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Modeling Dynamics of Technovation in Competitive Manufacturing*

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Abstract:
Technovation (technovation + innovation) is a crucial factor for survival and competitive strength of organizations. For manufacturing units, technovations of the product system and of the processes generating these products are essential. Majority of literature focuses either on product technovation or on process technovation. Referring to the complexity and inherent dynamics of industrial technovation process decision-making in technovation management is a challenging job. In addition to numerous interactions with the environment, complexity of technovation processes in manufacturing units results from interactions between product and process technovation. This paper provides modeling dynamics of technovation processes reflecting the interdependencies of the product-process technovation system. The model gives an insight into the dynamic consequences of actions in technovation management and allows testing different technovation strategies. Conclusions concerning the implementation of product and process technovations in manufacturing units are drawn.

Key Words: Technovation, Competitive Manufacturing, Market Outcome, Value of Experimentation, Product and Process Technovation in Manufacturing, Product - Technovation Linkage, System Dynamics.

1. Introduction

In economics, business and government policy must be substantially different, not an insignificant change. In economics the change must increase value, customer value, or producer value. Technovations are intended to make someone better off, and the succession of many technovations grows the whole economy.

The classic definitions of technovation include the act of introducing something new: something newly introduced the introduction of something new, a new idea, method or device, the successful exploitation of new ideas, change that creates a new dimension of performance and the process of making improvements by introducing something new. The term technovation may refer to both radical and incremental changes to products, processes or services. The often unspoken goal of technovation is to solve a problem. Technovation is an important topic in the study of economics, business, technovation, sociology, and engineering. Since technovation is also considered a major driver of the economy, the factors that lead to technovation are also considered to be critical to policy makers.

2. What is Globalisation?

There are many different definitions of globalisation, but most acknowledge the greater movement of people, goods, capital and ideas due to increased economic integration which in turn is propelled by increased trade and investment. It is like moving towards living in a borderless world. There has always been a sharing of goods, services, knowledge and cultures between people and countries, but in recent years improved technologies and a reduction of barriers means the speed of exchange is much faster.

Globalisation provides opportunities and challenges. Bigger markets can mean bigger profits which leads to greater wealth for investing in development and reducing poverty in many countries. Weak domestic policies, institutions and infrastructure and trade barriers can restrict a country’s ability to take advantages of the changes. Each country makes decisions and policies that position them to maximise the benefits and minimise the challenges presented by globalisation.
The issues and perceived effects of globalisation excite strong feelings, tempting people to regard it in terms of black and white, when in fact globalisation is an extremely complex web of many things.

3. Conceptualizing Technovation

Technovation has been studied in a variety of contexts, including in relation to technovation, commerce, social systems, economic development, and policy construction. There are, therefore, naturally a wide range of approaches to conceptualising technovation in the scholarly literature. Fortunately, however, a consistent theme may be identified: technovation is typically understood as the successful introduction of something new and useful, for example introducing new methods, techniques, or practices or new or altered products and services. An important distinction is normally made between invention and technovation. Invention is the first occurrence of an idea for a new product or process, while technovation is the first attempt to carry it out into practice.

It is useful, when conceptualizing technovation, to consider whether other words suffice. Authors point out that invention - the creation of new tools or the novel compilation of existing tools - is often confused with technovation. Many product and service enhancements may fall more rigorously under the term improvement. Change and creativity are also words that may often be substituted for technovation. What, then, is technovation that makes it necessary to have a different word from these others, or is it a catch-all word, a loose synonym? Current literature blurs the concept of technovation with value creation, value extraction and operational execution. In this view, a technovation is not an invention until someone successfully implements and makes money on an idea. Extracting the essential concept of technovation from these other closely linked notions is no easy thing.

One emerging approach is to use these other notions as the constituent elements of technovation as an action: Technovation occurs when someone uses an invention - or uses existing tools in a new way - to change how the world works, how people organize themselves, and how they conduct their lives. Note, in this view inventions may be concepts, physical devices or any other set of things that facilitate an action. A technovation in this light occurs whether or not the act of innovating succeeds in generating value for its champions. Technovation is distinct from improvement in that it causes society to reorganize. It is distinct from problem solving and is perhaps more rigorously seen as new problem creation. And in this view, technovation applies whether the act generates positive or negative results.

