship between TOC and performance is the article of Mabin and Balderstone (2000). The empirical analysis of a sample of firms showed that TOC adoption lead to a 70 % mean reduction in order-to-delivery lead time, a 65 % mean reduction in manufacturing cycle time, a 49 % mean reduction in inventory, a 63 % mean increase in throughput/revenue, a 44 % mean improvement in due date performance.

4 Research Framework

The main purpose of the second part of the chapter is twofold. Firstly, we study whether TOC practices are adopted in different ways across firms belonging to some European countries. After having identifying the differences and similarities in the adoption of TOC, we investigate the impact on the performance of manufacturing plants deriving from the adoption of TOC practices. As explained before, this study considers TOC in the narrow view meaning that we refer to a suite of integrated management tools applied to the operations management/production area only. For this reason, hereafter we will use the term “TOC production”.

In order to carry out the study three hypotheses have been established. The first is defined as follows:

H1: There is no difference between TOC production practices across the countries.

In manufacturing firms, TOC could be implemented using a paradigmatic approach or a contingent one. In the first case it is assumed that there is one best way of organising manufacturing based on TOC principles which means adopting a specific set of tools and methodologies. Thus, TOC production should be adopted and implemented in an almost identical similar style across different manufacturing plants. On the other hand, the contingency theory of the firm (Lawrence and Lorsch 1967; Galbraith 1973, 1977), suggests that every company can design its own TOC production strategy in terms of organisation and management.

The next hypothesis concerns with the linkage between TOC production and performance, i.e. TOC production is considered a key determinant for firm's performance. We consider only the operational measures of manufacturing plants, judging unrealistic to analyse the impact on the financial measures in view of the heterogeneity of the sample (firms belonging to different industries and countries). The second hypothesis is defined as:

H2: TOC production practices significantly contribute to manufacturing performance.

The last argument is about the similarity in the impact of TOC practices across the countries. We are not only interested in evaluating whether the adoption of the TOC production practice has an impact on firms' operating performance but even if this impact manifests itself differently among companies belonging to various countries. The third hypothesis is defined as:

H3: There is no difference on the impact of TOC production practices on manufacturing performance across the countries.

In order to test the three hypotheses so far defined, first of all we need to develop appropriate scales measuring different aspects of TOC production.

Starting from the considerations made so far, to test the research hypotheses listed above we propose seven scales measuring different aspects of TOC production as follows:

1. Drum–buffer–rope methodology (DBRM): assesses use of the DBR methodology as it is described in the literature;
2. Time-Buffer Management (TBUM): evaluates whether different time buffers are used to protect the drum from the effects of disruptions at non-constraint resources;
3. MRP for optimised schedules (MRPO): ascertains whether the firm makes use of a modified MRP procedure to determine net requirements of materials;
4. Material movement with transfer batches smaller than production batches (MAMO): measures whether transferring units of product from one process step to another is made in small quantities in order to reduce the time for a batch of parts to get through a system;
5. Non-constraint resources with excess capacity (NCEC): examines if non-constraint equipment has some degree of excess capacity which enables smoother operation of the constraint(s);

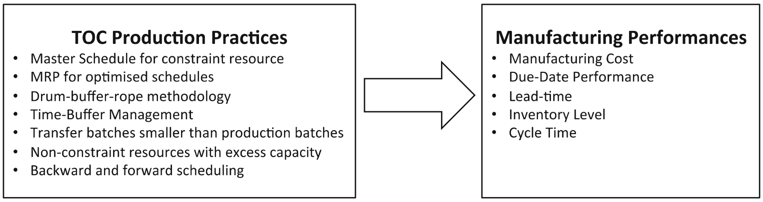

Fig. 2 The research framework

6. Master Schedule optimized for constraint resource (MPSO): inquiries if the MPS is developed taking into account the constraints;
7. Backward and forward scheduling (BFSC): measures if an hybrid push/pull logic is used to scheduling production.

As regards the impact of TOC practices on the performance of manufacturing plants, this study employs five indicators as follows:

1. Manufacturing Cost (MFCS)
2. Due-Date Performance (DUDP)
3. Lead-time (LETI)
4. Inventory Level (INLE)
5. Cycle Time (CYTI)

Figure 2 illustrates the research framework of the study.

5 Data Collection and Measurement Analysis

This study analyses the data collected from 61 manufacturing plants in Spain (8 plants), United Kingdom (12 plants), Germany (14 plants), Italy (13 plants), and France (14 plants) through an extensive questionnaire survey which has been conducted in the 2014. The plants belong to one of the following industries: aeronautic, electronic, mechanical, machinery, automobile, pressure equipment, textiles and clothing.

In each plant, degree of implementation of TOC practices were evaluated by seven individuals including supervisors, production control manager, production planning manager, inventory manager, supply chain manager, plant manager and controller. The degree of implementation for each TOC practice has been evaluated in seven points Likert scale (1: Strongly disagree, 4: Neither agree nor disagree, 7: Strongly agree).

Finally, the five operational measures of manufacturing plants were subjectively judged by the supply chain manager, plant manager and controller. Each manager was asked to indicate his/her opinion about how the plant compares to its competitors in the same industry on a global basis on a five-point Likert scale (1 = Poor or low end of the industry, 2 = Below average, 3 = Average, 4 = Equivalent to competitor, 5 = Superior or top of the industry).

Table 2 Measurement analysis of TOC measurement scales

Measurement scale	Min.	Max.	Mean	SD	Cronbach's alpha	Eigenvalue (percentage of variance)
Drum–buffer–rope methodology (DBRM)	2.350	6.561	4.552	0.883	0.660	2.33 (52)
Time-Buffer management (TBUM)	1.730	6.450	4.939	0.875	0.760	2.43 (58)
MRP for optimised schedules (MRPO)	1.750	6.128	3.302	0.834	0.780	2.36 (52)
Material movement with transfer batches smaller than production batches (MAMO)	1.700	6.786	4.386	1.203	0.850	2.22 (53)
Nonconstraint resources with excess capacity (NCEC)	3.830	6.450	5.451	0.698	0.730	2.50 (47)
Master Schedule for constraint resource (MPSO)	3.575	6.950	4.299	0.732	0.740	2.33 (49)
Backward and forward scheduling (BFSC)	3.563	7.330	5.797	0.695	0.780	2.85 (55)

The first step of analytical process is the analysis of reliability and validity of seven measurement scales. In this study, Cronbach's alpha coefficient was calculated for each measurement scale to evaluate its reliability. Table 2 shows that the alpha value for all of the seven scales exceeded the minimum acceptable value of 0.60 for the pooled sample and country-wise samples. Most of the scales have alpha values above 0.75, indicating that the scales were internally consistent.

As regards construct validity which ensures that all question items in a scale measure the same construct, within-scale factor analysis was conducted with the three criteria: uni-dimensionality, a minimum eigenvalue of 1, and item factor loadings in excess of 0.40. The results of measurement analysis shown in Table 1 prove that all scales have satisfactory construct validity. All of the scales have an eigenvalue of more than two. The factor loadings of question items are more than 0.40, mostly ranged between 0.70 and 0.90.

6 Data Analysis

Firstly, we examine the country effect on the implementation of TOC production. One-way ANOVA was used to identify the similarities and differences in TOC production practices across the countries. The last two columns of Table 3 show the value of the *F*-statistic and the corresponding significance level. If we set the significance level at 5 %, the ANOVA test suggests that all of the TOC practices are significantly different across the countries except MRP for optimised schedules.

In addition, Tukey pairwise comparison tests of mean differences were conducted to identify how TOC practices differ between each pair of countries. This

Table 3 TOC production practices across countries

Measurement scale	SPA	UK	GER	FRA	ITA	Pair wise difference	F	Sig.
DBRM	4.858	4.858	4.003	5.123	4.455	(SPA-GER), (UK-GER), (UK-FRA), (UK-GER), (ITL-FRA)	12.444	0.000
TBUM	4.333	4.434	3.564	4.900	4.598	(SPA-GER), (UK-GER), (FRA-GER), (ITL-FRA)	11.556	0.000
MRPO	3.899	3.456	3.965	4.200	3.900		1.234	0.423
MAMO	4.003	4.765	3.099	5.198	4.189	(SPA-GER), (SPA-FRA), (UK-GER), (UK-FRA), (GER-FRA), (GER-ITL), (FRA-ITL)	35.845	0.000
NCEC	5.423	4.834	4.993	5.394	4.864	(UK-FRA), (GER-FRA), (FRA-ITL)	5.043	0.002
MPSO	4.544	5.102	4.675	5.102	4.834	(UK-GER), (GER-FRA)	3.789	0.005
BFSC	5.456	4.944	5.399	5.206	5.100	(SPA-UK), (UK-GER)	4.205	0.001

SPA Spain, *GER* Germany, *UK* United Kingdom, *ITL* Italy, *FRA* France

comparison detected several important aspects of TOC practices as they are universally adopted in different countries.

The largest difference across the countries exists in *Material movement with transfer batches smaller than production batches* and *drum–buffer–rope methodology*. Generally, Spanish and French plants exhibit higher scores in every TOC scale than German, Italian, and British plants. German and Italian plants tend to show lower scores than other countries except *Backward and forward scheduling*. French respondents tell that every TOC practice is important. The similarities were found between United Kingdom and Italy and between Spain and France (except *Material movement with transfer batches smaller than production batches*). The results also indicate the most important aspect of TOC production for each country: Ma*terial movement with transfer batches smaller than production batches* (Spain, Germany, and Italy)*, Master Schedule optimized for constraint resource* (United Kingdom), *Non-constraint resources with excess capacity* (France). In contrast, *MRP for optimised schedules* was found unpopular to those countries. In summary TOC practices vary widely among countries. Each country evaluated the importance of TOC in different ways. As the result we would like to reject the hypothesis H1 and state that there is significant difference in TOC practices across the countries.

Table 4 Correlation between TOC production practices and performance

Measurement scale	Manufacturing cost	Due date performance	Lead-time	Inventory level	Cycle-time
DBRM	UK,FRA	GER, ITL	FRA	UK	UK
TBUM	UK	UK, SPA	UK, FRA	UK	UK
MRPO	FRA	GER, ITL	FRA	UK	
MAMO			ITL, UK	UK	UK
NCEC	UK	GER, UK	GER, ITL, UK, FRA	UK	UK
MPSO	GER, UK, FRA	ITL, SPA	UK	UK	UK
BFSC	GER	FRA	UK, FRA		

SPA Spain, *GER* Germany, *UK* United Kingdom, *ITL* Italy, *FRA* France

Next, simple correlation coefficients are shown in Table 4 to identify the relationship between TOC production practices and operational performances. Table 4 has 35 cells, each corresponding to a pair of one TOC production practice and one performance indicator. Each cell includes the abbreviated name of the countries for which significant correlation was found between the TOC production practice and the performance indicator. It is found that correlations between TOC practices and performance indicators appear differently across the countries. The TOC practices are considerably connected with high performance at British plants. Setting the significant level at 0.5 % as suggested in the literature, the number of pairs of significant correlation for the British sample is 22 out of 35. This number is 9, 5, 6, and 2 for France, Italy, Germany, and Spain respectively.

In general, TOC practices are more or less associated with every operational performance measure. Especially, every TOC practice significantly correlates with *Manufacturing cost, Due-date Performance*, and *Lead-time* in all of the five countries. In addition, all the TOC practices are significantly related with *Inventory level* and *Cycle time* for the British sample. The most popular TOC practices may be attributed to *drum–buffer–rope methodology, Non-constraint resources with excess capacity* and *Master Schedule optimized for constraint resource,* while *Material movement with transfer batches smaller than production batches* can be effective in British and Italian plants only. *Lead-time* and *Inventory level* are the performance indicators that are benefited most from adopting TOC practices for the pooled sample, while an evidence of the effect of TOC production on the reduction in *Inventory level* and *Cycle time* can be found for the British sample only.

To better testing the second and third hypotheses, regression analysis was conducted for the pooled sample with utilization of four dummy variables representing four countries: SPA (Spain), GER (Germany), ITL (Italy), and FRA (France). These four dummy variables were include because the effect of country need to be removed before evaluating the impact of TOC production practices on operational performance that can be generalized across countries. Table 5 shows the results. If significant level is set at 5 % by using two-tailed test, the regression

Table 5 Regression on the effect of TOC production practices on performance using dummy variables

	Manufacturing cost as dependent variable		Due date performance as dependent variable		Lead-time as dependent variable		Inventory level as dependent variable		Cycle time as dependent variable	
R^2	0.432		0.425		0.393		0.394		0.286	
Adjusted R^2	0.123		0.225		0.218		0.149		0.023	
F and *p*	1.323	(0.075)	1.854	(0.020)	2.181	(0.004)	1.545	(0.046)	1.132	(0.403)
df	144		144		144		144		144	
(Constant)	−0.274	0.870	0.371	0.811	−0.635	0.632	−0.516	0.753	0.309	0.832
SPA	0.211	0.854	−0.120	0.912	2.363	0.027	0.180	0.873	0.001	0.999
GER	−0.159	0.896	−0.716	0.532	1.843	0.099	1.117	0.348	1.001	0.428
FRA	−0.184	0.882	−0.046	0.969	−0.684	0.550	0.099	0.936	0.645	0.623
ITL	1.668	0.197	−0.283	0.817	0.526	0.657	0.888	0.485	0.199	0.883
DBRM	0.181	0.593	−0.492	0.130	0.090	0.774	0.236	0.479	−0.098	0.782
TBUM	0.177	0.625	0.745	0.032	0.494	0.142	0.326	0.359	0.432	0.256
MRPO	−0.309	0.185	−0.195	0.378	−0.436	0.044	−0.204	0.374	−0.181	0.458
MAMO	0.551	0.100	0.086	0.786	0.319	0.301	0.536	0.107	0.492	0.160
NCEC	0.318	0.415	0.021	0.954	0.372	0.302	−0.013	0.973	0.280	0.495
MPSO	0.117	0.813	0.447	0.344	0.029	0.949	0.458	0.347	0.197	0.705
BFSC	−0.226	0.364	0.069	0.772	0.087	0.706	−0.432	0.084	−0.196	0.455
SPA × DBRM	0.088	0.945	0.324	0.788	−0.419	0.721	−0.009	0.994	0.193	0.884
SPA × TBUM	0.195	0.847	0.353	0.713	−1.151	0.218	−0.766	0.442	−0.136	0.897
SPA × MRPO	0.000	1.000	−0.130	0.799	1.067	0.032	−0.711	0.179	−0.146	0.791
SPA × MAMO	−0.714	0.266	−0.057	0.926	−0.589	0.319	−0.199	0.752	−0.545	0.417
SPA × NCEC	−1.833	0.174	−0.083	0.948	−1.127	0.363	0.611	0.644	0.441	0.750
SPA × MPSO	0.354	0.804	−0.101	0.941	0.062	0.962	−1.615	0.250	−0.115	0.938

(continued)

Table 5 (continued)

