

Unlocking the potential of process innovation: a conceptual framework for the exploitation of advanced manufacturing technologies

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Abstract

This paper aims at providing a holistic understanding of the determinants that influence the realization of benefits of new manufacturing technologies. Based on findings from operations management and strategic decision-making literature, we propose a framework that explicitly distinguishes between the phase of decision-making and the phase of implementation of advanced manufacturing technologies. Based on a broad literature review, contingency factors are presented and related to each phase of the process model.

Keywords: Advanced Manufacturing Technologies (AMT), Decision Making, Implementation

Introduction

Global manufacturers experience increasing competitive pressure, due to cost pressure from manufacturers in developing countries, rapidly changing customer demands and demanding legal requirements. Additionally, the paradigm shift from standardized big scale manufacturing to flexible low-volume manufacturing during the last 20 years is still prevailing and forces manufacturing divisions to constantly adopt advanced manufacturing technologies (AMT) and new management practices. Several studies have shown that integrated manufacturing (IM), consisting of Total Quality Management (TQM), Just in Time (JIT) and AMT leads to superior performance (Challis et al., 2002, Cua et al., 2001). As for the purpose of this paper more relevant, also the relationship between investments in AMT and performance has been well documented and empirically tested (Idris et al., 2008; Kotha & Swamidass, 2000; Swamidass & Kotha, 1998). The vast body of literature provides evidence that new manufacturing technologies are important for the success of manufacturing companies, but it also recognizes that most firms are not able to fully realize their expected benefits of AMT. Thus, the question is how this shortcoming can be overcome.

The first attempt to do so is done in this paper as it aims at providing a conceptual framework for the effective adoption of new manufacturing technologies. Based on literature review and experiences from discussions with several managers of Swiss manufacturing firms, we try to give a holistic picture of determinants that influence the effective and efficient application of new manufacturing technologies. To do so, we provide theoretical background why new manufacturing technologies contribute to the competitive advantage of a firm by incorporating the resource-based view (RBV) and

the concept of dynamic capabilities to explain superior performance in dynamic environments. Our goal is to contribute to the operations management field by extending existing literature on advanced manufacturing technologies. Therefore this paper makes a threefold contribution: First, we propose a conceptual framework of technology adoption that consolidates findings of existing literature on AMT as well as linking the operations management literature to the concept of dynamic capabilities as proposed by Teece (2007). Second, we explicitly take into account the different characteristics of different phases of the technology adoption process. By dividing the process into a decision phase in which the decision about a potential adoption of a certain technology is made, and an implementation phase in which the respective technology is implemented within the firm. We claim that these two phases have distinct characteristics that lead to different determinants for the success of each phase. Researchers as well as managers should take this into account to better understand the influencing factors for technology adoption. Third, we suggest a more detailed picture of performance gains by new manufacturing technologies by explaining how operational performance mediates the relationship between technology adoption and organizational performance.

Therefore, the literature on RBV and dynamic capabilities will be reviewed in the next section with regard to the relevance of the theoretical framework for the application of new manufacturing technologies. Afterwards, we will describe the model and develop a set of testable propositions. The concluding section will shortly discuss the expected results from proposition testing and point to some limitations that are inherent to the paper.

The resource-based view and dynamic capabilities

The ultimate ambition in the strategy field is to find an explanation why some firms perform better than others (Rumelt et al., 1991). For this attempt, the RBV has become one of the most influential views in the strategic management literature. According to the RBV, competitive advantage can be attained by controlling of unique resource bundles which are valuable, rare, inimitable and non-substitutable (Barney, 1991).