A convenient definition of technovation from an organizational perspective is given by Luecke and Katz (2003), who wrote: “Technovation . . . is generally understood as the successful introduction of a new thing or method . . . Technovation is the embodiment, combination, or synthesis of knowledge in original, relevant, valued new products, processes, or services.” Technovation typically involves creativity, but is not identical to it: technovation involves acting on the creative ideas to make some specific and tangible difference in the domain in which the technovation occurs. Amabile et al (1996) propose: “All technovation begins with creative ideas . . . We define technovation as the successful implementation of creative ideas within an organization. In this view, creativity by individuals and teams is a starting point for technovation; the first is necessary but not sufficient condition for the second”. For technovation to occur, something more than the generation of a creative idea or insight is required: the insight must be put into action to make a genuine difference, resulting for example in new or altered business processes within the organisation, or changes in the products and services provided. A further characterization of technovation is as an organizational or management process. Davila et al (2006) write: “Technovation, like many business functions, is a management process that requires specific tools, rules, and discipline.” It should be noted, however, that the term ‘technovation’ is used by many authors rather interchangeably with the term ‘creativity’ when discussing individual and organizational creative activity. Davila et al (2006) comments,” Often, in common parlance, the words creativity and technovation are used interchangeably. They shouldn’t be, because while creativity implies coming up with ideas, it’s the “bringing ideas to life”. . . that makes technovation the distinct undertaking it is.” The distinctions between creativity and technovation discussed above are by no means fixed or universal in the technovation literature. They are, however observed by a considerable number of scholars in technovation studies.
From the above point of view the emphasis is moved from the introduction of specific novel and useful ideas to the general organizational processes and procedures for generating, considering, and acting on such insights leading to significant organizational improvements in terms of improved or new business products, services, or internal processes. Through these varieties of viewpoints, creativity is typically seen as the basis for technovation, and technovation as the successful implementation of creative ideas within an organization. From this point of view, creativity may be displayed by individuals, but technovation occurs in the organizational context only.

4. Types of Technovation

Scholars have identified a variety of classifications for types technovations. Here is an unordered ad-hoc list of examples:

Business model technovation involves changing the way business is done in terms of capturing value. Marketing technovation is the development of new marketing methods with improvement in product design or packaging, product promotion or pricing. Organizational technovation involves the creation or alteration of business structures, practices, and models, and may therefore include process, marketing and business model technovation. Process technovation involves the implementation of a new or significantly improved production or delivery method. Product technovation involves the introduction of a new good or service that is new or substantially improved. Service technovation refers to service product technovation which might be, compared to goods product technovation or process technovation, relatively less involving technological advance but more interactive and information-intensive.

Supply chain technovation where technovations occur in the sourcing of input products from suppliers and the delivery of output products to customer’s. Substantial technovation introduces a different product or service within the same line, such as the movement of a candle organisation into marketing the electric lightbulb. Financial technovation through which new financial services and products are developed, by combining basic financial attributes (ownership, risk-sharing, liquidity, credit) in progressive innovative ways, as well as reactive exploration of borders and strength of tax law. The dynamic spectrum of financial technovation, where business processes, services and products are adapted and improved so new valuable chains emerge, therefore may be seen to involve most of the above mentioned types of technovation. Incremental technovations is a step forward along a technovation trajectory, or from the known to the unknown, with little uncertainty about outcomes and success and is generally minor improvements made by those working day to day with existing methods and technovation (both process and product), responding to short term goals. Most technovations are incremental technovations.