	Manufacturing cost as dependent variable		Due date performance as dependent variable		Lead-time as dependent variable		Inventory level as dependent variable		Cycle time as dependent variable	
SPA × BFSC	1.706	0.117	−0.036	0.972	−0.113	0.910	2.905	0.008	0.365	0.745
GER × DBRM	−0.270	0.806	1.615	0.125	0.043	0.966	−0.513	0.636	−0.207	0.857
GER × TBUM	−0.226	0.751	−1.313	0.055	−0.763	0.246	−1.235	0.080	−1.632	0.030
GER × MRPO	0.486	0.374	0.789	0.131	0.500	0.322	0.639	0.237	0.730	0.204
GER × MAMO	−0.488	0.337	0.234	0.628	−0.843	0.074	−0.416	0.408	−0.361	0.497
GER × NCEC	−1.429	0.267	0.647	0.596	−0.048	0.968	0.141	0.911	−0.264	0.844
GER × MPSO	0.247	0.876	−2.520	0.098	−0.220	0.881	−0.291	0.852	0.403	0.809
GER × BFSC	2.399	0.126	1.541	0.300	−0.112	0.938	1.333	0.387	0.824	0.614
FRA × DBRM	1.321	0.435	3.614	0.026	1.766	0.259	−2.045	0.215	−0.652	0.710
FRA × TBUM	−0.459	0.698	−1.923	0.089	0.027	0.980	1.655	0.150	0.465	0.703
FRA × MRPO	1.565	0.107	0.863	0.348	1.778	0.048	1.435	0.137	1.763	0.087
FRA × MAMO	−0.478	0.659	−0.977	0.344	−1.370	0.172	0.047	0.965	0.172	0.880
FRA × NCEC	−4.022	0.027	−0.987	0.563	−2.166	0.192	−2.230	0.224	−1.446	0.458
FRA × MPSO	1.073	0.566	−2.777	0.120	−2.014	0.244	−2.570	0.157	−1.350	0.485
FRA × BFSC	1.087	0.492	2.350	0.120	2.398	0.102	3.584	0.023	0.230	0.889
ITL × DBRM	−1.056	0.327	1.157	0.264	−0.205	0.837	−0.490	0.643	0.945	0.402
ITL × TBUM	0.289	0.745	−1.422	0.093	−0.875	0.285	−1.076	0.219	−1.088	0.242
ITL × MRPO	0.314	0.547	1.085	0.032	0.362	0.455	0.511	0.321	0.249	0.648
ITL × MAMO	0.150	0.845	0.141	0.847	0.238	0.738	−0.958	0.207	−0.588	0.465
ITL × NCEC	−0.999	0.361	−0.120	0.909	−0.070	0.945	0.357	0.740	−0.395	0.729
ITL × MPSO	0.131	0.933	−1.108	0.458	0.162	0.911	−1.066	0.486	−1.158	0.479
ITL × BFSC	−0.259	0.831	0.410	0.721	−0.223	0.842	2.037	0.092	1.773	0.166

results suggest the significant contribution of TOC practices to *Due-date performance*, *Lead-time* and *Inventory level*. They also reveal the significant differences in the determinants of manufacturing performance among five countries.

For example, there are considerable differences in the impact of *MRP for optimised schedules* on *Due-date performance* (between United Kingdom and Italy) and the impact of *Backward and forward scheduling* on *Inventory level* (between Spain and United Kingdom).

To confirm these findings additional regression analysis have been performed to check whether the coefficients in a particular regression model are the same for the samples of different countries, after dividing the pooled sample into five sub-samples representing each country. We need to compare an estimated regression model including measurement scales as independent variables for the pooled sample with the corresponding model applied for five sub-samples. In doing this no restrictions are imposed on the values of regression coefficients so that they can take different values for different countries. In this way we enable regression coefficients to take different values by an F test (Mabin and Balderstone 2000).

The results of regression analysis of five manufacturing performance indicators are shown in Tables 6, 7, 8, 9, and 10.

It is noticed that the significant level for regression coefficients is set at 5 % with two-tailed test and that the results of Chow (1960) test have been presented at the bottom of each table. The hypothesis H2 is accepted for the pooled sample, the Spanish sample (if taking *Due-date performance* as a dependent variable), the British sample (if taking *Inventory level* as a dependent variable), and the French sample (if taking *Lead-time* as a dependent variable). Because the results from the Chow test show the highly significant level of F statistic, we should reject the hypothesis H3 and state that the determinants of TOC performance are largely different across the countries.

7 Discussions and Conclusions

Seven TOC production measurement scales have been proposed and utilized in this study to test the impact of TOC practices on operational performance. We obtained mixed results when those TOC practices were compared across five countries. There are two important findings that should be highlighted.

Firstly, statistical analyses indicate that TOC production has been adopted and implemented in different ways. TOC production is relatively important in French and Spanish plants while it is not so important in German and Italian plants. In between those are British plants where TOC production has been adopted earlier than other countries. However, the close connection between high manufacturing performance and TOC practices indicate that British plants are effectively utilizing TOC practices to improve operational performance in term of *Inventory level*. Spanish plants are successful to implement TOC production to improve their *Due-date performance*, while French plants have introduced TOC practices to enhance

Table 6 Impact of TOC production practices on manufacturing cost

	SPA	UK	GER	FRA	ITL	Pooled sample
R^2	0.269	0.429	0.196	0.586	0.324	0.169
Adjusted R^2	−0.016	0.263	0.009	0.405	0.062	0.127
F and p	0.945 (0.497)	2.577 (0.039)	1.048 (0.420)	3.241 (0.024)	1.234 (0.335)	4.000 (0.001)
(Constant)	0.285 (0.909)	−0.235 (0.881)	−0.560 (0.759)	−0.670 (0.682)	3.585 (0.079)	0.265 (0.709)
DBRM	0.180 (0.617)	0.178 (0.577)	0.062 (0.783)	0.560 (0.082)	−0.305 (0.280)	0.102 (0.397)
TBUM	0.176 (0.606)	0.130 (0.621)	0.054 (0.806)	−0.054 (0.842)	0.273 (0.219)	0.041 (0.685)
MRPO	−0.252 (0.331)	−0.381 (0.150)	−0.031 (0.871)	0.414 (0.084)	−0.138 (0.577)	−0.090 (0.335)
MAMO	0.025 (0.913)	0.407 (0.093)	0.160 (0.399)	0.161 (0.465)	0.499 (0.053)	0.114 (0.239)
NCEC	−0.242 (0.360)	0.298 (0.398)	−0.189 (0.411)	−0.965 (0.005)	−0.124 (0.600)	−0.106 (0.296)
MPSO	0.227 (0.466)	0.098 (0.792)	0.221 (0.349)	0.474 (0.120)	0.167 (0.467)	0.274 (0.007)
BFSC	0.314 (0.264)	−0.188 (0.349)	0.296 (0.230)	0.115 (0.660)	−0.305 (0.160)	0.159 (0.087)

Chow test: F = 6.487 p = 0.000

Table 7 Impact of TOC production practices on due-date performance

	SPA	UK	GER	FRA	ITL	Pooled sample
R^2	0.529	0.225	0.369	0.454	0.413	0.162
Adjusted R^2	0.345	0.008	0.221	0.215	0.197	0.120
F and p	2.885 (0.033)	1.036 (0.432)	2.502 (0.038)	1.898 (0.137)	1.914 (0.123)	3.868 (0.001)
(Constant)	0.064 (0.968)	0.676 (0.722)	−0.595 (0.705)	0.474 (0.799)	−0.554 (0.794)	0.628 (0.366)
DBRM	−0.366 (0.213)	−0.424 (0.253)	0.157 (0.434)	0.817 (0.031)	0.019 (0.940)	0.073 (0.542)
TBUM	0.781 (0.010)	0.547 (0.079)	0.055 (0.775)	−0.366 (0.251)	0.030 (0.877)	0.065 (0.517)
MRPO	−0.297 (0.159)	−0.194 (0.512)	0.233 (0.181)	0.116 (0.658)	0.502 (0.035)	0.121 (0.192)
MAMO	0.096 (0.607)	0.080 (0.767)	0.223 (0.188)	−0.317 (0.217)	0.091 (0.683)	0.044 (0.644)
NCEC	0.010 (0.961)	0.003 (0.994)	0.279 (0.174)	−0.281 (0.421)	−0.035 (0.867)	0.103 (0.305)
MPSO	0.438 (0.090)	0.273 (0.526)	−0.495 (0.023)	−0.455 (0.190)	0.120 (0.571)	−0.027 (0.790)
BFSC	0.091 (0.682)	0.056 (0.806)	0.317 (0.150)	0.770 (0.019)	0.127 (0.521)	0.210 (0.025)

Chow test: F = 8.205 p = 0.000

Table 8 Impact of TOC production practices on lead time

	SPA	UK	GER	FRA	ITL	Pooled sample
R^2	0.088	0.477	0.336	0.669	0.289	0.223
Adjusted R^2	−0.267	0.331	0.181	0.524	0.027	0.184
F and p	0.247 (0.967)	3.260 (0.013)	2.166 (0.067)	4.623 (0.005)	1.104 (0.400)	5.743 (0.000)
(Constant)	3.718 (0.025)	−0.568 (0.668)	2.644 (0.045)	−2.006 (0.190)	−0.080 (0.972)	1.355 (0.022)
DBRM	−0.114 (0.776)	0.109 (0.718)	0.142 (0.489)	0.593 (0.043)	0.052 (0.851)	0.156 (0.176)
TBUM	−0.048 (0.899)	0.388 (0.126)	0.157 (0.430)	0.274 (0.270)	0.062 (0.768)	0.023 (0.812)
MRPO	0.281 (0.330)	−0.444 (0.076)	−0.186 (0.295)	0.307 (0.146)	−0.245 (0.326)	−0.085 (0.342)
MAMO	−0.011 (0.967)	0.251 (0.261)	−0.325 (0.065)	−0.215 (0.278)	0.235 (0.345)	−0.175 (0.061)
NCEC	−0.037 (0.899)	0.337 (0.316)	0.462 (0.032)	−0.263 (0.335)	0.370 (0.123)	0.372 (0.000)
MPSO	0.090 (0.795)	−0.025 (0.943)	−0.065 (0.762)	−0.531 (0.057)	0.108 (0.641)	−0.023 (0.809)
BFSC	0.099 (0.748)	0.062 (0.742)	−0.006 (0.979)	0.614 (0.017)	0.010 (0.965)	0.112 (0.209)

Chow test: $F = 8.335$ $p = 0.000$

Table 9 Impact of TOC production practices on inventory level

	SPA	UK	GER	FRA	ITL	Pooled sample
R^2	0.347	0.564	0.158	0.377	0.224	0.096
Adjusted R^2	0.093	0.437	−0.039	0.086	−0.078	0.050
F and p	1.365 (0.279)	4.439 (0.003)	0.803(0.592)	1.296 (0.317)	0.743 (0.640)	2.077 (0.050)
(Constant)	−0.094 (0.968)	0.055 (0.968)	2.454 (0.204)	−0.070 (0.977)	0.979 (0.600)	0.875 (0.238)
DBRM	0.202 (0.554)	0.282 (0.312)	0.111 (0.629)	−0.234 (0.533)	0.124 (0.678)	0.114 (0.361)
TBUM	−0.091 (0.778)	0.272 (0.233)	−0.377 (0.100)	0.629 (0.080)	−0.194 (0.409)	−0.097 (0.360)
MRPO	−0.553 (0.032)	−0.209 (0.345)	0.139 (0.484)	0.213 (0.478)	0.136 (0.608)	0.011 (0.908)
MAMO	0.323 (0.153)	0.434 (0.045)	0.151 (0.437)	0.260 (0.346)	−0.118 (0.651)	0.098 (0.333)
NCEC	0.170 (0.494)	−0.043 (0.890)	0.063 (0.788)	−0.542 (0.172)	0.172 (0.500)	0.099 (0.352)
MPSO	−0.191 (0.516)	0.259 (0.431)	0.326 (0.181)	−0.286 (0.443)	0.279 (0.260)	0.054 (0.608)
BFSC	0.478 (0.080)	−0.354 (0.053)	−0.154 (0.538)	0.598 (0.093)	0.113 (0.616)	0.140 (0.151)

Chow test: F = 8.324 p = 0.000

Table 10 Impact of TOC production practices on cycle time

	SPA	UK	GER	FRA	ITL	Pooled sample
R^2	0.233	0.319	0.344	0.127	0.171	0.121
Adjusted R^2	−0.082	0.129	0.191	−0.281	−0.151	0.076
F and p	0.739 (0.643)	1.674 (0.161)	2.249 (0.058)	0.311 (0.938)	0.532 (0.799)	2.683 (0.012)
(Constant)	0.543 (0.765)	0.692 (0.642)	2.446 (0.076)	1.805 (0.477)	0.772 (0.711)	1.879 (0.003)
DBRM	−0.004 (0.991)	−0.068 (0.843)	−0.111 (0.584)	−0.159 (0.719)	0.292 (0.348)	0.068 (0.584)
TBUM	0.211 (0.565)	0.316 (0.269)	−0.604 (0.004)	0.328 (0.421)	−0.113 (0.641)	−0.250 (0.018)
MRPO	−0.267 (0.330)	−0.230 (0.408)	0.235 (0.186)	0.393 (0.273)	−0.009 (0.974)	0.080 (0.407)
MAMO	0.119 (0.628)	0.354 (0.167)	0.150 (0.381)	0.239 (0.462)	0.072 (0.789)	0.060 (0.551)
NCEC	0.395 (0.164)	0.227 (0.551)	0.187 (0.367)	−0.198 (0.665)	0.102 (0.697)	0.220 (0.036)
MPSO	0.127 (0.698)	0.099 (0.805)	0.319 (0.139)	−0.164 (0.708)	−0.107 (0.671)	0.115 (0.270)
BFSC	−0.125 (0.669)	−0.141 (0.512)	−0.013 (0.952)	−0.012 (0.977)	0.230 (0.331)	0.017 (0.856)

Chow test: F = 7.333 p = 0.000

their *Lead-times*. In contrast, German and Italian cases prove that high manufacturing performance can be achieved by other means rather than TOC production. This indicates that each country should find its own path for improving the performance depending on its specific context and competitive environment. Secondly, this study highlights importance of specific TOC practices. *Drum–buffer–rope methodology*, *Non-constraint resources with excess capacity* and *Master Schedule optimized for constraint resource* are regarded as the most effective approaches to improve manufacturing performance of their plants.

As regards the link between TOC and performance a first interesting finding of the study is that one particular TOC practice can simultaneously associate with several performance indicators. In particular, *drum–buffer–rope methodology, Master Schedule optimized for constraint resource* and *Time-Buffer Management* are the practices that have an impact on all the different manufacturing performance. A second outcome is that there is difference in the impact of specific TOC practice on performance indicators across countries. This difference may be attribute to the effect of two different set of factors: external factors such as different geography and industry sectors, and internal factors related to number of employees, ownership, manufacturing strategy, level of automation and so on. All these factors would play important roles on the effective implementation of TOC production.

Despite of some limitations in term of sample size and the utilization of subjective performance measures, this study significantly contributes to the literature by providing an empirical evidence for the impact of TOC production on manufacturing performance. The results of a series of statistical analyses support the contingency perspective which suggests that the relationship between TOC practices and plant performance is contingent (dependent) upon the internal and external situation of the firm.

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Exploring Critical Success Factors for Implementing Green Lean Six Sigma

Anass Cherrafi, Said Elfezazi, Andrea Chiarini, Ahmed Mokhlis and Khalid Benhida

Abstract Research has shown that implementation of Green and Lean Six Sigma make a positive impact on economic, environmental and social performance. Many organizations have already started to integrate the two approaches. However, evidence suggests that these organizations find their implementation challenging, and in many cases they are unsuccessful. The purpose of this paper is to present an analysis of research on Green Lean Six Sigma focusing on success factors in its implementation through a systematic literature review combined with the lesson learned from authors' experiences and verified by a survey of organizations. The findings have led to the identification of five success factors and their ranking according to the organizations that had implemented this initiative. The findings also have led to development of framework for implementing Green Lean Six Sigma. Both academicians and professionals will find this paper useful, as it explore critical success factors for successful Green Lean Six Sigma implementation and provides a concise description of each success factors that will be very helpful for organizations to understand and implement Green Lean Six Sigma.