As the RBV approach is inherently static, the explanatory power of this theory has limitations in explaining how firms in dynamic environments can gain sustainable competitive advantage over time (Teece, 2007). To overcome this shortcoming, the concept of dynamic capabilities introduces a notion of organizational renewal, as managers need to constantly alter resource and capability configurations within an organization to adapt to environmental change (Helfat & Peteraf, 2003). Hence, dynamic capabilities are defined as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organization's ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions" (Teece et al., 1997: 516). It is important to mention that superior organizational performance is not caused by dynamic capabilities as such, but from the resource configurations that are resulting from the use of dynamic capabilities. Dynamic capabilities are hence necessary, but not sufficient for competitive advantage and one has to distinguish between dynamic capabilities and their outcomes (Eisenhardt & Martin, 2000).

Superior manufacturing competence is a central source of competitive advantage for manufacturing firms and the underlying production technology is an essential part of this competence. Manufacturers can differentiate from competitors by achieving cost efficiency, quality, flexibility, and lead time reduction without trade-offs (Sun, 2000). Rapid technological change and fast shifting customer needs force firms to constantly

discover and develop opportunities like the effective and efficient transfer of manufacturing technologies into the value chain of the company (Teece, 2007). With regard to new manufacturing technologies, the selection and development of the right technology is an important task to achieve organizational fit with the environment. The ability to manage this integration and to adequately adapt production processes exhibits a substantial dynamic capability of a manufacturing firm, which can be seen as the assembling and orchestrating of difficult-to-orchestrate assets (Teece, 2007). The competitive advantage itself is generated by more efficient and effective production processes caused by the implementation of a new manufacturing technology in combination with complementary assets like manufacturing practices of TQM, JIT, etc. (Cua et al., 2001). The simultaneous organizational transformation (Leonard-Barton, 1988) and the development of routines (Teece, 2007) are major prerequisites to fully exploit the benefits of new production technologies.

Conceptual Framework

The aim of the theoretical framework is to provide a holistic picture of the factors that influence the effectiveness and efficiency of adoption processes of new manufacturing technologies. According to Noori (1990), we define AMTs as new technologies which are used directly by the firm in the production of a product. Thus, our definition of AMT is broader than those of many other authors who define AMT as computer-controlled process technology (Idris et al., 2008; Swamidass & Kotha, 1998; Sun, 2000; Zammuto & O'Connor, 1992) or at least a technology that integrates any kind of information technology (Dean & Snell, 1996). Although we recognize that most of today's innovative manufacturing technologies meet this definition, we claim that the involvement of information technology is not a necessary condition as the framework should hold true also for manufacturers in developing countries and manufacturing companies that produce for niche markets, who might deliberately apply production technologies which are not IT-based. Other authors distinguish hard-based from soft-based AMTs (Sun, 2000). Hard-based AMT refers mainly to physical technologies used in engineering, processing and administration, while soft-based AMT covers Total Quality Management (TQM) and Just In Time (JIT). We understand those so-called soft-based AMT rather to be a management practice by which AMTs are accompanied and follow recent operations management literature (Ketokivi & Schroeder, 2004; Cua et al., 2001).

In the past, most manufacturing companies have implemented any sort of AMT. However, research found that "not all AMT perform as expected. Some AMT perform very bad and leads to a total failure. Some AMTs perform "satisfactory", but did not produce the full benefits. Other AMTs perform well on the shop floor level, while the business performances of the companies were not improved" (Sun, 2000: 632). Although recent work has sharpened the understanding how to successfully implement new technologies, we believe some still existing inconsistencies in research findings could be resolved by providing a more fine-grained model of technology adoption. Dividing the adoption process of technologies in separate process steps of decision-making and an implementation phase copes with differing characteristics of those sub-processes.

Although many contingencies have been identified that influence the performance when firms adopt new manufacturing technology, the central question rests unsolved, namely whether the insufficient benefits should be traced back to an unsatisfying decision for a certain technology, or if the implementation of the right technology failed.