A value-added business process, this involves making minor changes over time to sustain the growth of a organisation without making sweeping changes to product lines, services, or markets in which competition currently exists. Breakthrough, disruptive or radical technovation involves launching an entirely novel product or service rather than providing improved products and services along the same lines as currently. The uncertainty of breakthrough technovations means that seldom do companies achieve their breakthrough goals this way, but those times that breakthrough technovation does work, the rewards can be tremendous. There is often considerable uncertainty about future outcomes. People may question if this is, or is not, an advancement of a technovation or process. Radical technovation involves considerable change in basic technologies and methods, created by those working outside mainstream industry and outside existing paradigms. Social technovation a number of different definitions, but predominantly refers to either technovations that aim to meet a societal need or the social processes used to develop a technovation.

5. Technovation And Market Outcome

Market Outcome from technovation can be studied from different lenses. The industrial organizational approach of market characterization according to the degree of competitive pressure and the consequent modelling of firm behaviour often using sophisticated game theoretic tools, while permitting mathematical modelling, has shifted the ground away from an intuitive understanding of markets. The earlier visual framework in economics, of market demand and supply along price and quantity dimensions, has given way to powerful mathematical models which though
intellectually satisfying has led policymakers and managers to look for more intuitive and less theoretical analyses to which they can relate at a practical level. Non-quantifiable variables find little place in these models, and when they do, mathematical gymnastics (such as the use of different demand elasticities for differentiated products) embrace many of these qualitative variables, but in an intuitively unsatisfactory way.

In the management (strategy) literature on the other hand, there is a vast array of relatively simple and intuitive models for both managers and consultants to choose from. Most of these models provide insights to the manager which help in crafting a strategic plan consistent with the desired aims. Indeed most strategy models are generally simple, wherein lie their virtue. In the process however, these models often fail to offer insights into situations beyond that for which they are designed, often due to the adoption of frameworks seldom analytical, seldom rigorous. The situational analyses of these models often tend to be descriptive and seldom robust and rarely present behavioural relationship between variables under study.

From an academic point of view, there is often a divorce between industrial organisation theory and strategic management models. While many economists view management models as being too simplistic, strategic management consultants perceive academic economists as being too theoretical and the analytical tools that they devise as too complex for managers to understand.

Technovation literature while rich in typologies and descriptions of technovation dynamics is mostly technovation focused. Most research on technovation has been devoted to the process (technological) of technovation, or has otherwise taken a how to (innovate) approach. The integrated technovation model goes some way to providing the academic, the manager and the consultant an intuitive understanding of the technovation – market linkages in a simple yet rigorous framework of Technovation, Market Archetypes and Outcome - An Integrated Framework.

The integrated model presents a new framework for understanding firm and market dynamics, as it relates to technovation. The model is enriched by the different strands of literature - industrial organization, management and technovation. The integrated approach that allows the academic, the management consultant and the manager alike to understand where a product (or a single product firm) is located in an integrated technovation space, why it is so located and which then provides valuable clues as to what to do while designing strategy. The integration of the important determinant variables in one visual framework with a robust and an internally consistent theoretical basis is an important step towards devising comprehensive firm strategy. The integrated framework provides vital clues towards framing what to guide for managers and consultants. Furthermore, the model permits metrics and consequently diagnostics of both the firm and the sector and this set of assessment tools provide a valuable guide for devising strategy.

6. Sources of Technovation

There are several sources of technovation. In the linear model the traditionally recognized source is manufacturer technovation. This is where an agent (person or business) innovates in order to sell the technovation. Another source of technovation, only now becoming widely recognized, is end-user technovation. This is where an agent (person or organisation) develops a technovation for their own (personal or in-house) use because existing products do not meet their needs. Eric von Hippel has identified end-user technovation as the most important and critical Sources of Technovation.

Technovation is achieved in many ways, with much attention now given to formal research and development for “breakthrough technovations.” But technovations may be developed by less formal on-the-job modifications of practice, through exchange and combination of professional experience and by many other routes. The more radical and revolutionary technovations tend to emerge, while more incremental technovations may emerge from practice - but there are many exceptions to each of these trends.