Keywords Lean Six Sigma · Sustainability · Green · Critical success factors · Framework

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1 Introduction

Recently, with the increase competitive business environment the globalization and the weight on stakeholder's orientation, the market dynamic has changed. Traditionally, efficiency, profitability, responsiveness and customer satisfaction have been the key concern for organizations (Green et al. 2012; Mohanty and Deshmukh 1999). However, with the public's growing environmental awareness, increasing requirements of customers, regulators, and other stakeholders about sustainability, the organizations have been forced to change their way of working (Wilson 2010; Singh and Mahmood 2014). Different management systems, such as Lean Manufacturing, Six Sigma and Green, have been explored by a growing number of companies to become more competitive and meet market, environmental and social demands (Kleindorfer et al. 2005; Diaz-Elsayed et al. 2013; King and Lenox 2001). Many studies have confirmed that Lean Six Sigma can be seen as new opportunities for business sustainability improvement (Larson and Greenwood 2014; Bergmiller and McCright 2009; Carvalho and Cruz-Machado 2009). Lean Six Sigma and Green initiatives are often seen as compatible strategies because of their joint focus on waste elimination, efficient use of resources and focus on satisfying customer needs (Garza-Reyes 2015a, b; EPA 2015; Chiarini 2013a; Duarte and Cruz-Machado 2013; Ng et al. 2015; Han and Lee 2002; Mollenkopf et al. 2010; Hines et al. 2004; Yang et al. 2011). Some researchers have suggested that Lean Six Sigma and Green are synergetic approaches that can improve the sustainability performance (Pampanelli et al. 2011; Garza-Reyes et al. 2014; Herrmann et al. 2008; Dües et al. 2013; Sarkis 2003). In this context, the use of the DMAIC methodology can provide a proven framework for helping organizations to identifying, defining, prioritizing, conducting, managing, achieving, sustaining and improving sustainability projects (Garza-Reyes 2015a, b). However, there are some difficulties in the understanding of the basic mechanisms through which the two strategies can be integrated. Only few organizations have been success to implement Green Lean Six Sigma (Alves and Alves 2015). The Green Lean Six Sigma implementation faces many challenges and barriers. There are many factors that can enable the Green Lean Six Sigma implementation process. This paper aims to identify the critical success factor (CSFs) for the successful implementation of the Green Lean Six Sigma. The secondary goals is to prepare a platform for further studies, specifically for Green Lean Six Sigma implementation strategy development and analyzing the interactions between Green Lean Six Sigma success factors.

The present paper is structured into six sections, in addition to this introduction. The subsequent sections present the literature review, the research methodology, the success factors for successful Green Lean Six Sigma implementation and survey results and discussions which are followed by conclusions, limitations and future work.

2 Literature Review

Many organizations have implemented Lean Six Sigma initiative in order to increase efficiency, reduce costs, improve customer response time and contribute to improve quality (Bergmiller and McCright 2009). Others have implemented Green manufacturing resulting in reduced waste generation, energy and raw material consumption, and in the use of hazardous materials (Bergmiller and McCright 2009; Verrier et al. 2014). Green manufacturing is defined by Allwood (2015) as a system to "develop technologies to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or generation of waste". According to EPA (2015), Green manufacturing is defined as "the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Green manufacturing also enhances employee, community, and product safety".

On the other hand, Lean Six Sigma is defined as a combination of Lean and Six Sigma philosophies (Sheridan 2000; Chiarini 2013b). It is a business improvement methodology that aims to maximize shareholder value, and bottom line results by improving quality, customer satisfaction, speed and costs: it achieves this by using principles and tools from both Lean and Six Sigma (Laureani and Antony 2012; Snee 2010).

The relationship between Lean Six Sigma and Green manufacturing has been well examined in recent studies (Garza-Reyes 2015a, b). Researchers suggest that Lean Six Sigma and Green manufacturing are concurrent and thus can be effectively integrated (Garza-Reyes 2015a, b; Dües et al. 2013). They have a lot of elements and end results in common related to waste reduction, product design, lead time reduction, and use of various techniques and approaches to manage supply chain relations, organizations, and people (Chiarini 2014; Larson and Greenwood 2014; Garza-Reyes 2015a, b; Dües et al. 2013; Johansson and Sundin 2014; Wiengarten et al. 2013). Thus, the Green Lean Six Sigma has emerged as an initiative to improve the environmental efficiency of organizations while still achieving their economic objectives (Galeazzo et al. 2013; Deif 2011; Rao 2004; Shrivastava 1995).

3 Research Methodology

According to this paper objective, the research methodology followed was based on a combination of research methodology approaches. This includes systematic literature review, lessons learned from authors' experiences in the implementation of Green Lean Six Sigma and survey of organizations. The basic steps flowed are shown in Fig. 1.

The literature review was conducted using many sources, including peer reviewed journal articles and books from both academic and professional

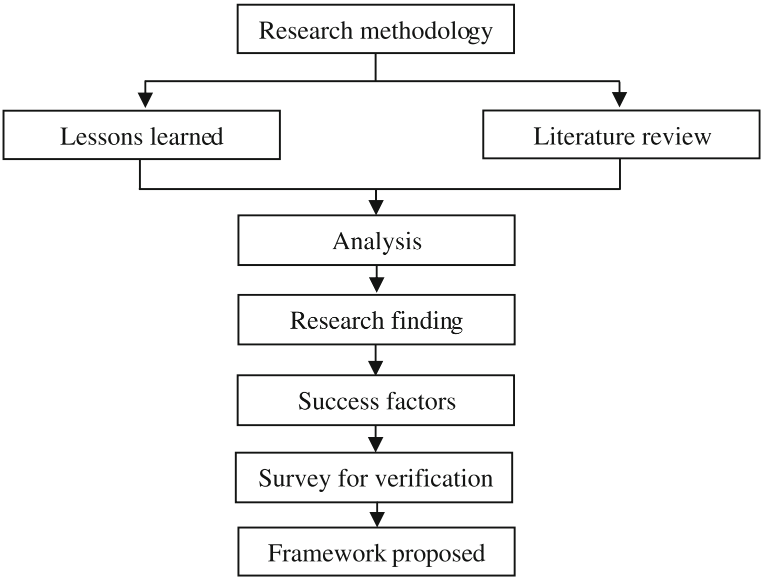

Fig. 1 Research methodology

organizations and publishers; test-books, dissertations, conference papers and unpublished working were excluded. Relevant publications were identified in the main management databases (Elsevier ScienceDirect; Taylor & Francis, Springer, Emerald Database and Anbar International Management Database) using a number of keywords that are frequently used in the literature to describe the integration of Lean Six Sigma and Green strategies. The keyword combinations are indicated in Table 1. The search was done for the period 1993 to present day. The reason for selecting 1993 as the starting point was the publication of the first article discussing the relationship between Lean and Green (Maxwell et al. 1993).

The preliminary finding of literature review has shown the existence of gaps in knowledge. The research conducted in this field has not provided sufficient information on issues that affect the successful integration of Green and Lean Six Sigma within organizations. Therefore, we decided to include the lessons learned from our experience. This experience is based on an action research project developed from 2013 to 2015 by a team of Lean Six Sigma and sustainability experts from

Table 1 Keyword combinations for the literature search

Lean Manufacturing
Six Sigma
Lean Six Sigma
Green Lean Six Sigma
Green
Sustainability

Table 2 List of organizations involved in this study

Company	Size	Business sector
C1	SME	Agri-food
C2	Multinational	Automotive
C3	SME	Metal industries
C4	Multinational	Textile industries

academia and industry. This project was applied in a group comprised four companies of different sizes operating in diverse range of industries (see Table 2).

As shown in Fig. 1, in order to verify whether organizations that had implemented Green Lean Six Sigma still recognize the same set of factors and which ones they would consider as more important, a survey was developed. A questionnaire was designed and distributed to 450 companies, from various countries and industries that have already integrate Green and Lean Six Sigma. The response rate was 25 %, with 113 responses received. In order to measure the consistency of our survey, a reliability test was conducted based on Cronbach's α coefficient and using JMP software. The results indicate that the alpha coefficients are between 0.72 and 0.94. According to Nunnally (1987) a reliability coefficient of 0.6 or higher is considered an acceptable level of internal consistency. Therefore; we can conclude that the data collected is reliable for analysis. The results of the survey are discussed in Sect. 5.

For this paper, results obtained from the literature review, authors experience and survey was structured according to thematic synthesis. This method was selected due to its effectiveness. In addition, this article follows the introduction, methods, results, and discussion structure to report the findings. This structure, according to Smith (2000) and Booth et al. (2012), provides an easy and clear to follow flow for the readers of the paper.

4 CSFs for the Implementation of Green Lean Six Sigma

According to Rungasamy et al. (2002), CSFs are those factors necessary to the success of any initiative or program, in the sense that, if goals associated with the factors are not achieved, the implementation of the initiative will perhaps fail catastrophically. The challenge to implement Green Lean Six Sigma is to recognize how to integrate Lean Six Sigma and Green as a systematic approach and identify the best way to sustain the results. Thus, the determination of CSF is critical as it helps organization to focus their efforts and resources on these factors to increase the chance of success.

The CSFs identified through literature review and several lessons that were learned during our experiences are summarizing in the following:

4.1 Organisational Readiness to Implement Green Lean Six Sigma

It is important to first understand the preparedness of an organization to implement Green Lean Six Sigma initiative. This action increases the probability of success of the project before an organization invests its resources heavily on the strategy. Based on our experience we suggest that organizations should realize a diagnostic in order to determine its weaknesses and strengths and understand its maturity level to evaluate their own positioning in the Green Lean Six Sigma journey. The results of the diagnostic will indicate whether or not an organization is in a position to implement Green Lean Six Sigma initiative.

4.2 Project Selection and Prioritization

Project selection and prioritization is the most challenging phase experienced during a Green Lean Six Sigma initiative. Project selection methodology helps organization to prioritize the project that will give the best return. In addition, selection of the right project will develop confidence in management and employees towards the Green Lean Six Sigma strategy. This in turn will encourage organization to invest and take future efforts into the initiative. It is important to take into consideration the following elements while selecting potential Green Lean Six Sigma projects:

- Selected project needs to be aligned with organizational strategic objectives and stakeholders issues.
- Selected project must be feasible to implement from a resource and technical standpoint.
- Project goals should be clear to the team members involved in the Green Lean Six Sigma initiative.
- Project selected should have the capacity to show measurable sustainability improvements in short time.

Other factors in project selection are having the right people. It is important to attract the best employees from all levels and departments. Team members are selected for their availability, skills and experience with the process under improvement.

4.3 Commitment of Top Management and Employees

The involvement and commitment of top management and employees in the implementation of Green Lean Six Sigma initiative is critical for long-term success

(Pampanelli et al. 2014; Bergmiller and McCright 2009; Longoni and Annachiara 2014; Vinodh et al. 2011; Maskell and Pojasek 2008; Washington State Department of Ecology's, 2007; Park and Linich 2008; EPA 2007; Alves and Alves 2015). Without this commitment, it is absolutely a waste of time and energy. The authors believe that an observable commitment by the leadership was crucial to motivate employees and support the strategic role of the initiative. Top management must define the vision, strategic direction and develop an organization culture that promotes continuous improvement in order to improve sustainability performance. Furthermore, they must be able to lead and motivate employees to achieve the economic, social and environmental goals of the organization. In addition, organization must ensure the respect of people, empowerment of creativity; recognition plays a vital role in this context. In turn, employees must engage to ensure the successful implementation of the Green Lean Six Sigma projects according to company strategies and should act as a team (Pampanelli et al. 2014; Longoni and Annachiara 2014; Alves and Alves 2015).

4.4 Communication

One of the challenges identified by the authors' is that there is a poor communication during the implementation of Green Lean Six Sigma, especially during the early phases of deployment. Organization needs to establish a common language for change and improvement (EPA 2007; Alsagheer and Hamdan 2011; Washington State Department of Ecology's 2007; Helper et al. 1997). Furthermore, different stakeholders may have misunderstanding about the Green Lean Six Sigma initiative and their impact on sustainability performance. Only through effective communication, stakeholders will be more engaged and the employees can work as a team for solving different sustainability problems which facilitate the Green Lean Six Sigma implementation.

4.5 Resource and Skills to Facilitate Implementation

One of the most vital requirements for developing and sustaining process-improvement initiative such as Green Lean Six Sigma is to build human capital by developing the appropriate training and education to employees (Pampanelli et al. 2014; Sobral and Jabbour 2013; Park and Linich 2008; EPA 2007; Vinodh et al. 2011). The employees should be able to understand and use the Lean Six Sigma tools and techniques into daily operations in order to improve sustainability performance. Team members should be given the necessary resources (financial and technique) and adequate time to implement and execute a project which results in improved economic, environmental and social performance.

4.6 Focus on Measurement and Results

Performance measurement is important for Green Lean Six Sigma efforts, it permits to organization to identify the sustainability problems, evaluate the effectiveness of an action plan, and monitor progress towards the goals (Pampanelli et al. 2014; Washington State Department of Ecology's 2007; Park and Linich 2008; EPA 2007). The measurement system allows any influencing parameters to be detected and can serve also as a basis for decision-making. In addition, organization should to keep in mind that Green Lean Six sigma is not about tools or methodologies. It is about improving sustainability performance and outcomes in order to achieve better results. In this context, top management should make sure results are the cornerstone of any messaging about the initiative.

5 Survey Result and Discussion

The respondents to the survey were asked to score on a Likert scale their perceived importance of each CSF, with 1—not very important; 2—not important; 3—important; 4—very important; 5—critical. The results of the survey are showed in Fig. 2 and Table 3, where the various factors have been classified accordingly to their mean score. A CSF with the highest mean score is considered as the most important factor. According to the respondents' "commitment of top management and employees" is considered the most important with an average of 4.7, followed by "organizational readiness to implement Green Lean Six Sigma", "project selection and prioritization" and "resource and skills to facilitate implementation".

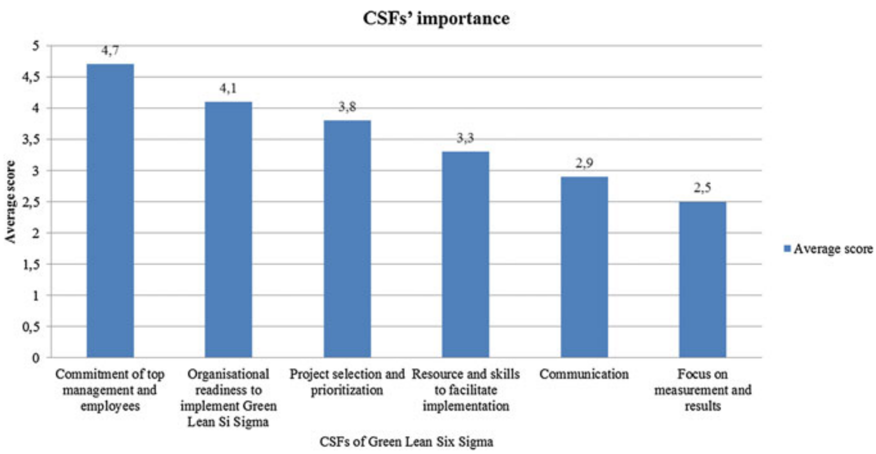

Fig. 2 CSFs' importance

Table 3 Average importance scores for CSFs

CSFs	Average score
Commitment of top management and employees	4.7
Organizational readiness to implement Green Lean Six Sigma	4.1
Project selection and prioritization	3.8
Resource and skills to facilitate implementation	3.3
Communication	2.9
Focus on measurement and results	2.5

Furthermore, respondents do not consider "communication" and "focus on measurement and results" as important for a successful implementation of Green Lean Six Sigma.