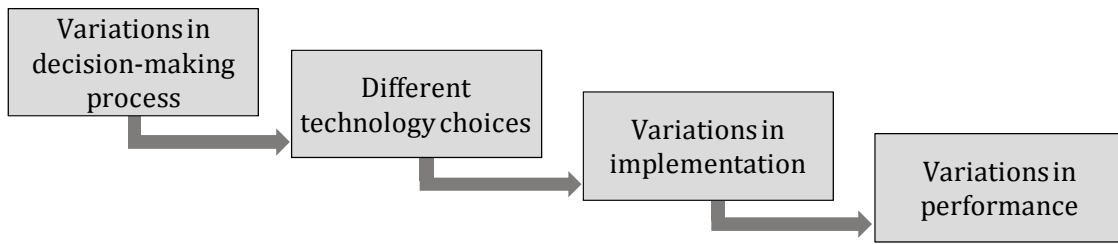


Figure 1 - Assumptions underlying the technology adoption process

Research in strategy process has already recognized this problem and developed two separate research streams on strategic decision making (Eisenhardt & Zbaracki, 1992) and strategy implementation (Rapert et al., 2002). A strategic decision is defined as one which is "important, in terms of the actions taken, the resources committed, or the precedents set" (Mintzberg et al., 1976: 246). The underlying assumption is that variations in the decision making process lead to different strategic or technology choices (decision effectiveness). Different technology choices lead to variations in the implementation phase and both, decision making for and implementation of a technology, determine the outcome (performance) of the technology adoption (Dean & Sharfman, 1996). Thus, we hypothesize that a model, which explicitly takes the two different phases of decision making about a technology and implementation of a certain technology into account has more explanatory power than existing models that do not so.

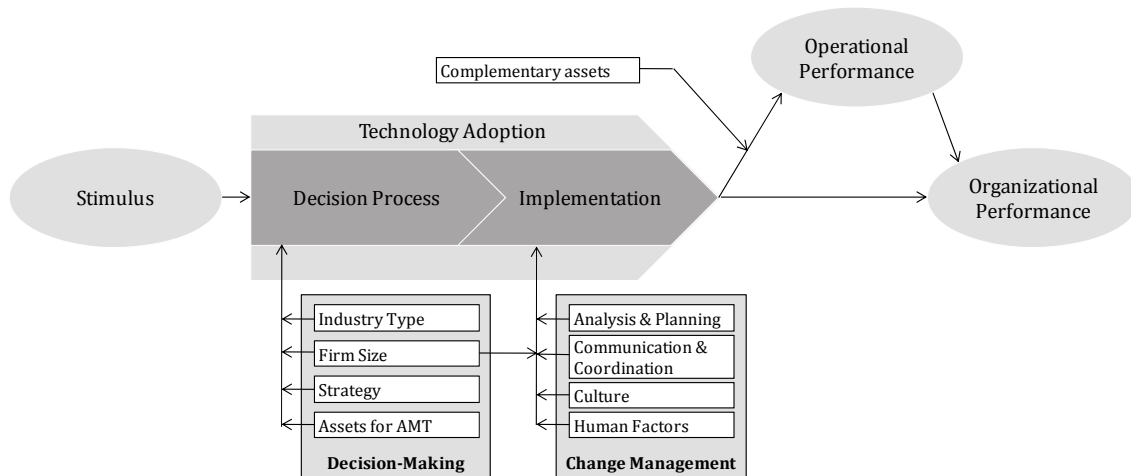


Figure 2 - Conceptual Framework for Manufacturing Technology Adoption

The decision-making process requires scanning of the environment, the collection of relevant information, alignment of the technological alternatives with business strategy and the analysis and evaluation of those alternatives, the process shows typical characteristics of strategic decision-making (Hough & White, 2003). In contrast to that, the implementation phase of manufacturing technologies is characterized by typical change management attributes including a straight project management and planning, consideration of human and emotional factor, therefore securing good communication with all stakeholders that are affected by the technological change (Cakar et al., 2007; Siegal et al, 1996). In addition, the decision and the implementation of a technology often involves different people, because varying competencies are needed, which also reflects the different characteristics of both tasks. Therefore we consider the following influencing factors that are divided in four decision-making influencing factors and four change management influencing factors:

Industry type

We propose the industry type to have influence on the decision making process whether to adopt new manufacturing technologies or not. Industries that are characterized by high competitive pressure are more apt to adopt new manufacturing technologies as effective and efficient manufacturing processes are a mandate for firm survival. Additionally, regulatory standards in the pharmaceutical industry or the food industry might restrict certain process innovations and hence, also limit the possibility to introduce new manufacturing technology. Due to this argumentation we propose:

P1a: Firms in high competitive industries have a higher propensity to implement new manufacturing technologies than firms in industries with low competition.

P1b: Firms in highly regulated industries have a lower propensity to implement new manufacturing technologies than firms in low regulated industries.

Firm Size

Reichstein & Salter (2006) found empirical support that firm size has a significant effect on process innovation. Swamidass and Kotha (1998) showed that AMT use and firm size are linearly correlated, which is supported by Sohal et al. (2006) who found a positive and significant direct effect of company size on the adoption of AMT. An interesting finding is presented by Gupta and Whitehouse (2001). First, they take into account that technology might lead to a decrease of plant size caused by increased automation at the expense of labor force. Second, they find support that smaller firms get better performance from technology implementation, but their results also indicate that the size of the firm does interact favorably with the AMT strategy. This corroborates our argument that the phase of technology implementation should be separated from the decision phase as the effect of firm size on the strategic decision to adopt a technology differs from the effect on the implementation of a technology. On the one hand, bigger firms have more resources to identify new technological opportunities and invest in AMT. On the other hand, larger organizations tend to be more complex than small ones which makes the implementation of technology and the integration into complex process more difficult (Swink & Nair, 2007). Hence, we assume:

P2a: Firm Size is positively correlated with the propensity of a firm to implement new manufacturing technologies.

P2b: Firm Size is negatively correlated with the implementation efficiency of new manufacturing technologies.

Strategy

New production technologies need to be in line with the business strategy of the organization and the manufacturing strategy should be linked to the marketing strategy to gain better performance (Small & Yasin, 1997). Reichstein and Salter (2006) found that firms with a clear product development strategy are in a better position to achieve radical process innovation. In contrast to that, firms that pursue AMT mainly for cost reduction purposes will be less apt to invest in AMT. The benefits of AMT like increased flexibility, higher quality, reduced lead time and time-to-market are often rather intangible. Thus, managers who consider AMT purely as a means for continuous improvement and cost savings and do not see a strategic value beyond efficiency gains will underestimate the real value of AMT and thus, will be more reluctant to invest in AMT (Swink & Nair, 2007). This is in line with the argumentation of Kotha and Swamidass (2000) and Sohal et al. (2006) who stress the need to consider a

multidimensional view of AMT performance. Managers will only make decisions that require high investments and are often irreversible - like the adoption of AMT, if they are really aware of the real strategic benefit of AMT.

P3a: Companies that recognize the strategic value of AMT and connect manufacturing strategy with business strategy will invest more in AMT.

Strategic decisions like investments in new manufacturing technologies also depend upon the people who make these decisions and their personal characteristics (risk aversion, enthusiasm). Getting the right people into the decision making process is an important task and is necessary to choose the appropriate technology. Several studies found that the participation of manufacturing managers in the strategic investment decisions of new manufacturing technologies has a positive effect on performance and competitive capabilities (Brown, 2001, Tracey, 1999). Thus, we assume:

P3b: The involvement of manufacturing managers in the decision process is positively correlated with decision effectiveness and consequently with performance.