Regarding user technovation, rarely user innovators may become entrepreneurs, selling their product, or more often they may choose to trade their technovation in exchange for other technovations. Nowadays, they may also choose to freely reveal their technovations, using methods like open source. In such networks of technovation the creativity of the users or communities of users can further develop
technologies and their use. Whether technovation is mainly supply-pushed (based on new technological possibilities) or demand-led (based on social needs and market requirements) has been a hotly debated topic. Similarly, what exactly drives technovation in organizations and economies remains an open question.

More theoretical work moves beyond this simple dualistic problem and through empirical work shows that technovation does not just happen within the industrial supply-side, or as a result of the articulation of user demand, but through a complex processes that links many different players together (developers, users, intermediaries etc). Work on social networks suggests that much of the most successful technovation occurs at the boundaries of organisations and industries where the problems and needs of users and the potential of technologies can be linked together in a creative process that challenges both.

7. Value of Experimentation

When an innovative idea requires a new business model, or radically redesigns the delivery of value to focus on the customer, a real world experimentation approach increases the chances of market success. New models and experiences can’t be tested through traditional market research methods. Pilot programs for new technovations set the path in stone too early thus increasing the costs of failure.

Stefan Thomke has written on the importance of experimentation. Experimentation Matters argues that every organisation’s ability to innovate depends on a series of experiments [successful or not], that help create new products and services or improve old ones. That period between the earliest point in the design cycle and the final release should be filled with experimentation, failure, analysis, and yet another round of experimentation. “Lather, rinse, repeat,” Thomke says. Unfortunately, uncertainty often causes the most able innovators to bypass the experimental stage.

Thomke outlines six principles companies can follow to unlock their innovative potential.

1. Anticipate and Exploit Early Information Through ‘Front-Loaded’ Technovation Processes
2. Experiment Frequently but Do Not Overload Your Organization.
3. Integrate New and Traditional Technologies to Unlock Performance.
4. Organize for Rapid Experimentation.
5. Fail Early and Often but Avoid ‘Mistakes’.
6. Manage Projects as Experiments.

Thomke further explores what would happen if the principles outlined above were used beyond the confines of the individual organization. For instance, innovators are collaboratively leveraging compact geography, economic and demographic diversity and close-knit networks to quickly and cost-effectively test new business models through a real-world experimentation lab.

8. Diffusion of Technovations

Once technovation occurs, technovations may be spread from the innovator to other individuals and groups. This process has been studied extensively in the scholarly literature from a variety of viewpoints, most notably in Everett Rogers’ classic book, The Diffusion of Technovations. However, this ‘linear model’ of technovation has been substantially challenged by scholars in and much research has shown that the simple invention-technovation-diffusion model does not do justice to the multilevel, non-linear processes that firms, entrepreneurs and users participate in to create successful and sustainable technovations.

Rogers proposed that the life cycle of technovations can be described using the ‘s-curve’ or diffusion curve. The s-curve is derived from half of a normal distribution curve. There is an assumption that new products are likely to have “product Life”, i.e. a start-up phase, a rapid increase in revenue and eventual decline. In fact the great majority of technovations never gets off the bottom of the curve, and never produces normal returns. The s-curve maps growth of revenue or productivity against time. In the early stage of a particular technovation, growth is relatively slow as the new product establishes itself. At some point customers begin to demand and the product growth increases more rapidly. New incremental technovations or changes to the product allow growth
to continue. Towards the end of its life cycle growth slows and may even begin to decline. In the later stages, no amount of new investment in that product will yield a normal rate of return.

9. Goals of Technovation

Programs of organizational technovation are typically tightly linked to organizational goals and objectives, to the business plan, and to market competitive positioning. For example, one driver for technovation programs in corporations is to achieve growth objectives. As Davila notes, “Companies cannot grow through cost reduction and reengineering alone . . . Technovation is the key element in providing aggressive top-line growth and for increasing bottom-line results.”

