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Product Design and Manufacturing Process: Dynamic Implications for Innovation Management

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ABSTRACT

For industrial companies innovations of the product system as well as innovations of the manufacturing processes are essential. Due to technological facts there is a tight relationship between technical products and the processes implemented to generate these products. Innovation management has to take into account the dynamics of the underlying product-process interactions and the resulting constraints coming to a coherent implementation of the different types of innovation.

A System Dynamics based approach covering the essential underlying cause and effect relationships provides suitable support for understanding and managing the complexity and the inherent dynamics of the industrial innovation process. The System Dynamics model developed here links the cycle of product innovation to the innovation cycle of the related manufacturing process and allows to analyse the dynamic consequences of different activities in innovation management.

One result from the product-process connection is the existence of the productivity and flexibility trade-off. For industrial companies´ competitive strength managing production process efficiency as well as product variety is essential. Based on the simulation model the long-term effects of the implementation of different types of innovation innovations are analysed.

Introduction

As a respond to global competition companies have increased the introduction of technologically sophisticated products as well as adoption of advanced technologies and changes in organizational structure and processes. For industrial firms the development of new products and services is the focal point of strategy and a crucial factor for competitive strength and survival. The firm´s competitive position is determined by the ability to innovate it´s product portfolio and the time required to bring new products to the market. Firms have to launch new sophisticated products in increasingly fast cycles and their ability to ramp up to full scale production volume rapidly is crucial for success (Pisano 1997). Thus for industrial companies innovations of the product system and particularly innovations of the related processes are essential.

Due to technological facts there is a tight relationship between technical products and the processes implemented to generate these products. Developing innovation strategies management has to take into account the underlying product-process interactions. Changes in the product system have significant consequences for the firm´s manufacturing system and for technical and administrative processes (Utterback, Abernathy 1975; Hayes, Wheelwright 1979 a, 1979 b; Kim et al. 1992). Much of the complexity of innovation processes in industrial companies results from these interactions between product and process innovation.

Innovation management in manufacturing companies is asked to create integrated innovation and manufacturing strategies. For a development of integrated strategies considering the product-process interaction further investigation of the inter-dependencies of product innovations and the related production processes is necessary.

Patterns of Product and Process Innovation in Industrial Companies

Any innovative activity has to take into consideration the underlying interdependencies as well as the company´s competitive strategy. At any stage of development innovative decisions have to be consistent with business strategy. Central factor of competitive strategy is the choice of the market position and it´s realization. Usually, strategies more dominated by the marketing function focus on innovative product technology while price leadership will go along with innovations regarding production process efficiency and large scale production. Results from empirical research show, that founding competitive strategies primarily on competencies regarding product innovation in an isolated manner can carry the risk of neglecting important competencies in operations such as for example cost efficiency and time performance (Milling, Hasenpusch 2000). An improved performance of manufacturing companies can be expected from tighter linkages between product and process innovation (Kim et al. 1992).

Dependent on the stage in product and process life cycle and on competitive strategy there can exist a complementary or a competitive relationship between the implementation of product and process innovations. The product-process life cycle theory of Utterback and Abernathy (Utterback, Abernathy 1975) provides a useful model helping to understand the pattern of industrial innovation processes. This model succeeds in encompassing the mutual relationships between the stages of a product´s life cycle, the related production process` stages of development and competitive strategy elements.

Following Utterback and Abernathy innovation is stimulated or inhibited by different forces changing over time. By identifying, and then separating process and product innovations, the industrial innovation pattern is related to three different stages. When a new technological paradigm is coming up, product innovation is strongly driven by the demand of new product features. After the emergence of a dominant design and increasing market demand, process innovations are mainly output rate stimulated while product innovation activity diminishes. In later stages of the innovation cycle tighter linkages between product and process features occur. Product and process changes are highly interdependent which must be taken into consideration by management. Further product innovation activities inhibit the stability of manufacturing operations and put at risk process flow and production efficiency (Abernathy, Clark 1983). Due to these constraints the product innovation rate decreases, while further process innovations are mainly cost driven. The identified stages can be related to the strategies performance maximization, sales maximization, and cost minimization.

The fundamental ideas of this model can be found in current literature (e.g. Ettlie 1995, Damanpour, Gopalakrishnan 1999) and the concept still appears to be valid for many industrial settings (Butler 1988). The description of patterns of innovation and the analysis of interaction between the elements structure, technology, strategy, and performance identifies essential underlying cause and effect relationships and provides fundamental ideas giving substantial support for the generation of a System Dynamics model focusing on the product-process interdepencies in manufacturing firms.

A Feedback Perspective of Product Innovation and Manufacturing Process

The management of innovation is located in a highly complex and dynamic environment. There exists interaction inside the organization and interaction between the organization and it´s environment. The underlying interdependencies are numerous and not always transparent for management. Due to the complexity and the dynamic behavior of the system there can exist a large time gap between an action and the evidence of it´s consequences what makes decision processes in innovation management difficult.

Purpose of this paper is the investigation of the mutual interactions and consequences of implementation of product and process innovations in manufacturing companies. Due

to the complexity of the industrial innovation process a System Dynamics approach seems to be useful to get a deeper understanding and to give an idea of the dynamic consequences of actions in innovation management. The objective is to come to a more effective and efficient management of innovation processes in manufacturing companies.