It is not a surprise the high score of "commitment of top management and employees". It is very important for the introduction of Green Lean Six Sigma in organization, and the results of the survey confirm the thinking process of authors and many experts and researchers (Bergmiller and McCright 2009; EPA 2015; Pampanelli et al. 2014; Longoni and Annachiara 2014; Vinodh et al. 2011; Park and Linich 2008).

Organizational readiness to implement Green Lean Six Sigma has also been widely perceived by respondents as one of the most important CSF to implement Green Lean Six Sigma. This is because without organizational readiness, this improvement effort may face barriers and problems during their deployment. It is appears that this factors is more important to practitioners than it was in the literature, where a small number of studies identified it (EPA 2015; Pampanelli et al. 2011; Longoni and Annachiara 2014; Helper et al. 1997).

However, it is surprising to see the low score of "communication" and "focus on measurement and results", as these were often mentioned in the literature as a two key elements that encourage team members to make more effort and focus on more important activities to achieve objectives of Green Lean Six Sigma project (EPA 2015; Park and Linich 2008).

Based on survey results, we propose a specific integrated framework for implementing Green Lean Six Sigma. The framework provides a comprehensive set of six categories used to assess an organization to integrate Green and Lean Six Sigma. It illustrates the cause and effect relationships between the CSFs on performance and the results achieved (Fig. 3).

In the framework, there are six categories used to assess an organization. It is important to first understand the preparedness of an organization to integrate Green and Lean Six Sigma initiative. This step will increase the probability of success of the project before an organization invests its resources heavily on the strategy. Commitment of top management and employees helps to set the strategic direction for the organization and drives the mindset of excellence. Project selection and prioritization are positioned after commitment of top management and employees to demonstrate the importance of selection of the right project. Communication is developed based on understanding external and internal stakeholder requirements,

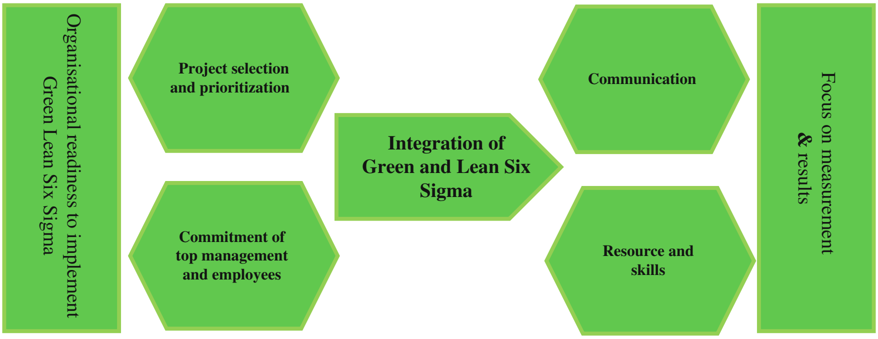

Fig. 3 Framework to implement Green Lean Six Sigma

which guides the implementation of initiative based on resources and skills of people to achieve desired Results. Measurement is part of the system, which supports decision-making and drives improvements.

6 Conclusion and Agenda for Future Work

Lean Six Sigma and Green are very powerful strategies that share common elements related especially to waste reduction. They are compatible and even synergistic and can be integrated to form a superior strategy to achieve economic, social and environmental performance.

This paper aims to identify the CSFs effecting Green Lean Six Sigma implementation. A characterization of each CSF is presented, based on literature review and lessons learned through authors experiences. Second, a survey was conducted in order to verify and rank these CSFs. Based on the results of this survey, the two factors of "commitment of top management and employees" and "organizational readiness to implement Green Lean Six Sigma" have been shown to be the extremely important CSFs for Green Lean Six Sigma implementation.

Through a better understanding of these CSFs, organization will have an idea about the way to deploy Green Lean Six Sigma as a systematic way and recognize the "success formula".

Academics and practitioners could use the results of this paper for future survey development, and as the basis for developing hypotheses for testing, as, for example, which factors are most widely impact the implementation of Green Lean Six Sigma initiative.

This is one of the first attempts to propose the identification of CSFs for implementing Green Lean Six Sigma initiative and for that there are many aspects that need to be investigated further. The experience acquired through four projects and is may be not sufficient to generalize our findings. In addition the data for the survey came especially from developed countries. Therefore, The Green Lean Six

Sigma implementation may vary from geographic location and culture of the company. It will be pertinent to classify the CSFs using data from some other emerging and developing countries.

The next step of the study will be looking into the development of a Green Lean Six Sigma Readiness Index Model based on the CSFs for the successful deployment of Green Lean Six Sigma. The authors are interested also to study the structural relationship between Green Lean Six Sigma success factors and developing a model of these CSFs using modeling techniques such as interpretive structural modeling, analytical hierarchy process, and structural equation modeling.

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S&OP Related Key Performance Measures with Integration of Sustainability: A Decoupling Point Based and Modularized View on Supply Chains

Sayeh Noroozi and Joakim Wikner

Abstract Key performance measures (KPMs) play an important role in the management of supply chains. An important integrator of the supply chain management is Sales and Operations Planning (S&OP) that connects the strategic and operational plans. S&OP usually impacts supply chain performance through the management of resources and customer satisfaction. This paper suggests a new classification for S&OP-related KPMs. The classification follows a typology of decision categories which are based on decoupling points. The typology supports a modularized approach to supply chain design and provides the possibility to select the KPMs according to the decision criteria of each module. The KPMs are further linked to the SCOR performance attributes to provide the link to the companies' strategic directives and the strategic conflicts which appear in the modules of the typology are discussed. The sustainable KPMs have also been included in order to provide opportunities for improved sustainable performance. The integration of sustainable KPMs helps in creating competitive advantages for companies through development of capabilities which are beneficial but hard to replicate by competitors. The paper ends with an example that illustrates how the classification can be applied to a case company.

Keywords Key performance measures · Sales and operations planning · Sustainability · SCOR model · Decoupling points

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1 Introduction

Key performance measures (KPMs) play an important role in the analysis, design, and management of supply chains in order to measure the performance of an existing system, compare possible scenarios (Beamon 1998), and provide the basis for continuous improvement (Chae 2009). Successful supply chain management is dependent on a closed-loop planning and execution system and supply chain management metrics are considered as a set of performance measures which evaluates the planning system (ibid.). Despite the importance of performance measures, many companies find it difficult to identify the appropriate set of KPMs for their business or are mainly focused on economic KPMs and pay less attention to the other supply chain aspects such as customer service, and demand/supply accuracy (ibid.). Focusing on financial KPMs does, however, tend to put emphasis on short term cost reduction with a reactive nature (Kaplan and Norton 1992) rather than long term development of competitive advantages (Hayes and Abernathy 1980).

Sales and Operations Planning (S&OP) is a planning process with the purpose of balancing demand and supply at an aggregate level (Thomé et al. 2014). S&OP is known as a supply chain integrator (Basu and Wright 2008) and has an important role as it connects strategic and operational plans and integrates the supply chain partners in the planning process. S&OP, as an integrator, affects the performance of companies (Thomé et al. 2014). Many KPMs have been defined for S&OP including customer satisfaction, cash-to-cash cycle time, lead-time (Thomé et al. 2012b) and delivery speed (Thomé et al. 2014).

Another issue which recently has been under focus (Ahi and Searcy 2013) and can influence the companies' performance is the integration of all three categories of sustainability, i.e. economic, environmental and social, into planning processes (Husgafvel et al. 2015). To make sustainability operationally relevant, it is important to also reflect sustainability in the performance measures. The integration of Sustainable Key Performance Measures (SKPMs) related to economic, environmental and social aspects into all levels of planning hierarchy and decision making processes helps companies to be more proactive and to overcome the present and future sustainability challenges and provides long-term benefits (Husgafvel et al. 2015). S&OP is crucially important in this regard due to its essential role in linking the strategic and the operational activities as well as its integrative nature in connecting different functions both within and between companies (Wallace and Stahl 2008; Thomé et al. 2014). Economic KPMs have already been studied at the S&OP level to some extent (see e.g. Thomé et al. 2012b) but environmental and social aspects have not been explicitly integrated in S&OP to any significant extent. Including these measures helps in understanding the companies' environmental footprints and helps them to improve the environmental performance while earning customer recognition and eventually financial benefits through either revenue increase or cost reduction (Ambec and Lanoie 2008). Opportunities for increasing revenue include better access to certain markets, selling differentiated niche product and pollution control technologies (ibid.). Cost reduction opportunities include improved relation with external stakeholders, risk management and decreasing cost of material, energy, labor and capital (ibid.). Environmental practices increase the competitiveness of companies as well (Husgafvel et al. 2015) since companies can develop capabilities which are beneficial yet hard to replicate by competitors (Hajmohammad et al. 2013). Social sustainability practices are crucial since they emphasize sustainable (human) resource use and hence enable companies to reduce risks and costs (Husgafvel et al. 2015). The three sustainable categories are interdependent (United Nations 2007) and some studies show that improved environmental performance can lead to decreased labor cost through reducing the cost of absenteeism, illnesses and recruitment (Ambec and Lanoie 2008), as well as noise and accidents (Dekker et al. 2012). Thus, in order to gain the long term benefits, it is crucial for sustainability measures to be considered systematically in the S&OP process.

The S&OP-related KPMs have previously been classified based on criteria such as demand and supply aspects (Milliken 2008), the SCOR model (plan, source, production, delivery), or have been mainly focused on financial performance (see e.g. Chae 2009). This paper intends to take a different approach by classifying the S&OP-related KPMs based on a typology which is based on decoupling points and highlights flow based decision categories. The typology, introduced by Wikner and Noroozi (2014), is based on a modularized view of supply chain through key decision categories. The three decision categories (dimensions) of the typology are the type of object being transformed in the system, the mode applied in the transformation, and the driver of the transformation. The decision categories are related to discretization decoupling point, control mode decoupling point, and customer order decoupling point respectively. These decision categories have been chosen due to their applicability to manufacturing companies, see Sect. 3.1. The relevance of decoupling points lies in the fact that different managerial approaches and planning decisions are required at each side of a decoupling point (see e.g. Giesberts and Tang 1992; Van Donk 2001) which also implies the need for differentiated performance measures.

This approach helps us to recognize the specific requirements of supply chain management following a modularized approach. The integration of SKPMs to this classification has also been emphasized and different SKPMs are suggested according to the requirements of the supply chain modules identified through the typology. The importance of a modularized supply chain has been long emphasized in the literature to achieve competitiveness, see e.g. Fisher (1997). This approach, i.e. the classification of performance measures based on the modularized view of supply chain, helps in better understanding of the supply chain which can lead to precise recognition of problems and in-time solutions. In addition, it helps in standardization of knowledge for each module.

Another issue regarding KPMs is that the relation between S&OP-related KPMs and the strategic goals of companies have not been fully covered in the literature. Due to the importance of hierarchical alignment between different planning levels, in this paper the S&OP level performance measures have further been linked to the

Supply Chain Operations Reference (SCOR) model's performance attributes (Supply Chain Council 2012) in order to emphasize the importance of the alignment between strategic goals and companies' performance measures.

The purpose of the current paper is to develop a classification of the performance measures related to Sales and Operations Planning (S&OP) according to a typology of decision categories based on decoupling points in order to provide support for a modularized supply chain design. The link between S&OP level KPMs and strategic goals is emphasized as well.

Through a narrative literature review, some examples of performance measures are gathered to show how the classification is deployed.

The studied KPMs are at the S&OP level and thus, follow the scope of the S&OP process. However, since the classification used in this paper is based on a typology in the production context, the KPMs related to inbound, outbound and reverse logistics are not covered and the main emphasis is on manufacturing activities and hence manufacturing companies. The focus is on internal activities of a focal actor and thus, the relations with other supply chain actors are not included.

The current paper intends to include all three categories of sustainability; however, this concept is not the main focus of this paper. Sustainability is a broad concept and it is difficult to include all its aspects in a paper. Therefore, only concepts related to the manufacturing context within a focal actor and related to S&OP are emphasized and issues related to e.g. society, policy making, supply chain partners, etc. are excluded since they are not fully under control of the manufacturing companies. Following the Global Reporting Initiative (GRI) report structure, within the economic category the economic performance (i.e. direct economic value generated and distributed) is under focus (Global Reporting Initiative 2015b). Within the environmental category; materials, energy, water, emissions, and effluents and waste are studied (ibid.). Within the social category only employment, occupational health and safety, and training and education within the sub-category of labor practices and decent work are emphasized (ibid.).

The rest of the paper is as follow. We first introduce the methodology of this paper containing conceptualization and narrative literature review, which helps in recognizing the existing gaps in the body of literature and the way we aim to fill these gaps. Thereafter, we review the literature in order to highlight the gaps. The three final sections contain the suggested classification of identified KPMs and SKPMs, analysis, application, and the paper ends with conclusion and further research.

2 Methodology

In this section, the conceptualization process and the literature review method are first discussed and in the end, the classification process of the gathered KPMs and SKPMs is described.

2.1 Conceptualization

This paper aims to suggest a new classification for the S&OP-related performance measures according to a typology of decision categories (DCs) which are based on decoupling points. The paper is conceptual in nature meaning that it contains "the mental representation of an idea" through deductive reasoning and logical thinking (MacInnis 2011). In research, the four general conceptual goals are envisioning, explicating, relating and debating (ibid.). In line with MacInnis (2011), the current paper's conceptual goal is to relate different concepts through integration, i.e. seeing concepts in a new way and with a holistic approach. In this paper, the present classifications for KPMs/SKPMs are reviewed, the gaps are identified and a new approach for the classification of the KPMs/SKPMs is suggested. In order to align the decisions made at S&OP level with the strategic goals of manufacturing companies, the S&OP level KPMs are linked to the SCOR model's five strategic performance attributes (PAs) (Supply Chain Council 2012). In addition, sustainability measures are integrated in the classification in order to provide competitive advantages for proactive manufacturing companies. In order to recognize the gaps in the body of literature as well as to provide a firm basis for the new classification, a literature review has been performed.

2.2 Narrative Literature Review

Since the aim of conceptual research is to provide new insights into the conventional problems, literature review is a fundamental part of a conceptual research (Wacker 1998). However, since several topics are integrated together in the current paper, a systematic literature review is challenging to perform due to the inherent complexity and instead a narrative literature review has been performed (Baumeister and Leary 1997) in order to gain knowledge about the field as well as to provide the basis for configuring the strategic aspects of the DCs (the dimensions) of the typology. A narrative review is a "comprehensive narrative synthesis of previously published information" which often discusses context and theory and is suitable for provoking thoughts and controversy (Green et al. 2006, p. 103). According to Green et al. (2006), a paper based on narrative literature review should provide the following information: source of information, search terms, selection criteria and results.

2.2.1 Source of Information and Search Terms

The narrative review in the current paper includes (but is not restricted to) decoupling points, performance measures, performance measures classification, S&OP, and economic, environmental and social sustainability.