In general, business organisations spend a significant amount of their turnover on technovation i.e. making changes to their established products, processes and services. The amount of investment can vary from as low as a half a percent of turnover for organisations with a low rate of change to anything over twenty percent of turnover for organisations with a high rate of change. The average investment across all types of organizations is four percent. For an organisation with a mega turnover, this represents an investment of forty million units. This budget will typically be spread across various functions including marketing, product design, information systems, manufacturing systems and quality assurance. The investment may vary by industry and by market positioning.

One survey across a large number of manufacturing and services organisations found, ranked in decreasing order of popularity, which systematic programs of organizational technovation are most frequently driven by:

1. Improved quality
2. Creation of new markets
3. Extension of the product range
4. Reduced labour costs
5. Improved production processes
6. Reduced materials
7. Reduced environmental damage
8. Replacement of products/services
9. Reduced energy consumption
10. Conformance to regulations

These goals vary between improvements to products, processes and services and dispel a popular myth that technovation deals mainly with new product development. Most of the goals could apply to any organisation be it a manufacturing facility, marketing firm, hospital or local government.

10. Failure of Technovation

Attaining goals must be the ultimate objective of the technovation process. Unfortunately, most technovation fails to meet organisational goals. Figures vary considerably depending on the research. Some research quotes failure rates of fifty percent while other research quotes as high as ninety percent of technovation has no impact on organisational goals.

One survey regarding product technovation quotes that out of three thousand ideas for new products, only one becomes a success in the marketplace. Failure is an inevitable part of the technovation process, and most successful organisations factor in an appropriate level of risk. Perhaps it is because all organisations experience failure that many choose not to monitor the level of failure very closely. The impact of failure goes beyond the simple loss of investment. Failure can also lead to loss of morale among employees, an increase in cynicism and even higher resistance to change in the future.

Technovations that fail are often potentially ‘good’ ideas but have been rejected or ‘shelved’ due to budgetary constraints, lack of skills or poor fit with current goals. Failures should be identified and screened out as early in the process as possible. Early screening avoids unsuitable ideas devouring scarce resources that are needed to progress more beneficial ones. Organizations can learn how to avoid failure when it is openly discussed and debated. The lessons learned from failure often reside longer in the organisational consciousness than lessons learned from success. While learning is important, high failure rates throughout the technovation process are wasteful and a threat to the organisation’s future.

The causes of failure have been widely researched and can vary considerably. Some causes will be external to the organisation and outside its influence of control. Others will be internal and ultimately within the control of the organisation. Internal causes of failure
can be divided into causes associated with the cultural infrastructure and causes associated with the technovation process itself. Failure in the cultural infrastructure varies between organisations but the following are common across all organisations at some stage in their life cycle:

1. Poor Leadership
2. Poor Organisation
3. Poor Communication
4. Poor Empowerment
5. Poor Knowledge Management

Common causes of failure within the technovation process in most organisations can be differentiated into five types:

1. Poor goal definition
2. Poor alignment of actions to goals
3. Poor participation in teams
4. Poor monitoring of results
5. Poor communication and access to information

Effective goal definition requires that organisations state explicitly what their goals are in terms understandable to everyone involved in the technovation process. This often involves stating goals in a number of ways. Effective alignment of actions to goals should link explicit actions such as ideas and projects to specific goals. It also implies effective management of action portfolios. Participation in teams refers to the behaviour of individuals in and of teams, and each individual should have an explicitly allocated responsibility regarding their role in goals and actions and the payment and rewards systems that link them to goal attainment. Finally, effective monitoring of results requires the monitoring of all goals, actions and teams involved in the technovation process.

Technovation can fail if seen as an organisational process whose success stems from a mechanistic approach i.e. ‘pull lever obtain result’. While ‘driving’ change has an emphasis on control, enforcement and structures it is only a partial truth in achieving technovation. Organisational gatekeepers frame the organisational environment that “Enables” technovation; however technovation is “Enacted” - recognised, developed, applied and adopted - through individuals.