Assets for AMT

According to Sohal et al. (2006), the "assets for AMT represent the AMT knowledge base of firms". The adoption of AMT is path-dependent on the competences of a firm to adopt new technologies, which requires the accumulation of human assets. Thus, the adoption of AMT is a learning process and correlates with prior efforts of a company to integrate new manufacturing technologies. In line with Sohal et al. (2006) we argue that getting in the position to develop adequate technology alternatives requires firms to allocate a suitable amount of resources to install structures and routines that help to identify available technologies. Furthermore, the effective analysis, evaluation and selection of technology alternatives is a firm specific capability, which is subject to organizational learning. Experience about the right decision criteria and performance measures as well as methods like technology scouting, roadmapping, etc. are capabilities that have to be learned and help firm in the adoption of AMT (Small & Yasin, 1997). This leads us to the following propositions:

P4a: The resource dedication of firms for developing AMT alternatives is positively correlated with decision effectiveness of AMT decisions.

P4b: Firms that already use structures and routines for AMT have an increased propensity to invest in AMT.

Analysis and Planning

Slagmulder and Bruggeman (1992) observed that companies that did not pay enough attention to technical and organizational aspects in the a priori analysis experienced more transition problems during the implementation phase. Small and Yasin (1997) provide empirical evidence that firms exerting higher effort on pre-installation and planning activities during the implementation phase achieve higher levels of performance. Udo and Ehie (1996) also mention that system planning and integration are determinants of implementation success. Thus, it seems that the success of the technology implementation phase is rather characterized by analysis and planning efforts, which suggests that the implementation phase is far better predictable compared to the decision phase. Thus, we assume:

P5: Firms that make more effort on analysis and planning during the implementation phase are more successful in AMT implementation.

Communication and Coordination

Udo and Ehie (1996) identified communication as a key element in successful implementation of JIT. They also found that effective communication at the individual, inter-group and intra-group levels can have a major influence on AMT implementation. Sohal et al. (2006) found empirical evidence for a second-order factor *adoption of AMT construct* that comprises a factor *communication and commitment*. Boyer et al. (1997: 333) found soft integration, "which focuses on facilitating communication among different functions and workgroups" to be a moderator for increased performance due to AMT. Proper project management, which is part of coordination, is found to be a critical success factor for the implementation process of strategic manufacturing initiatives (Minarro-Viseras et al., 2005). Especially a team-based project management approach, which is appropriate to facilitate cross-functional communication was empirically validated to be the most critical for implementation and performance of AMT (Small & Yasin, 1997). That is why we propose the following:

P6: Communication and Coordination activities are positively correlated with implementation success.

Culture

Besides the physical and organizational closeness, also the cultural closeness between user and producer of a technology is important for the successful implementation of AMT (Gertler, 1995). Several author have pointed to the importance of organizational culture for technology adoption (McDermott & Stock, 1999; Zammuto & O'Connor, 1992). We adopt the competing values framework from McDermott and Stock (1999), which is separated in two dimension, each with two opposing value orientations. The first dimension is the flexibility-control axis with focus on change or stability, the second dimension is the internal-external axis, separating activities occurring within or outside the organization. Along the whole technology adoption process, a flexibility accentuating culture is favorable as new technologies and processes always require to move away from well established routines. Additionally, especially during the decision phase when scanning of the environment and scouting for technological developments is important, an external oriented culture is supportive, whereas the implementation is rather inside-orientated. This reasoning leads to the following propositions:

P7a: Firms with a flexibility orientated organizational culture have a greater propensity to invest in AMT and are more successful in implementing it.

P7b: An external orientated organizational culture is especially favorable in the strategic decision phase about technology investments.