The keywords being used to gather the S&OP level KPMs are performance measures, performance indicators, and metrics in combination with sales and operations planning, tactical planning, process industry, discrete manufacturing industry, lean and project management. For SKPMs the keywords sustainable, economic, environmental, social and corporate social responsibility have been added.

The keywords were searched in ScienceDirect and EBSCO since they contain a large body of literature in areas related to operations management and industrial studies including peer-reviewed full-text articles. Where appropriate, the reference lists of the previous studies have been used in order to dig into specific areas related to the topic of the current paper (Croom 2009).

2.2.2 Selection Criteria

In order to distinguish the measures related to S&OP, the control and time perspective have been considered, i.e. the papers related to tactical level and with medium time horizon (both correspond to S&OP) have been selected and reviewed. The S&OP related measures have been derived from these papers and are classified as explained in Sect. 2.3.

2.2.3 Results

As the result of the literature search and refinement of the papers, 77 articles were reviewed based on their full content. The main scientific journals found as the result are Journal of Cleaner Production, International Journal of Operations & Production Management, International Journal of Production Economics, International Journal of Production Research and International Journal of Productivity and Performance Management. Among these, Journal of Cleaner Production is the main source for papers focused on sustainability. In addition to the scientific journals, international documents such as the Supply Chain Operations Reference model (SCOR), Global Reporting Initiative (GRI), and related International Organization for Standardization (ISO) standards have been reviewed since they are all relevant and applicable in the manufacturing companies.

2.3 Classification Process

The S&OP level KPMs and the SKPMs have been gathered from the above mentioned references for all the decision categories (dimensions) of the typology. Taking the object type (refers to the flow object being continuous or discrete, see Sect. 3.1) as an example to show how the review is performed and the measures extracted, the papers based on continuous object are collected and reviewed separately from the papers based on discrete object and the KPMs for each group are gathered independently. This means that if a measure, e.g. inventory level, is listed under both continuous object and discrete object, it is originating from two different sets of papers. This approach is used for all the dimensions and helps in identifying the strategic aspects related to each module. The KPMs are then compared to the performance measures in the SCOR model in order to be linked with the five performance attributes (PAs) of the SCOR model and thus to be connected to the company's strategy. These strategically-aligned KPMs are then compared to the strategic aspects of each dimension. The aim is to gain a better understanding about each dimension and the KPMs which are of strategic importance for it. Note that as performed by the SCOR model, all the environmental KPMs in this paper are just linked to GreenSCOR and are not further linked to the five PAs since even the SCOR model itself does not connect the environmental KPMs to the five PAs.

3 Literature Review

In this section, the literature on classification systems related to performance measures systems, S&OP, and sustainability are reviewed, and existing gaps are highlighted. But, first a typology based on decision categories and decoupling points is presented as it is the basis for the suggested classification in the current paper. As the result of the identified gaps in the literature review process, the frameworks for this paper are suggested at the end of this section in Tables 1 and 2.

3.1 Decision Categories (DCs)

In line with the APICS dictionary, flow management, i.e. the actual transformation of materials during the production process, through decoupling points implies the recognition of discontinuities or disconnections in terms of decoupling points, between processes (Blackstone Jr. 2010). Wikner (2014) suggests that a decoupling point is related to a particular decision category (DC). A DC concerns a certain aspect of decision making, such as what actually drives the flow, whereas an actual decision may concern several DCs, such as when a planning method is selected which might depend on the driver of flow and its repetitiveness in combination. A DC is based on a specific criterion that may have different properties for different parts of the flow and the point where the properties change is referred to as a decoupling point. Consequently, different managerial approaches and planning decisions are required at each side of the decoupling points (see e.g. Giesberts and Tang 1992). Accordingly, different KPMs are required to measure the performance at each side of a decoupling point.

The typology introduced by Wikner and Noroozi (2014) is used as the basis of classification of KPMs and SKPMs in this paper, see Fig. 1. This typology is based on flow characteristics and covers three main DCs which here are referred to as the dimensions of the typology: object type related to the flow object being continuous

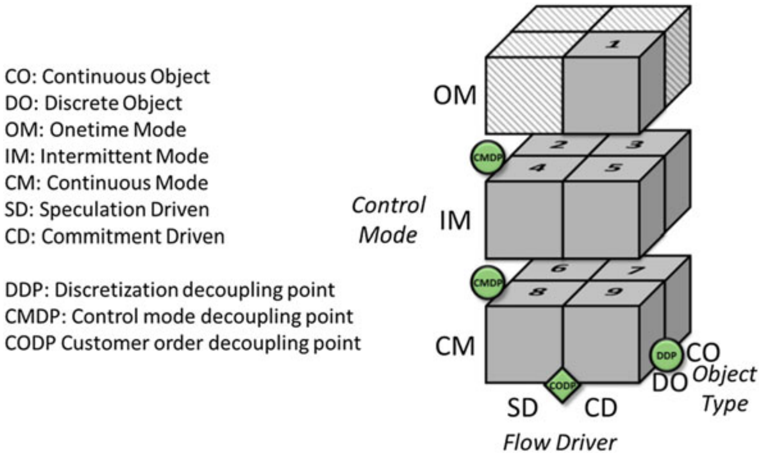

Fig. 1 Typology of decision categories based on decoupling points (Wikner and Noroozi 2014)

object (CO) or discrete object (DO); control mode related to the flow of material being continuous mode (CM), intermittent mode (IM) or onetime mode (OM); and flow driver related to if the flow is speculation driven (SD) (based on forecast) or commitment driven (CD) (based on customer order). These dimensions are related to discretization decoupling point (DDP), control mode decoupling point (CMDP) and customer order decoupling point (CODP) respectively. The dashed boxes in Fig. 1 are not prone to be relevant since OM is mainly applicable for discrete objects and customer order driven flows. Thus, they are excluded from the typology.

Other classifications could be used as the basis for categorizing the S&OP related performance measures, see e.g. MacCarthy and Fernandes (2000) or SCOR model (Supply Chain Council 2012). MacCarthy and Fernandes (2000) emphasize the importance of repetitivity (here referred to as control mode). The SCOR model includes the concept of flow driver but does not explicitly cover the two other dimensions of the typology. We, however, believe that the dimensions suggested by Wikner and Noroozi (2014), which are in line with Constable and New (1976), are key in flow management and thus more appropriate for our purpose. The importance of flow driver has already been emphasized in the literature (see e.g. Hoekstra and Romme 1992; Supply Chain Council 2012; Wikner 2014). The object type is essential (see e.g. Woodward 1965; Taylor and Bolander 1994) since it distinguishes process industries and discrete manufacturing industries (Noroozi 2014) and the control mode is important (see e.g. Wild 1971; McCarthy 1995) due to the view it provides on production planning (MacCarthy and Fernandes 2000). Wikner and Noroozi (2014) suggest that the combination of the dimensions in the typology leads to the supply chain modularization that can improve the understanding of companies' supply chains. Each dimension can include hybridity, e.g. process industries are usually a hybrid of continuous objects and discrete objects which are separated by DDP (Noroozi 2014). Different dimensions also can be interrelated which is referred to as cross hybridity and each module represents a cross hybridity of the three DCs. For detailed information, readers are referred to Wikner and Noroozi (2014). Each module, illustrated by a box in Fig. 1, is a combination of three DCs and needs specific measures related to its characteristics which would help the companies to make better decisions. The use of the typology fulfils the need for different KPMs in various locations as noted by Neely et al. (1995) and for different products/product families, referred to as supply chain segmentation in the literature (see e.g. Van der Veeken and Rutten 1998), at the S&OP level. SKPMs are also classified on the same basis which is in line with the purpose of this paper to emphasize the integration of SKPMs at the S&OP level. It should be noticed that the SKPMs in this paper are considered as a subset of KPMs. The reason to distinguish them is to put particular emphasis on sustainability issues.

3.2 Performance Measures and Performance Attributes (PAs)

Performance measure is “the actual value measured for the criterion” when criterion is defined as “the characteristic to be measured” (Blackstone Jr. 2010). Since each DC is also based on a criterion there is a connection between the DCs and the criteria to be measured. Performance management system then is “a system for collecting, measuring and comparing a measure to a standard for a specific criterion for an operation, item, good, service, business, etc.” (Blackstone Jr. 2010). Neely et al. (1995, p. 80) suggest that a performance measure is a “metric used to quantify the efficiency and/or effectiveness of an action” where effectiveness means how well the customer requirements are satisfied and efficiency refers to how economically the company can fulfil the customer requirements. They then define performance measurement system as “a set of metrics used to quantify both the efficiency and effectiveness of actions” (Neely et al. 1995, p. 81).

Different classifications and system designs have been suggested for performance measures. Leong et al. (1990) classify the performance measures based on five dimensions, namely cost, quality, delivery performance (including dependability and speed), flexibility (including volume, product mix, changeover, modification, retouring, material and sequencing) and finally product and process innovativeness. Kaplan and Norton (1992) introduce the balanced scorecard and use the four perspectives of financial, customer, internal processes, and innovation and learning. A strength of the balanced scorecard is that it integrates different perspectives of the company with different goals and thus emphasizes the optimization of the whole system rather than the sub-optimization of individual functions and connects KPMs to the company’s strategic goals (Kaplan and Norton 1992); however, the competitors perspective is less obvious in this framework (Neely et al. 1995). Another widely used approach for classification of performance measures is the Supply Chain Operations Reference (SCOR) model developed by the Supply-Chain Council (SCC), now merged with APICS and known as APICS SCC. The SCOR model is a reference model and does not include any goals for the measures but the suggested measures help companies to benchmark their processes with best practices (Sürie and Wagner 2010). The SCOR model has five performance attributes which are related to the strategy namely reliability, responsiveness, agility, cost and assets. A performance attribute represents a group of metrics used to express a strategy (Supply Chain Council 2012). An attribute cannot be measured per se but is used to set strategic directions (ibid.). Thus, the attributes should be distinguished from the performance measures or the metrics. The SCOR model consists of three hierarchical process levels (Supply Chain Council 2012). Level 1 is process type which includes plan, source, make, deliver and return. Level 2 of the SCOR model is process categories and finally level 3 is called process (Supply Chain Council 2012). Performance measures are related to each of these three process levels and have a hierarchical relation as well, meaning that level 1 metrics can be further decomposed into level 2 and level 3 metrics which helps in identifying the cause of the poor performance (Sürie and Wagner 2010). As shown in Table 1, the SCOR model has been selected in this paper as the foundation to link the strategic perspectives to the S&OP KPMs because of its wide scope on different process types as well as its ability to link the hierarchy of KPMs to the strategic directives of the company through the performance attributes. SCOR is widely used by manufacturing companies since it provides standard knowledge for different processes and thus facilitates bench-marking and knowledge sharing. This feature of SCOR is in line with the modularized approach used in the current paper. In addition, the hierarchical structure of the performance measures and their relation to the PAs can help companies to be alert and focused on the PAs which provide competitive advantages for them. As emphasized in the literature on competitive strategy (see e.g. WheelWright 1984; Porter 1985; Hallgren and Olhager 2009) companies might follow cost-leadership or differentiation strategy to compete in the market. If they follow the cost-leadership strategy, reliability, cost and assets among the five PAs are strategically more important for them to stay competitive (ibid.). On the other hand, if they follow the differentiation strategy, they mainly compete based on responsiveness and agility (ibid.). Thus, companies should make a trade-off among PAs, according to their specific supply chain designs, in order to gain competitive advantages.

3.3 Key Performance Measures (KPMs) for Sales and Operations Planning (S&OP)

In this part the literature about S&OP, performance measures for S&OP, and the relation between S&OP and sustainability are reviewed and discussed.

3.3.1 Sales and Operations Planning

S&OP emerged as an important part of Manufacturing resource planning (MRPII) (Wight 1984) and has been improved since the 1970s (Basu and Wright 2008). Traditionally, S&OP is defined as “a dynamic process in which the company’s operating plan is updated on a regular monthly or more frequent basis” (Ling and Goddard 1988, p. 11). APICS dictionary defines S&OP as “a process to develop tactical plans that provide management the ability to strategically direct its businesses to achieve competitive advantage on a continuous basis by integrating customer-focused marketing plans for new and existing products with the management of the supply chain. The process brings together all the plans for the business (sales, marketing, development, manufacturing, sourcing, and financial) into one integrated set of plans” (Blackstone Jr. 2010). Even though S&OP is mainly considered to be located at the tactical level of planning hierarchy, it has extensions towards strategic level (see e.g. Olhager et al. 2001; Olhager and Rudberg 2002) e.g. when it deals with capacity expansion (Thomé et al. 2012b) or risk management (Wallace and Stahl 2008). S&OP is a monthly planning process with a horizon of 12–18 months and includes five steps of data gathering, demand planning, supply planning, pre-meeting and executive meeting (see e.g. Wallace and Stahl 2008). First, the S&OP process is about gathering data for demand and supply planning. Next, a demand plan is prepared which mainly is focused on forecasting the future demand for present and new products. This plan is sent to the next step where capacity planning is performed based on the demand plan (required capacity), available capacity and inventory/backlog levels. In the two final steps, people from different related areas in the company gather and discuss issues related to the balance of demand and supply plans, review critical KPMs and come to an agreement on a final game plan for the company (Wallace and Stahl 2008; Jacobs et al. 2011).

S&OP has the main role to balance the demand and supply at an aggregate level and connects the strategic and operational plans in companies and is closely related to the companies’ performance (Thomé et al. 2012a). S&OP usually affects supply chain performance measures through the management of resources (referring to cost), output (customer responsiveness) and flexibility (responsiveness to changes and uncertainties), see e.g. Beamon (1999) and Thomé et al. (2012a). Recently, by cause of increased competition, economic situation and globalization complexities S&OP has extended to cover the whole supply chain and is considered as the integrator of total supply chain management (Noroozi 2014). This integration includes both inter-company and intra-company activities i.e. the integration of different functions within the company as well as the involvement of key customer actors and supplier actors in the process (see e.g. Affonso et al. 2008; Thomé et al. 2014; Tuomikangas and Kaipia 2014; Noroozi 2014).

3.3.2 General Performance Measures

The integrated supply chain puts emphasize on measures which are externally focused, value-based and network oriented, empower the customer actors and value the intellectual property (Basu 2001). The cross-functional nature of S&OP enables companies to develop cross-functional performance measures in order to avoid sub-optimization of performance in separate departments and instead, focus on optimizing the whole companies' performance (Thomé et al. 2012b).

The S&OP-related KPMs have usually been classified based on criteria such as S&OP process (see e.g. Milliken 2008; Davis and Novack 2012; Tuomikangas and Kaipia 2014), the SCOR model (Chae 2009; Thomé et al. 2012b), or have been mainly focused on financial performance (see e.g. Chae2009; Feng et al. 2008). Ling and Goddard (1988) use customer service and financial performance as the bases for performance measures. Tuomikangas and Kaipia (2014) classify the performance measures in the three groups of financial, operations and process. The missing point with these sources is that they usually do not consider the fact that the performance measures might be different in various locations (Neely et al. 1995). In addition, different products/product families, based on the supply chain segmentation (Van der Veeken and Rutten 1998), might need different measures. The relation between the S&OP level KPMs and the companies' strategic directives needs more attention as well in order to provide competitive advantages. These gaps are the focus area of the current paper. Another issue usually ignored in the S&OP literature is sustainability which is discussed below.

3.3.3 Sustainability and Sustainable Performance Measures

First, we need to differentiate between green and sustainable supply chain. According to Ahi and Searcy (2013, p. 335), the most cited definition of green supply chain management is "integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end of life management of the product after its useful life." The most cited definition of sustainable supply chain is "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three categories of sustainable development, i.e. economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Ahi and Searcy 2013, p. 336). Thus, simply said, green supply chain is mainly focused on environmental category while sustainable supply chain has a broader scope and includes economic and social categories as well.