Individuals are the ‘atom’ of the organisation close to the minutiae of daily activities. Within individuals gritty appreciation of the small detail combines with a sense of desired organisational objectives to deliver (and innovate for) a product/service offer. From this perspective technovation succeeds from strategic structures that engage the individual to the organisation’s benefit. Technovation pivots on intrinsically motivated individuals, within a supportive culture, informed by a broad sense of the future. Technovation, imply change, and can be counter to an organisation’s orthodoxy. Space for fair hearing of innovative ideas is required to balance the potential autoimmune exclusion that quells an infant innovative culture.

11. Measures of Technovation

Individual and team-level assessment can be conducted by surveys and workshops. Business measures related to finances, processes, employees and customers in balanced scorecards can be viewed from the technovation perspective (e.g. new product revenue, time to market, customer and employee perception and satisfaction). Organizational capabilities can be evaluated through various evaluation frameworks model.

Many scholars claim that there is a great bias towards the “science and technovation mode” (SandT-mode or STI-mode), while the “learning by doing, using and interacting mode” (DUI-mode) is widely ignored. For an example, that means you can have the better high tech or software, but there are also crucial learning tasks important for technovation. These measurements and research are rarely done.

12. Economic Conceptions of Technovation

According to Regis Cabral: “Technovation is a new element introduced in the network which changes, even if momentarily, the costs of transactions between at least two actors, elements or nodes, in the network.” Joseph Schumpeter defined economic technovation in The Theory of Economic Development, as:

1. The introduction of a new good —that is one with which consumers are not yet familiar— or of a new quality of a good.
2. The introduction of a new method of production, which need by no means be founded upon a discovery scientifically new, and can also exist in a new way of handling a commodity commercially.

3. The opening of a new market, which is a market into which the particular branch of manufacture of the country in question has not previously entered, whether or not this market has existed before.

4. The conquest of a new source of supply of raw materials or half-manufactured goods, again irrespective of whether this source already exists or whether it has first to be created.

5. The carrying out of the new organization of any industry, like the creation of a monopoly position (through trustification) or the breaking up of a monopoly position

13. Management of Technovation

Technovation is regarded as the focal point of an organization’s strategy and a crucial factor for it’s competitive strength and survival. Organizations develop technovations to adapt to their external environment and to react to perceived changes inside or outside the organization. Technovations can be implemented in the organization’s outcomes, it’s structure, and it’s processes in order to maintain or to improve the level of performance or effectiveness. Various types of technovations can be differentiated: social, organizational, administrative or technical, incremental or fundamental, product or process. In any organization a large number of objects of the technovation process can be named. This paper examines product and process technovations of industrial manufacturing units. The management of technovation 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.

In the organisational context, technovation may be linked to performance and growth through improvements in efficiency, productivity, quality, competitive positioning, market share, etc. All organisations can innovate, including for example hospitals, universities, and local governments. While technovation typically adds value, technovation may also have a negative or destructive effect as new developments clear away or change old organisational forms and practices. Organisations that do not innovate effectively may be destroyed by those that do. Hence technovation typically involves risk. A key challenge in technovation is maintaining a balance between process and product technovations where process technovations tend to involve a business model which may develop shareholder satisfaction through improved efficiencies while product technovations develop customer support however at the risk of costly R&D that can erode shareholder returns.

Very often decisions which are crucial for an organization’s survival have to be generated under lack of time. Any approach providing support and leading to more rational decision-making is welcome. Decision-making at this level of complexity cannot be automated, but it can be substantially supported by formalized models. A Computable System based on the System Dynamics approach would be able to cover the complexity and inherent dynamics of the technovation process. A thorough understanding of the system and it’s dynamic behavior is essential to come to an effective and efficient management of the entire technovation process. A comprehensive and causal approach to model building is required to explain and to help to understand why specific behavior occurs. A System Dynamics model can give an idea of the dynamic consequences of actions in technovation management and allows testing different technovation strategies. The congruency and the synchronous adoption of different technovation types is an important factor for organizational adoption.