Human Factors

Although literature always reports of organizations and firms that adopt a technology, it is still the people - worker, managers, etc. who can influence the decision process whether to adopt a technology, which technology alternative to invest in and how to implement it. In the analysis of Minarro-Viseras et al. (2005) respondents ranked the people category first, meaning this to be the most important factor in the process of manufacturing strategy implementation. For example, a project manager's individual qualities and skills are the most critical factor for the success of the implementation of a strategic manufacturing initiative. Consistent with this findings, Udo and Ehie (1996) report the lack of top management's continued support and poor commitment to shopfloor employees to be major reasons for unsuccessful technology implementation. They come to the result that firms "should spend time and resources to earn the

commitment of the employees through positive belief and trust in AMT" (Udo & Ehie, 1996: 21) to realize the full potential of AMT. This statement is also empirically confirmed by Small and Yasin (1997) what leads us to the following proposition:

P8: The commitment of top management and shopfloor worker are both positively correlated with implementation success.

Complementary assets

Addressing opportunities like AMT adoption involves maintaining and improving technological competences and complementary assets like complementary management practices to achieve and sustain competitive advantage (Teece, 2007). For example, Boyer et al. (1997) found evidence for the synergistic effect of TQM programs with AMT to affect performance in a positive way, quoting also other authors suggesting that "many of the benefits of a specific technology can be traced back to infrastructural changes" (Boyer et al., 1997: 336). Consistent with that, Dean and Snell (1996) found integrated manufacturing to be correlated with improved performance. These findings suggest that complementary assets moderate the relationship between technology implementation and operational performance. Yet another complementary asset is design-manufacturing integration (DMI), the integration of product design and manufacturing process knowledge (Swink & Nair, 2007). DMI moderates the relationship between AMT usage and manufacturing performance by having a positive influence on performance. Many publications point to the importance of internal and external learning (Boyer et al., 1997; Schroeder et al., 2002; Small & Yasin, 1997). Preparing worker to understand the principles and purposes of AMT is an prerequisite to exploit the full benefits of AMT. Training for example directly results in improved quality, better process control and quicker response to the customer demands (Udo & Ehie, 1996). Due to numerous examples for such an moderating effect of complementary assets, we propose:

P9: The positive relationship between implementation of AMT and operational performance is positively moderated by complementary management practices like TQM, JIT, DMI and Training.

Performance

Many empirical studies on technology adoption prove the positive correlation of AMT adoption on performance. Although performance categories vary in literature, most publications refer to any kind of operational performance (increased flexibility, quality, improved process control, lower lead times, better turnover rates, etc.) or organizational performance (increasing ROI, market growth, etc.). Although this is a legitimate classification, we think that a more accurate understanding of the relationship between technology adoption and performance might have more explanatory power than previous models. AMT has an indirect effect on organizational performance, which is mediated by operational performance. Operational efficiency and effectiveness lead to superior processes and products that should result in improved organizational performance. Furthermore, we propose that AMT adoption also has a direct positive effect on organizational performance, which is neglected so far in the present literature. AMT eventually enables firms to realize new product designs due to advanced processing, which leads to predominant product properties. The increased willingness to pay of the customers will result in improved organizational performance, without affecting operational performance. Thus, we assume:

P10: The positive correlation between successful implementation of AMT and organizational performance is partly mediated by operational performance.

Discussion and Conclusion

A firm's ability to integrate external technological know-how, develop individual technical solutions and therefore reconfigure manufacturing processes is a central source of competitive advantage for manufacturing companies. As many firms fail to fully exploit the benefit that lies in new technological solutions, we developed a holistic framework to understand various contingencies for the adoption process of new manufacturing technologies.

By taking into account the influencing factors that affect the adoption process, firms should be in the position to select manufacturing technologies more effectively and to manage the adoption process more efficiently with respect to the implementation of a certain technology. Because of all, providing a holistic model of the technology adoption process, explicitly distinguishing between a decision-making process and a technology implementation process, and providing a more detailed understanding of the performance side of manufacturing technologies, we aim at overcoming some of the limitations of previous work and extending research on advanced manufacturing technologies.

Of course, our paper holds some limitations. First, we do not consider interconnections between different influencing factors of the technology adoption process. Second, due to the conceptual character of the paper, we have not yet tested our propositions empirically. Thus, future research should validate our model by testing the proposed hypotheses.

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