Several classifications have been suggested for SKPMs. The United Nation Commission on Sustainable Development (CSD) has suggested a framework for sustainability measures which includes 15 main themes and 38 sub-themes being classified under four categories of economic, environmental, social and institutional (United Nations 2001). In the 3rd edition of CSD, a more integrated approach has been taken meaning that the measures are not divided into the four categories of sustainability as before (United Nations 2007). Therefore, 14 themes and 50 core measures have been defined with a combined focus on different categories of sustainability (ibid.). The measures addressed by the CSD framework are mainly focused on country/national level (ibid.) and thus are not all relevant for the business organizations (Labuschagne et al. 2005). Different countries or regions, however, might have specific requirements on companies' sustainable performance which should be met by the companies (ibid.). The other well-known practical classification of SKPMs is provided by the Global Reporting Initiative (GRI) which covers the three categories of sustainability i.e. economic, environmental and social (Global Reporting Initiative 2015a). The social category in the GRI is further divided into four sub-categories (Global Reporting Initiative 2015b). All categories and sub-categories are further divided into aspects and different measures are suggested for each aspect (ibid.). The GRI is the only widely recognized international initiative with regard to sustainability which covers the entire business organization (Labuschagne et al. 2005) and is broadly deployed by manufacturing companies. Therefore, the GRI reporting structure is used in the current paper in order to delimit the scope of sustainability. ICHEME (2002) uses the GRI structure and suggests sustainability measures which are specifically recommended for process industries. A well-stablished practical classification of green KPMs (GKPMs) is ISO 14031 which is based on plan-do-check-act (PDCA) model (ISO 1999). Bai et al. (2012) categorizes the economic and green performance measures based on SCOR model and use the gray-based neighborhood rough set theory in order to recognize a core set of important measures. Reefke and Trocchi (2013) in their paper add an additional perspective to the balanced scorecard for environmental and social KPMs.

By reviewing the literature about SKPMs/GKPMs, it can be noticed that these measures have not been classified based on the managerial levels (strategic, tactical and operational) in the literature (see e.g. Ahi and Searcy 2015) or are focused on the strategic level. There are two exceptions. Björklund et al. (2012) do a literature review accompanied by a case study and emphasize the need for identification of GKPMs at different managerial levels, however, their case study is only focused on strategic level. In the other paper, Dey and Cheffi (2013) use the analytic hierarchy process in order to classify the GKPMs based on the managerial levels and also on proactive/reactive factors which reflects the companies' attitude towards the environmental management. It can also be noticed from the review above that the social aspect of sustainability to a large extent has been neglected in the literature in the field of operations management and the main focus has been on environmental issues (see e.g. Hutchins and Sutherland 2008; Ahi and Searcy 2015), which is in line with the practices in the companies as well (Cuthbertson and Piotrowicz 2008).

Considering the literature on S&OP, the economic aspect of sustainability has previously been included in S&OP to some extent (see e.g. Thomé et al. 2012b) but the environmental and social issues have not been directly reflected on. Regarding the environmental issues, Arnold et al. (1998) suggests the integration of green production in the supply planning phase of S&OP. Some papers also consider the energy issues at S&OP level (see e.g. Mohanty and Singh 1992; Kiranoudis et al. 1995; Yin et al. 2003; Corsano et al. 2007; Shabani et al. 2014). It is therefore of interest to include the other aspects of environmental topic in S&OP in order to better align the companies' environmental strategies to the operations. In addition, since staff planning, and integration and collaboration between different partners both within and outside companies are important parts of S&OP process, integration of social KPMs is of relevance. Thus, in this paper the focus would be on sustainable KPMs in order to fill this gap.

3.4 Framework for Performance Measures in S&OP Based on Decision Categories and Performance Attributes

The summary of the theories discussed above in the literature review is presented as a framework for KPMs based on DCs and PAs at S&OP level in Table 1. In total the framework consists of three DCs, i.e. object type, control mode and flow driver, with a total of seven decision domains represented in the first three rows of Table 1. These are combined with the five performance attributes represented in the first column of the table resulting in a total of 35 categories of KPMs for S&OP. Some of KPMs are presented in Tables 3, 4, 5, 6, 7, 8 and 9 in order to show how this classification/framework can be used.

Table 1 represents each dimension/DC of the typology separately. These dimensions are then combined in order to cover the cross hybridities for each module at the strategic level in Table 10.

The SKPMs are classified similarly based on the three DCs and seven decision domains as can be seen in Table 2, the only difference is that they are not linked to the PAs. This is due to the fact that even the SCOR model itself does not link the

Table 1 KPMs for DCs related to SCOR PAs at the S&OP level

Performance Attributes (PAs)	Decision Categories (DCs)						
	Object type		Control Mode			Flow Driver	
	DO	CO	OM	IM	CM	SD	CD
Reliability							
Responsiveness							
Agility							
Cost							
Asset							
Discussed in (section)	4.1.1 Table 3	4.1.3 Table 4	4.2.1 Table 5	4.2.3 Table 6	4.2.5 Table 7	4.3.1 Table 8	4.3.3 Table 9

Table 2 SKPMs for DCs

Decision categories (DCs)						
Object type		Control mode			Flow driver	
DO	CO	OM	IM	CM	SD	CD
Sustainable key performance measures (SKPMs)						
Sect. 4.1.2	Sect. 4.1.4	Sect. 4.2.2	Sect. 4.2.4	Sect. 4.2.6	Sect. 4.3.2	Sect. 4.3.4

GKPMs to the PAs and in general, these links are not yet well defined in the literature and thus not included here. The seven categories of suggested SKPMs at S&OP level are presented in the upcoming sections of the paper as shown in Table 2.

Tables 1 and 2 represent the new classifications suggested here for the S&OP-related performance measures and are the new contributions of the current paper.

4 Performance Measures Classification at S&OP Level Based on the Decision Categories

In this part, the S&OP-related performance measures are classified based on the typology's three decision categories i.e. object type, control mode and flow driver and according to the suggested framework in Table 1. The sustainable KPMs are classified on a similar basis as illustrated in Table 2. It should be noted that the economic category is included in Tables 3, 4, 5, 6, 7, 8 and 9 while the environmental and social categories are presented separately. The main focus in this section is to show how the classifications suggested in Tables 1 and 2 can be used through the suggested KPMs and SKPMs. The tables and discussions provided in this part aim to fill the gaps identified in the literature review (see Sect. 3) in three different ways. First of all, Tables 3, 4, 5, 6, 7, 8 and 9 address the need for different performance measures in different locations and/or supply chain segments at the S&OP level. Second, the KPMs are linked to the SCOR's PAs in order to provide the link between S&OP level KPMs and the strategic directives of companies. Third, different SKPMs are suggested that can be used at the S&OP level in order to improve the companies' sustainable performance as well as their competitiveness.

Using the framework suggested by Wikner (2014), each flow discontinuity can be considered as related to a decision category where decision category is defined as a group of decisions fundamentally important for a specific purpose. Each decision category has a scope which is based on a decision criterion. A decision category also consists of one or more decision domains where the domains identify the common aspects for decision making, related to a decision criterion and within a decision category (ibid.). The decision domains are separated by a decoupling point. This implies that before and after a decoupling point, different management approaches, decisions and measures are required which all are based on the decision criterion (ibid.).

Table 3 Discrete object (DO)/generic performance measures related to S&OP

Performance attribute according to the SCOR model	KPMs	References
Reliability	Customer service	Supply Chain Council (2012), Dougherty and Gray (2006)
	Forecast accuracy	Thomé et al. (2012b)
	Quality	Ling and Goddard (1988)
	Past due and backorder	Ling and Goddard (1988)
	Perfect order fulfillment	Supply Chain Council (2012)
	Number of staff-related environmental violations	Supply Chain Council (2012)
Responsiveness	Order fulfillment cycle time	Supply Chain Council (2012)
	Asset turns	Supply Chain Council (2012)
Agility	Customer return	Ling and Goddard (1988)
	Net profit, return on sale	Maskell and Baggaley (2004)
	Direct labor availability	Supply Chain Council (2012)
Cost	Production cost	Maskell and Baggaley (2004)
	Material cost	Maskell and Baggaley (2004)
Assets	Inventory level (work-in-process, finished goods)	Maskell and Baggaley (2004), Ling and Goddard (1988)
	Capacity utilization (bottlenecks, labor and key material availability)	Maskell and Baggaley (2004), Supply Chain Council (2012)
	Return on working capital	Supply Chain Council (2012)
	Supply chain revenue	Supply Chain Council (2012)
	Cash flow	Ling and Goddard (1988)

Table 4 Continuous object (CO) performance measures related to S&OP

Performance attribute according to the SCOR model	KPMs	References
Reliability	Yield variability	Fransoo and Rutten (1994), Supply Chain Council (2012), Feng et al. (2011)
Responsiveness	Set-up time	Fransoo (1993), Boonmee and Sethanan (2016)
	Manufacturing cycle time	Fransoo and Rutten (1994)
Agility	–	–
Cost	Total cost (minimization)	Noroozi (2014)
Assets	Capacity utilization	Taylor and Bolander (1994)
	Inventory level (work-in-process, finished goods)	Kiranoudis et al. (1995), Shabani et al. (2014)

Table 5 Onetime mode (OM) performance measures related to S&OP

Performance attribute according to the SCOR model	KPMs	References
Reliability	Meeting schedule goals (e.g. Percentage of time variance)	Zwikael and Globerson (2006), Luu et al. (2008), Marques et al. (2011), Mir and Pinnington (2014)
	Impact on customer (customer satisfaction on service/product, customer loyalty)	Zwikael and Globerson (2006), Luu et al. (2008), Bryde (2003), Mir and Pinnington (2014)
	Quality management system/continuous improvement	Luu et al. (2008), Bryde (2003), Marques et al. (2011), Mir and Pinnington (2014)
Responsiveness	–	–
Agility	–	–
Cost	Meeting budget goals (e.g. percentage of cost variance, cost effectiveness, net present value, return on investment, profit per unit, profitability)	Zwikael and Globerson (2006), Luu et al. (2008), Bryde (2003), Marques et al. (2011), Mir and Pinnington (2014)
Assets	Labor (resource management)	Luu et al. (2008), Marques et al. (2011)

Table 6 Intermittent mode (IM) performance measures related to S&OP

Performance attribute according to the SCOR model	KPMs	References
Reliability	–	–
Responsiveness	Set-up time	Fransoo (1993), Olhager and Rudberg (2002)
	Cycle time	Fransoo (1993), Olhager and Rudberg (2002)
Agility	Excess capacity (related to flexibility)	Fransoo (1993), Olhager and Rudberg (2002), Olhager et al. (2001)
Cost	–	–
Assets	–	–

4.1 Decision Category 1: Object Type

As discussed in the literature review (see Sect. 3.1), object type can be continuous or discrete. CO refers to uncountable continuous material/products while DO is distinct and countable (Wikner and Noroozi 2014). The object type can be used to distinguish

Table 7 Continuous mode (CM) performance measures related to S&OP

Performance attribute according to the SCOR model	KPMs	References
Reliability	Lead-time	Carvalho et al. (2011), Diego Fernando and Rivera Cadavid (2007), Dougherty and Gray (2006), Maskell and Baggaley (2004)
	Delivery performance	Supply Chain Council (2012)
	Scrap and rework expenses	Diego Fernando and Rivera Cadavid (2007)
Responsiveness (if related to cycle time and SMED)	Set-up time	Diego Fernando and Rivera Cadavid (2007)
Agility	–	–
Cost	–	–
Assets	Inventory level (WIP, FG)	Diego Fernando and Rivera Cadavid (2007), Maskell and Baggaley (2004)
	Scrap and rework percentage	Diego Fernando and Rivera Cadavid (2007)

Table 8 Speculation driven (SD) performance measures related to S&OP

Performance attribute according to the SCOR model	KPMs	References
Reliability	Forecast accuracy	Maskell and Baggaley (2004)
	Product availability	Ling and Goddard (1988)
Responsiveness	Manufacturing cycle time	Supply Chain Council (2012)
Agility	–	–
Cost	Cost	Olhager (2003), Mason-Jones et al. (2000)
Assets	Inventory level (WIP or FG)	Berry and Hill (1992)
	Waste percentage	Mason-Jones et al. (2000)

process industries and discrete manufacturing industries (Noroozi 2014). Process industries have both CO (also referred to as continuous production) and DO (referred to as discrete production) while discrete manufacturing companies only have DO (ibid.). In the flow object, two decision domains of CO and DO are separated by the DDP and thus, need different KPMs to reflect their specific requirements.

Table 9 Commitment driven (CD) performance measures related to S&OP

Performance attribute according to the SCOR model	KPMs	References
Reliability	Backlog level	Berry and Hill (1992), Maskell and Baggaley (2004), Dougherty and Gray (2006), Wallace and Stahl (2008)
	Lead-time	Carvalho et al. (2011), Olhager (2003), Mason-Jones et al. (2000)
	Service level, perfect order fulfillment	Carvalho et al. (2011), Mason-Jones et al. (2000), Supply Chain Council (2012)
Responsiveness	Manufacturing cycle time	Supply Chain Council (2012), Mason-Jones et al. (2000)
	Delivery speed	Carvalho et al. (2011), Berry and Hill (1992)
Agility	Flexibility (to customer demand, market changes, new product)	Carvalho et al. (2011), Olhager (2003), Mason-Jones et al. (2000)
Cost	–	–
Assets	Work-in-process	Supply Chain Council (2012)

4.1.1 S&OP KPMs Related to Discrete Object (DO)

Most of the papers written about S&OP measures are about DOs or are not industry-specific. Thus the KPMs gathered in Table 3 are considered generic, meaning that they can be used as a basis for all industries. For a review of the S&OP level KPMs, the readers are referred to Thomé et al. (2012b). To illustrate how the table is constructed, take forecast accuracy as an example. This measure is mentioned by Thomé et al. (2012b) to be relevant at S&OP level. By comparing this measure to the SCOR model, it is concluded that forecast accuracy is related to reliability as one of the performance attributes which has a strategic value for the companies. In case a reference does not explicitly mention S&OP, the medium-term horizon and tactical relevance (both corresponding to S&OP) have been used as the selection criteria. For more information, readers are referred to Sect. 2.3. A similar logic has been used for other KPMs in Tables 3, 4, 5, 6, 7, 8 and 9.

4.1.2 Sustainable KPMs Related to Discrete Object (DO) at S&OP Level

Several classifications for sustainability practices are developed worldwide which are industry generic meaning that they can be used as a basis for all industries. Some examples are ISO 26000 (guidance on social responsibility) and GRI (Husgafvel et al. 2015), ISO 14031 (related to environmental sustainability) and

OHSAS 18001 (Occupational Health and Safety). New product introduction, related to time as well as sales amount, (Neely 1998; Maskell and Baggaley 2004; Goh and Eldridge 2015) is an important measure from the sustainability perspective (Supply Chain Council 2012).

Environmental measures include e.g. direct and indirect greenhouse gas emission, NO_X and SO_X emission, reduction of energy consumption, water withdrawal by source, and total weight of waste by type and disposal method (Global Reporting Initiative 2015b).