14. Product and Process Technovation in Manufacturing

Technovation is regarded as a crucial factor for the survival and the competitive strength of any industrial firm. Industrial firms have to adapt to increasing global competition and dynamics. This results in a large number of innovative products, processes and services
developed by the manufacturing units. The part of new products in the manufacturing units’ product portfolio increased in the last years. For industrial firms the development of new products and services is the engine of growth. 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. With product life cycles getting shorter it becomes even more essential to expand commercial production process capacity rapidly to generate sales revenues and recoup development investments.

Technovation is the focal point in the business strategy of any industrial firm. Industrial Manufacturing units are complex and dynamic systems showing numerous interactions with their environment. The management of successful adoption of technovations in these manufacturing units is a complex and difficult venture which has to take into account a large number of internal and external factors.

Developing technovation 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. In the process industries (‘Process Driven’, ‘Process Enabling’) an extraordinary close relationship between products and production process can be noticed. Technovation management in manufacturing units is asked to create integrated technovation and manufacturing strategies. An improved performance of manufacturing units can be expected from tighter linkages between product and process technovation.

15. Product - Technovation Linkage

For industrial manufacturing units technovations of the product portfolio as well as technovations of the processes generating these products are essential. In many cases the scientific literature focuses either on product technovation or on process technovation without explicitly taking into consideration the interaction between product and process technovation. The product-process life cycle theory provides a useful model helping to understand the pattern of many industrial technovation 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. By identifying, and then separating, process and product technovations the industrial technovation pattern could be related to three different stages of the technovation process: the uncoordinated, the segmental and the systemic. Utterback and Abernathy notice that the rate of product or process technovation depends on the present stage of the product’s life cycle. It has to be mentioned that this concept can refer to the life cycle of a single product line and it’s manufacturing process as well as to a specific product generation and the growth of a whole industrial branch related to this generation of products. The process of substitution by a completely different, sophisticated kind of products is not in the focus of investigation.

The first stage of the technovation process—the uncoordinated stage—is characterized by frequent changes in product design and low productivity of the related process. In this stage competition is merely based on product performance, a dominant product design has not evolved yet. Due to the uncoordinated and low integrated production process (technological and organizational) there are low constraints for product improvements. These frequent changes of product features inhibit process standardization efforts, which results in higher production costs.

After the emergence of a dominant product design, the firm—or the industrial branch—gradually enters the segmental stage. Specialized production equipment is introduced; the rate of technovation related to the production process increases, and the process becomes more coordinated. In this stage product technovations requiring radical changes in the production process are voided, the rising of the product technovation rate diminishes. Production costs decrease which leads to increasing sales and higher production volume.
In the systemic stage complex, highly integrated technological solutions are implemented in the firm, the production system is further standardized while cost minimization becomes an important goal. Tighter linkages between product and process features occur. Product and process changes are highly interdependent which must be taken into consideration by management. The process of standardization reduces the probability of further fundamental technovations in both the product and the process system. Due to these constraints both the product and the process technovation rate decrease.

As Utterback and Abernathy relate the three identified stages to the competitive strategies performance maximization, sales maximization and cost minimization, their approach has as well descriptive as normative attributes. The model provides explanations about systematic variations in the technovation process of industrial manufacturing units—fundamental ideas of possible and plausible cause and effect relationships—suitable for the generation of a System Dynamics Model. Implementing the fundamental ideas of the Utterback/Abernathy approach into a System Dynamics model specific adaptations taking into consideration the recent advances in sophisticated flexible production systems and computer aided manufacturing are necessary. These technological technovations in the recent years permit a higher degree of product variation at later stages. Nevertheless the fundamental ideas of this concept found in current literature and the concept still appears to be valid for many industrial settings.

Following the concept of Utterback/Abernathy, Hayes and Wheelwright suggest a two-dimensional product-process matrix linking product life cycle stage and process life cycle stage and reflecting a organisation’s position in the interrelated product-process system. The matrix represents the interaction of both the product and the process life cycle. The process life cycle-rows of the matrix represent the process structure going from great variety to highly standardized products. This matrix is helpful in describing industrial manufacturing units’ strategic options particularly with regard to the manufacturing function.