The generation of a System Dynamics model can be based on fundamental concepts desribing cause and effect relationships extracted from the literature mentioned in the section above. The approach refers to a full life cycle of a single technological paradigm covering emergence, growth maturity and decline. Although the impact of transition to a new technological paradigm is not under investigation there are implications for innovation management when substitutional technologies are coming up.

Figure 1 gives a first overview of the complex and dynamic structures driving the innovation of a product and it´s accompanying production process in a manufacturing company. It illustrates the interconnection between innovations of product systems and the related production process over the innovation cycle.

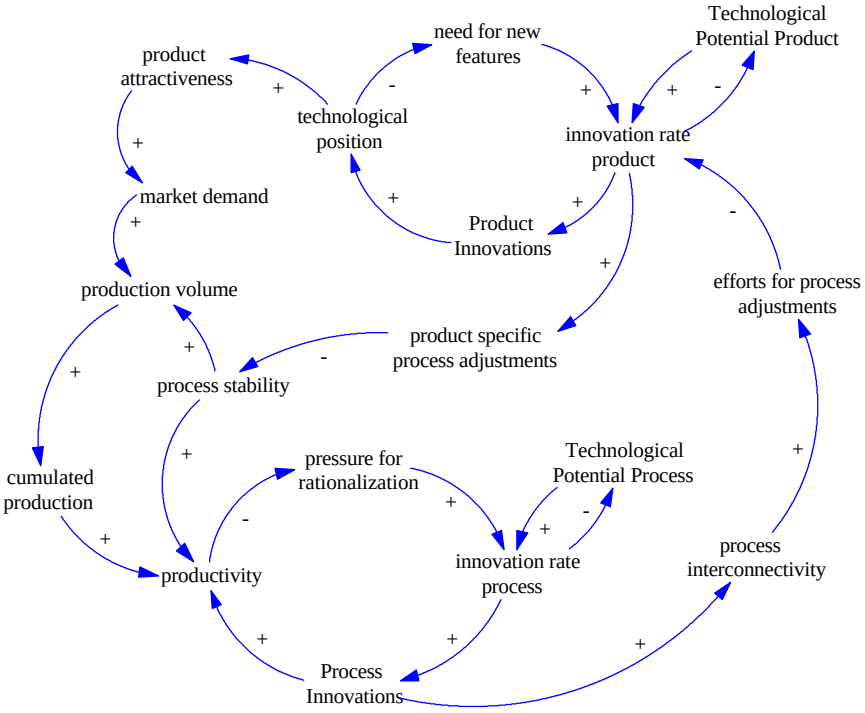

Figure 1: Core Feedback Structures driving Product and Process Innovation

The approach is based on the assumption that at the emergence of a new technologigal paradigm product innovation is mainly stimulated by demand for new product features while process innovation is mainly driven by pressure for rationalization. Due to experience curve effects further gains in productivity derive from growth of cumulated production. At the other hand productivity decreases with instabilities in the production process. Most deeper innovations in the product system demand for changes in production and manufacturing processes which often leads to instablilities. In their maturity stage, high volume production processes are highly complex and show systemic character. Tighter linkages between product and process features occur and significant changes in product features lead to disruption of current practice in production. Due to the systemic character of mature production processes efforts for process adjustments are high which usually leads to constraints for product innovation activity.

The dynamic behavior of product and process innovation driven by the feedback structures illustrated in Figure 1 can be analysed by a System Dynamics model. One result from the analysis is the trade-off between product innovation and rationalization of the production process. Figure 2 illustrates the decrease of the product innovation rate as a result of growing rationalization activities.

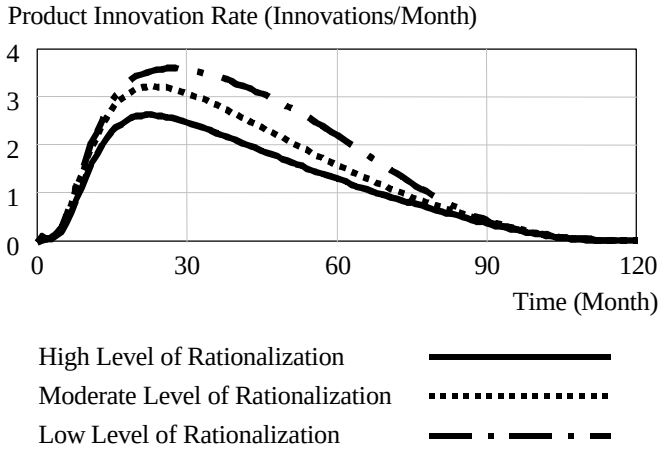

Fig. 2: Impact of Rationalization on Product Innovation Performance

Discussion and Conclusions

One result from the product-process connection is the existence of the productivity and flexibility trade-off. The analysis illustrates how the unlocking of the innovatiove potential for product technology is inhibited by constraints resulting from product-process interaction. The mutual constraints are essential and have to be taken into

consideration in the process of strategy generation. For industrial companies´ competitive strength managing production process efficiency as well as product variety is essential. In reaction to the dynamics of the competitive envirionment R&D in many companies attemps to shorten product life cycle capability, while the goal should be to lengten the product life. Better products with flexible designs have longer life cycles. Product innvation processes creating broader product variety and taking into consideration manufacturing specifications have longer useful life as well (Ettlie, Stoll, 1990). A decrease in degree of correlation between product features and accompanying process requirements will lead to a broader product variety as well as to higher process efficiency.

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Further information on the System Dynamics model and subsequent steps of model development are available on request.