Some examples of social measures are average hours of training per period per employee by gender and by employee category, type of injury and rates of injury, occupational diseases, and absenteeism, and total number of work-related fatalities, number of new employees by gender and age group (Global Reporting Initiative 2015b), and lost hours caused by injuries (Hutchins and Sutherland 2008). As can be notices, these measures are mainly related to employees' health, safety and satisfaction.

4.1.3 S&OP KPMs Related to Continuous Object (CO)

As mentioned above, CO refers to uncountable continuous material/products which are mainly used in process industries before the DDP (Abdulmalek et al. 2006). The presence of COs implies the deployment of production processes such as mixing, separating, forming and chemical reactions which affects the type of production resources in this domain (Fransoo and Rutten 1994).

In line with Olhager et al. (2001), before the DDP the companies usually try to use a level planning strategy. For more information on this subject, readers are referred to Noroozi (2014). Some KPMs for the CO domain are gathered in Table 4. It should be noted that some aspects of cost and assets can also be related to the sustainability issues. In this paper though they are classified as general measures of resource consumption and asset utilization and not further linked to the future business opportunities.

4.1.4 Sustainable KPMs Related to Continuous Object (CO) at S&OP Level

Regarding the sustainability issues, energy consumption (Yin et al. 2003; Shabani et al. 2014; Feng et al. 2011; Kopanos et al. 2012), material use, and waste released to environment are important measures (Puigjaner and Guillén-Gosálbez 2008). Regarding the waste and emissions, human health (carcinogenic) burden per unit value added, aquatic acidification per unit value added and ecotoxicity to aquatic life per unit value added can be measured (for more info see ICHEME 2002). The production of co-products and by-products is a common characteristic of process industries when dealing with CO (Taylor and Bolander 1994) which also is considered important from the sustainability point of view (ISO 1999). In addition, since process industries are usually located in the beginning of supply chain and use natural material (e.g. oil, metal, etc.), the Resource Depletion Potential (RDP) would be an important measure for them which is defined as "depletion of nonrenewable resources e.g. fossil fuels, metal and minerals in relation to the world's estimated reserve" (Puigjaner and Guillén-Gosálbez 2008, p. 655). Some other example measures for material use are quantity of processed, recycled or reused materials used; quantity of raw material reused in the production process; and quantity of hazardous materials used in the production process (ISO 1999). For energy and water, measures are e.g. quantity of energy used per product, quantity of each type of energy used and quantity of energy generated with by-products or process streams (ibid.) and percentage and total volume of water recycled and reused (Global Reporting Initiative 2015b). For some process industries such as food and oil industries, the amount of energy consumed for inventory holding is an important measure as well (Dekker et al. 2012).

Some of the social KPMs related to the scope of this paper are occupational health coverage (Husgafvel et al. 2014), and expenditure on illness and accident prevention divided by payroll expense (ICHEME 2002).

4.2 *Decision Category 2: Control Mode*

As described in the literature review (see Sect. 3.1), control mode can be onetime, intermittent and continuous. OM implies a unique transformation of material, IM is applied when there is a recurring demand and CM is applied when there is a high and stable demand (Wikner and Noroozi 2014). In the control mode, the three modes of OM, IM, and CM are separated by the CMDP (ibid.).

4.2.1 S&OP KPMs Related to Onetime Mode (OM)

According to Wikner and Noroozi (2014), the OM is related to a unique transformation of DOs that is performed only once.

This kind of transformation is usually related to complicated products/large projects and project management techniques are usually used in this matter (MacCarthy and Fernandes 2000). Thus, the specific KPMs for this type of transformation should reflect on the needs of the appropriate management style. The KPMs frequently referred to in the literature on S&OP/tactical level are shown in Table 5. It should be noted though that most of these authors believe that different projects based on their scope, context and risk might need different performance measures. They also suggest that meeting the cost, time and quality goals is not enough for a successful project. For example, Marques et al. (2011), based on The Project Management Body of Knowledge, suggest six more criteria including project integration, scope, human resource, communications, risk and procurement.

4.2.2 Sustainable KPMs Related to Onetime Mode (OM) at S&OP Level

Environmental issues specific for OM are not much reflected in the reviewed literature and labor safety and team performance are related to the social category (Luu et al. 2008; Marques et al. 2011; Mir and Pinnington 2014).

4.2.3 S&OP KPMs Related to Intermittent Mode (IM)

In the IM (campaign or batch production) and at S&OP level, according to Olhager and Rudberg (2002), set-up time and cycle time (the time required to manufacture an item) of product families are important. The deployment of chase strategy is also suggested with the IM (Olhager and Rudberg 2002) and usually the time-phased production techniques are used. The related KPMs are gathered in Table 6.

4.2.4 Sustainable KPMs Related to Intermittent Mode (IM) at S&OP Level

Environmental and social categories of sustainability specific for IM are not much reflected in the literature.

4.2.5 S&OP KPMs Related to Continuous Mode (CM)

CM is applicable when the demand is high and homogenous and the products flow continuously through the processes (Wikner and Noroozi 2014).

This environment is in line with rate-based production concepts such as lean (Wikner and Noroozi 2014). Thus, the KPMs at S&OP level which are applicable in a lean environment are gathered in Table 7. Lean as a concept is focused on all kinds of waste reduction through the use of Kanban, set-up time reduction and continuous improvement (Carvalho et al. 2011). Note that in Table 7 scrap and rework is categorized under reliability when it is related to perfect condition of deliveries and under assets when it refers to materials reused in the production process (Supply Chain Council 2012).

4.2.6 Sustainable KPMs Related to Continuous Mode (CM) at S&OP Level

As mentioned earlier, lean aims to decrease all kinds of waste. The KPMs suggested for waste are e.g. amount of liquid waste generated, amount of solid waste generated by a process and the percentage of recycled waste (Supply Chain Council 2012), and quantity of hazardous, recyclable or reusable waste (ISO 1999). All these practices imply better environmental performance. Some of the social measures in relation to lean are employees health and safety with regard to job variety, team work and improved ergonomics (Martínez-Jurado and Moyano-Fuentes 2014). However, the effect of lean on companies' sustainability is under debate. This is discussed further in Sect. 5.3.

4.3 *Decision Category 3: Flow Driver*

As mentioned in the literature review (see Sect. 3.1), flow driver can be SD and CD. SD flow is based on the demand forecast and is applied when customer actors are not willing to wait for the product/service, and CD flow is based on actual customer orders (Wikner and Noroozi 2014). In the flow driver, the SD and CD are separated by the CODP (ibid.). Usually, standard products are produced before CODP but both standard and customized products can be produced after CODP (Wikner 2014).

4.3.1 S&OP KPMs Related to Speculation Driven (SD)

In this case, the flow is triggered based on the speculation of future demand when the demand lead-time is shorter than the supply lead-time meaning that customer actors are not willing to wait for the ordered products (Wikner and Noroozi 2014).

In this case, the companies usually keep finished goods inventory and deliver directly from the stock. This type of manufacturing strategy is called make-to-stock and very often is related to lean concept (Mason-Jones et al. 2000). KPMs related to SD are gathered in Table 8. Note that some of lean KPMs mentioned in Table 7 can also be used in this domain.

4.3.2 Sustainable KPMs Related to Speculation Driven (SD) at S&OP Level

Due to the applicability of lean in SD flows, readers are referred to Sect. 4.2.6.

4.3.3 S&OP KPMs Related to Commitment Driven (CD)

In the CD flow, the customer orders are known when the transformation is performed (Wikner and Noroozi 2014). This manufacturing strategy is called make-to-order and very often is related to agility concept (see e.g. Mason-Jones et al. 2000). In an agile supply chain, the total lead-time should be minimized (ibid.). The CD KPMs are gathered in Table 9.

4.3.4 Sustainable KPMs Related to Commitment Driven (CD) at S&OP Level

Environmental and social categories of sustainability are not much reflected in the literature for this specific driver.

5 Analysis

In this section the strategic aspects of and competitiveness each dimension of the typology is discussed in order to gain a better understanding about the connection between S&OP level KPMs and the strategic objectives of the dimensions. Next, the dimensions are combined in the typology in order to scrutinize the cross hybridity in each module and its influence on the strategic aspects of each module.

The SKPMs are discussed separately in Sect. 5.3 and in line with Table 2. The reason is that, as mentioned earlier, the SKPMs are not further related to the five PAs in the SCOR model, with the exception of percentage of scrap/waste immediately reused in the production process which is classified under assets (Supply Chain Council 2012). It should be mentioned though that sustainable practices are usually considered to have a positive influence on the companies' performance such as increased profit and market share (see e.g. Ahi and Searcy 2015).

5.1 Strategic Aspects of the Dimensions

In this part, the relation between the S&OP-related KPMs and the PAs, correspondingly tactical and strategic levels, of each DC is scrutinized. The S&OP-related KPMs, which have been linked to the SCOR model's PAs in the previous section, are compared with the strategic aspects and competitiveness of each decision domain of the typology in order to earn a better understanding about each domain and their KPMs. To do so, first each decision domain is studied in order to distinguish which competitive priorities are important for it based on the domain's characteristics. These competitive priorities are explained through PAs. These priorities are then compared to the first columns of Tables 3, 4, 5, 6, 7, 8 and 9 in order to study how they are compatible, recognize which PAs are under focus in each domain and consequently, which KPMs should be emphasized.

5.1.1 Strategic Aspects of Object Type

The DO KPMs gathered in Table 3 reflect all different attributes. The reason is that the table contains all generic S&OP KPMs and S&OP usually is considered as a generic process which fits all types of industries employing various strategies

(Noroozi 2014). So these KPMs are general and would help all types of companies to stay in business.

In the CO flow, the main focus is usually on cost reduction and product availability since in this domain, usually specialized equipment is used and continuous production is deployed (Taylor and Bolander 1994) and use of level production is preferable (Olhager et al. 2001). This is associated with having few products, low work-in-process and high finished goods inventory, and high utilization (ibid.). Therefore, three out of five SCOR's PAs, i.e. reliability, cost, and assets are of strategic importance. The importance of these strategic aspects is in line with our findings represented in Table 4. Considering Table 4, cost, high inventory level of finished goods, short delivery lead-time and high capacity utilization are emphasized. Yield variability is important for some of the industries, dealing with CO and continuous production, such as oil and steel industry but not for all (Noroozi 2014). The two responsiveness KPMs i.e. set-up time and manufacturing lead-time might not directly be important strategically; however, they are important KPMs in this domain due to their effect on inventory level and cost. Long set-ups lead to larger batches and hence longer manufacturing lead-time which in turn leads to higher inventory and cost. Thus, the findings from Table 4 are in line with the importance of high utilization and resource management in the presence of CO (mainly applicable in process industries) as emphasized in the literature (see e.g. Noroozi 2014, Taylor and Bolander 1994; Fransoo and Rutten 1994).

5.1.2 Strategic Aspects of Control Mode

In the OM flow, according to many authors, the main focus is to meet the project goals regarding cost, time and quality (see e.g. Shenhar et al. 2001; Srivannaboon and Milosevic 2006) which are related to reliability and cost in the SCOR model. This is in line with our findings from the literature review presented in Table 5. Considering Table 5, it can be noticed that almost all KPMs are related to cost and reliability as well. Lead-time is usually very long (Jacobs et al. 2011) in OM which is also related to reliability and is included in the time aspect of project planning. Quality has a two-sided effect. On the one hand, it's related to the reliability aspect and on the other hand, it affects the future business opportunities and market share of the company which are vital for all businesses (Shenhar et al. 2001; Mir and Pinnington 2014). Another important input from Table 5 is resource management, which is related to assets. However, considering the limited time and budget of a project, the resource management has a direct impact on customer actors, the cost as well as reliability.

The IM flow is equivalent to campaign/batch production (Wikner and Noroozi 2014). The KPMs from Table 6 are focused on responsiveness and agility. The important factor in this mode type is the set-up time which affects the batch sizes and thus, the cycle time which in turn influence the manufacturing lead-time, the inventory level (Fransoo 1993) and customer satisfaction. Therefore, the reliability aspect is indirectly affected by the KPMs mentioned in Table 6. As mentioned in Sect. 4.2.3, chase production is recommended in IM flow which is in line with lead strategy (Olhager et al. 2001). According to Olhager et al. (2001), one way to achieve lead strategy is keeping excess capacity which provides flexibility and agility and in turn improves the responsiveness and customer satisfaction but has a negative effect on assets.

The CM flow implies an environment similar to lean. Lean concept is mainly focused on waste reduction including reduced defects, inventory, overproduction, over-processing, transportation, waste of talents, waiting time and motions (Liker 2004). Strategically, lean is focused on cost reduction, delivery performance and efficiency (Dougherty and Gray 2006) but it suffers on flexibility and responsiveness to customer actors especially in facing volatile demand (Carvalho et al. 2011). As can be noticed, the KPMs from Table 7 are also mainly focused on reliability and assets. Agility has not been emphasized in Table 7 and this is in line with other sources in the literature such as Christopher and Towill (2000), Mason-Jones et al. (2000), Olhager (2003) and Carvalho et al. (2011). These authors believe that lean is strategically focused on cost which is not in line with the agility purpose of service and customer value enhancement (ibid.). Set-up time reduction improves the lead-time which in turn increases reliability. Maskell and Baggaley (2004) emphasize several cost related KPMs such as material and production cost, net profit and return on sale which emphasize the importance of cost as an strategic issue for these companies; however, it can be argued that these KPMs are important for all types of industry. This is why the cost related KPMs are not included in Table 7.

5.1.3 Strategic Aspects of Flow Driver

In SD flows, the production is based on the speculation of customer demand (Wikner and Noroozi 2014) which in turn emphasizes the importance of forecast accuracy. According to Olhager et al. (2001), SD flow should deal with very short lead-time and usually deploys level production and lag strategy. The products are then kept in the inventory for further transformation or to be directly delivered to the customer actor, thus the inventory levels and product availability would be important KPMs for this domain (Wallace and Stahl 2008). The products produced based on speculation are usually standard/commodity, which together with level production and high utilization, imply the importance of low cost. Therefore, although the results of our literature review presented in Table 8 covers most of the SCOR performance attributes, the strategic focus of SD flow is on cost (Mason-Jones et al. 2000; Christopher and Towill 2000), reliability and assets. These strategies are in line with strategies mentioned for CM and lean concept (see Sect. 5.1.2) and as mentioned earlier, the lean KPMs are also applicable in the SD flow.

CD flows, on the other hand, deals with production based on customer order implying short delivery lead-time and so flexibility and fast delivery are strategically important (Olhager 2003). In order to meet the customer needs and achieve high service level, the CD flow usually follows chase production and lead strategy meaning that in this domain, adequate surplus or cushion capacity should be maintained (Olhager et al. 2001; Christopher and Towill 2000). Order backlog and work-in-process are important measures for CD since they affect the lead-time and competitiveness of companies (Dougherty and Gray 2006). The results of Table 9 emphasize reliability, agility and responsiveness. Literature sources emphasize the importance of agility and responsiveness for the CD flow as well (Mason-Jones et al. 2000; Olhager 2003).

5.2 *Analysis of the Typology Modules and Managerial Insights*

Gathering all the information mentioned in Sect. 5.1 for each dimension and positioning them in the typology in order to study the cross hybridities (see Sect. 3.4), results in some strategic conflicts in some of the modules as presented in Table 10. In line with the literature on competitive strategy (see e.g. WheelWright

Table 10 Analysis of the typology modules based on DCs and SCOR PAs

		Speculation driven (SD) (Table 7)	Commitment driven (CD) (Table 8)
Onetime mode (OM) (Table 4)	Continuous object (CO) (Table 3)	–	–
	Discrete object (DO) (Table 2)	–	Module 1. OM and CD (Reliability, responsiveness and agility)
Intermittent mode (IM) (Table 5)	Continuous object (CO) (Table 3)	Module 2. CO, SD (Reliability, cost and assets) icw.* IM (Responsiveness and agility)	Module 3. CO (Reliability, cost and assets) icw. IM, CD (Responsiveness and agility)
	Discrete object (DO) (Table 2)	Module 4. SD (Reliability, cost and assets) icw. IM (Responsiveness and agility)	Module 5. IM and CD (Reliability, responsiveness and agility)
Continuous mode (CM) (Table 6)	Continuous object (CO) (Table 3)	Module 6. CO, CM and SD (Reliability, cost and assets)	Module 7. CO and CM (Reliability, cost and assets) icw. CD (Responsiveness and agility)
	Discrete object (DO) (Table 2)	Module 8. CM and SD (Reliability, cost and assets)	Module 9. CM (Reliability, cost and assets) icw. CD (Responsiveness and agility)

*icw: in conflict with

1984; Porter 1985; Hallgren and Olhager 2009), the conflicts happen when reliability, cost and assets which are primarily focused on decreasing the cost through economy of scale and high utilization (also referred to as cost-leadership strategy by Porter 1985), are present at the same module with responsiveness and agility which are focused on fast response to the customer actors at (probable) higher costs (referred to as differentiation strategy by Porter 1985). Note that the modules numbers in this table are in line with Fig. 1.

As mentioned earlier, DO covers all PAs and thus is not influential in Table 10. As can be seen in Table 10, in module 1 the strategies are in line since OM mainly implies production of discrete products, such as buildings, based on specific customer orders (Hill and Hill 2009). In this module, not only meeting the budget goals (see e.g. Shenhar et al. 2001) but also reliability regarding the lead-time are essentials (see e.g. Carvalho et al. 2011; Marques et al. 2011). In module 5 as well production of DOs in batches according to customer orders is a common practice. Both IM and CD emphasize responsiveness and agility (see e.g. Olhager and Rudberg 2002; Mason-Jones et al. 2000) which in turn have positive effect on reliability measures.

In a similar way, modules 6 and 8 have in-line strategies since CM is compatible with the speculation driven flow for both CO and DO due to the importance of high utilization of the facility which is in line with the importance of assets and its influence on cost (see e.g. Taylor and Bolander 1994; Maskell and Baggaley 2004; Berry and Hill 1992). On the other hand, the conflict arises in modules 2, 3, 4, 7 and 9 (shown by gray in the table) when reliability, cost and assets contradict agility and responsiveness as specified in Table 10. The reason is that companies either compete on low cost or differentiation in the market (Porter 1985; Hallgren and Olhager 2009). Taking module 3 as an example, reliability, cost and assets are strategically important mainly for CO (Taylor and Bolander 1994) and responsiveness and agility are important for IM and CD (Olhager and Rudberg 2002; Mason-Jones et al. 2000). This illustrates a strategic mismatch or conflict for this module. The conflict arises since agility and responsiveness strategies usually emphasize on decreasing the lead-time through practices such as keeping capacity cushions (Olhager et al. 2001) which implies higher cost while the reliability, cost and assets strategies usually aim to decrease the cost through high utilization and longer lead-time. Thus, in modules 2, 3, 4, 7 and 9 more information is required to decide about which strategy is the most vital for that specific module for the company and accordingly, which KPMs should be used in order for the company to achieve its competitive goals with regards to each module. It depends on the customers' expectations of lead-time and cost, companies' competitive objectives to fulfill the customers' expectations as well as the competitive pressures (Hallgren and Olhager 2009). It should be noted that each module needs its own KPMs which can be different from what is required in another module within the same company. This approach has been emphasized by other researchers such as Neely et al. (1995), Van der Veeken and Rutten (1998) and Wallace and Stahl (2008) as well. In line with Giesberts and Tang (1992), the combination of different measures and management styles in different modules enable the companies to keep their competitiveness.

5.3 Analysis of Sustainable Key Performance Measures (SKPMs)

As mentioned in the literature review, the relation between the SKPMs and the companies' performance is not well-defined in the literature and a consensus has not yet been reached. The SCOR model totally separates the green KPMs and does not study their relation to the PAs (Supply Chain Council 2012). In addition, the SCOR model does not include the social aspect of sustainability.

Carter and Rogers (2008) put forward a different approach and suggest that activities at the intersection of the three categories of sustainability are the ones that can improve the companies' environmental and social performance while also can result in long-term economic benefits. They also mention that to achieve these benefits, companies should incorporate the three categories of sustainability in their strategic objectives and decision-making processes (ibid.). One of the main attempts in linking SKPMs to companies' strategic objectives is through the balanced scorecards. Figge et al. (2002) suggest three different ways to integrate sustainability into companies' strategy: (a) integration of environmental and social aspects in the four balanced scorecard perspectives, (b) introduction of the non-market perspective to balance scorecard, (c) a mixture of both. Reefke and Trocchi (2013) follows the work of Figge et al. (2002) and add some of the SKPMs with direct relations to competitive advantages under the four perspectives of the balanced scorecard such as recruit and training cost and revenue growth under financial perspective, quality under customer perspective, increased productivity under internal process perspective, and employees satisfaction under learning and growth perspective. The SKPMs with indirect effects are then classified under non-market perspective such as reduced emissions and better working conditions (ibid.). These papers are, however, generic and do not reflect the specific characteristics and the strategic preferences of the supply chain modules.

Considering the classification suggested in the current paper (see Table 2), it can be noticed that some of the DCs have stronger influences on the SKPMs which can be used in each domain. For example, in relation to the object type, there are several SKPMs specifically related to environmental sustainability defined for process industries (related to CO and continuous production) in e.g. ICHEME (2002). Some of the reasons for this specific attention can be the position of process industries in the supply chain and in relation to natural resources, production of co-/by-products (Taylor and Bolander 1994) and also involvement of chemicals in different types of process industries such as refineries, specialty chemicals and pharmaceutical industry. Regarding control mode and flow driver, the application of lean is vastly discussed in the literature in relation to mainly environmental and rarely social sustainability, in cases where continuous mode and/or speculation driven flow are used. The relation between lean and green can be different in various environments. Set-up time reduction is one of the focus areas of lean which leads to lower cost and better quality and thus lower waste level which consequently improves the environmental performance of the companies (Hajmohammad et al. 2013). The set-up time reduction also leads to lower inventory level which is supposed to decrease the emission level but it is not always the case. The reason is that the frequency of replenishment increases instead in order to keep a high service level and this can increase the supply chain emissions (ibid.). The relation between lean and social sustainability is also controversial. On the one hand, lean has a positive effect on employees' health and safety due to job variety, improved ergonomics, team work, increased responsible autonomy (Martínez-Jurado and Moyano-Fuentes 2014) and cross training (Maskell and Baggaley 2004; Diego Fernando and Rivera Cadavid 2007). On the other hand, some authors suggest that the stress is higher in a lean environment since the work is more intense and monotonous (Martínez-Jurado and Moyano-Fuentes 2014). Specific environmental and social KPMs were not found in relation to the other domains.

Table 11 illustrates to what extent the impact of sustainability measures was identified in the literature for the typology modules with regard to the framework presented in Table 2. If according to the section numbers mentioned in Table 11, a module is based on decision domains which are all influential from sustainability point of view, then a "***" (white) is assigned to that module, see modules 6 and 8. If none of the decision domains are influential then a "*" (medium gray) is assigned to the module, see modules 1, 3 and 5. If two of the decision domains are

Table 11 The impact of sustainability on the typology modules

		Speculation driven (SD) Section 4.3.2	Commitment driven (CD) Section 4.3.4
Onetime mode (OM) Section 4.2.2	Continuous object (CO) Section 4.1.4	N/A	N/A
	Discrete object (DO) Section 4.1.2	N/A	Module 1. *
Intermittent mode (IM) Section 4.2.4	Continuous object (CO) Section 4.1.4	Module 2. **	Module 3. *
	Discrete object (DO) Section 4.1.2	Module 4. **	Module 5. *
Continuous mode (CM) Section 4.2.6	Continuous object (CO) Section 4.1.4	Module 6. ***	Module 7. **
	Discrete object (DO) Section 4.1.2	Module 8. ***	Module 9. **

sustainably effective then a "**" (light gray) is used, see modules 2, 4, 7 and 9. And finally, the three dashed "modules" of Fig. 1 are indicated with N/A in Table 11. It can be concluded from Table 11 that when CM and SD (related to lean) are deployed with either CO or DO, there are issues discussed in the literature that should be handled with regard to sustainability. But for OM, IM and CD, not much influences have been found in the literature.

It should be noted that other types of analysis can also be used for environmental and social measures such as stakeholder theory or other organizational theories (see e.g. Figge et al. 2002) but these theories are not in the scope of the current paper.

An example is provided in the next section in order to explain how the framework presented in Table 1 in combination with Table 10 can help the companies to choose the relevant KPMs.

6 Application of the Classification

This part illustrates how the framework suggested in this paper can be used to design a performance measurement system. For clarification, an example of the production of metal cutting tools is used. The metal cutting tools are mainly made of cemented carbide. The main raw material being used is Ammonium-Para Tungstate (APT) which goes through a process of dissolutions, precipitations and separations. Pure tungsten powder is obtained from the hot reduction of the APT in hydrogen. Tungsten is then mixed with carbon and heated at high temperature in hydrogen in order to obtain tungsten carbide powder. Tungsten carbide is mixed with binder Cobalt and then the mixture is wet milled. The milling process affects the grain size and homogeneity of the slurry. The slurry gets dry through a spray-drying process where the tungsten carbide powder is formed. This powder is pressed into compacts in the compaction process. The compacts are machined or green shaped into a proper shape if required and then are sent to the sintering process where the cemented carbide obtains the properties of a high strength material. The compacts are usually sent to machining process and then shipped.

The production is batch-wise. The products are mainly make-to-stock but the company also produces some product families according to customer order. The make-to-order products are the focus of our example.

The first step to choose which KPMs should be used is to configure the production process of the company according to the typology suggested by Wikner and Noroozi (2014). Comparing the production process to the typology, it can be noticed that DDP is positioned at the compaction process where the powder turns into compact. Since the same mode is applied throughout the flow there is no CMDP positioned in the flow and the whole production is batch-wise (IM). The CODP is positioned at the inventory, located between the supplier actor and the focal actor, in line with the make-to-order strategy. Thus the company deals with modules 3 and 5 i.e. CO-IM-CD and DO-IM-CD respectively, see Fig. 2. Module 2 shown in Fig. 2 is related to the supplier actor where the main raw material is ordered on speculation and batch-wise.

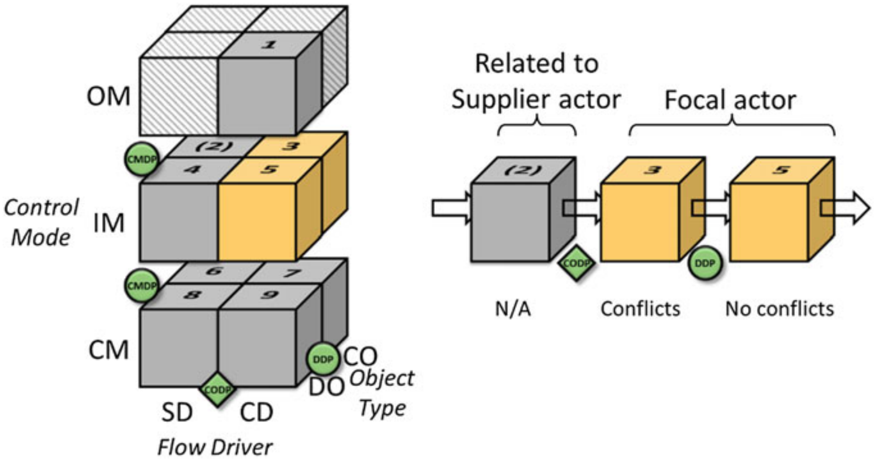

Fig. 2 The module based model of the tooling company

This module is related to purchasing and the control boundary of the company. Thus it is not in the scope of current paper and is excluded from the discussion here.

Referring to Table 10, it can be noticed that in module 5 the strategic directions are in line and there is no conflict between them but module 3 represents conflicts. Therefore, for module 5 the KPMs from Tables 2, 5 and 8 can be chosen and they are strategically aligned since reliability, responsiveness and agility emphasize a fast response to the customer actors which implies that customer actors care more about delivery lead-time rather than mere low costs. For module 3 the choice of KPMs is not as straightforward since CO emphasizes reliability, cost and assets which value low cost through high utilization while IM and CD focus on responsiveness and agility which emphasize shorter lead-times through increased flexibility. Still a combination of Tables 3, 5 and 8 can be used but depending on the company's strategy towards its customer actors, i.e. if the company competes on low cost or on agility and responsiveness, they can decide which KPMs are strategically of higher importance for them.

Since the SKPMs cannot be discussed in relation to PAs, they are excluded from the discussion here.

7 Conclusion and Further Research

The aim of this paper is to suggest a new classification of the S&OP level KPMs according to a decoupling point based typology. The reason for selecting this typology is to provide a foundation for selecting the KPMs based on the specific requirements of each module of the supply chain in relation to the DCs and PAs as presented in Table 1. The suggested classification can be used to fill the gaps in the literature in relation to the need for different performance measures in different locations and/or supply chain segments at S&OP level. Some KPMs are suggested to show how the classification can be used. However, an extensive literature review is required in order to gather all the KPMs and place them in the framework.

The sustainable KPMs related to all three categories of sustainability are suggested in this paper and classified according to the framework presented in Table 2. The main focus of the sustainability in the literature has been on economic and environmental categories and the social category has been lagging behind. Where present, the social KPMs are mainly related to employees' health and satisfaction. Within the environmental-related literature, our results show that it is not easy to find the measures' classifications based on the managerial levels. On the other hand, the literature on S&OP topics usually does not include environmental and social measures. The framework presented in this paper (see Table 2) addresses this gap by suggesting SKPMs at the S&OP level. This is however only a first step and more studies are required in this area.

Another contribution of this paper is to relate the suggested S&OP KPMs to the strategic goals of the companies. To the best of our knowledge, previous works have not addressed this issue directly even though the vertical integration in the companies has been emphasized to a large extent. To fill this gap, the five PAs of the SCOR model have been used and the KPMs are linked to these attributes, as illustrated in Table 1. Demonstrating these links is of particular importance at S&OP level since S&OP has the role of connecting the strategic and operational plans of the companies. S&OP also receives the managerial directives from the strategic planning level and provides feedback to it, thus S&OP is closely connected with the strategic level. The study of the links between KPMs and PAs shows conflicts in some of the modules as presented in Table 10 which require specific attention. Table 11 shows how sustainable KPMs affect each module of the typology according to the literature. However, the relation between SKPMs and the PAs is not well-defined since even the SCOR model itself separate part of these performance measures under GreenSCOR and does not link them directly to reliability, responsiveness, agility, cost or assets. Social category is not included in the SCOR model either. Extensive research is required in this field to link the SKPMs to PAs as well as to study the influence of cross hybridities on sustainability measures.

Further research is needed on the use of KPMs in practice as well. The empirical inputs would strengthen the selection of different KPMs for different modules of the typology, especially when there is conflict of interests. In addition, areas such as supply chain partners, purchasing, transportation, reverse logistics, and the sub-categories and aspects of the GRI excluded from the current paper provide further opportunities for research.

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