The Hayes/Wheelwright matrix concept provides substantial support in determining the direction and timing of technovation decisions in the light of a organisation’s manufacturing capabilities. Building on the ideas of Hayes/Wheelwright and the generic strategy typology proposed by Porter an ongoing conceptual framework is provided by Kotha / Orne. Using the dimensions “product line complexity” and “process structure complexity” this framework suggests a link between several critical elements in manufacturing competitiveness. It considers both the content of fit and the process of fit between structure, strategy, technovation and performance. It recognizes that the execution of the more generic business unit strategy inherently involves manufacturing and postulates the fit of between business-level strategy and manufacturing structure.

Kotha / Orne relate high process structure complexity in manufacturing and lower product line complexity to the strategy of cost leadership while the strategy of differentiation is related to higher product line complexity and lower process structure complexity. The organisation’s “process structure complexity” is characterized by the level of mechanization, systemization and interconnection of the production process while “product line complexity” is mainly characterized by the end product’s complexity and variety and it’s maturity in the product life cycle.

The frameworks of Utterback/Abernathy, Hayes/ Wheelwright and Kotha / Orne represent integrative approaches all succeeding in illustrating the tight interconnections between product, process and strategy in manufacturing units. Applied to industrial technovation management these synthesized frameworks give valuable hints for the development and implementation of specific types of technovation. They provide support for decision-making concerning the specific type, the timing and the extent of technovation in relation to maturity in product life cycle, manufacturing structure as well as in relation to manufacturing strategy and competitive strategy.
16. System Dynamics-based Decision-making

The frameworks described in the section above provide fundamental ideas giving substantial support for the generation of a System Dynamics model focusing on the process of technovation management in manufacturing firms. The description of patterns of technovation and the analysis of interaction between the elements structure, technovation, strategy, and performance identifies essential underlying cause and effect relationships. A synthesis of these ideas is a suitable foundation of a System Dynamics model covering the complexity and the inherent dynamics of the industrial technovation process.

Objective of this modeling approach is to enable insights into the specific dynamic behavior of the system and to offer a virtual environment to test different scenarios of technovation. A taxation of consequences of managerial decisions concerning investments into development, the rate, timing and implementation of certain types of technovations becomes possible in relation to specific product or process features. In it’s final state the model can serve as support tool for rational decision-making and strategy generation in technovation management for manufacturing units with a focus on product-process interdependencies. The objective is to support the development of coordinated and coherent policies instead of isolated operations. The analysis refers to the characteristics of a process segment and a single product line’s life cycle of one firm. At this level the transition to completely new product generations is not included.

A simple System Dynamics model serves as a first approach integrating the concepts described above linking the basic ideas together into a feedback structure. In this first step the model only covers four sectors in a simplified manner. Dominant variable is the conversion coefficient product technovation and it’s analog for process technovation which characterize the achievements in technovation implementation including promoting factors and constraints for the implementation of specific types of technovations. The model runs illustrate different scenarios forcing several process technovations leading to more flexible and less interconnected processes at the one hand and product technovations leading to more complex products on the other hand.

This behavior in general is confirmed by similar results indicated by investigations and it is consistent with the concepts described above. Number of implemented technovations in the product line and rate of product technovation over time. A higher rising product technovation rate is related to a business strategy more dominated by the marketing function. This strategy can be boosted by the acquisition of more versatile or flexible process equipment in combination with a more flexible organization and administrative processes that enable frequent changes in the product line.

17. Conclusions and Further Research

The model presented in this paper links—in a first step—the cycle of product technovation with the technovation of the related manufacturing process. Until the model can serve as a strategy support tool it requires further steps of development. Nevertheless at this state it is able to give an impression of the dynamics of product and process technovation in manufacturing units and illustrates their mutual constraints. These constraints are essential and to be taken into consideration in the process of strategy generation.

The importance of process flexibility and flexible administrative practices and the influence of high product line complexity is illustrated. From the feedback perspective all relevant interactions with focus on strategic implications of product-process interaction which cause the behavior of the system “industrial technovation” have to be represented. Further sets of variables reflecting for example customer’s and competitor’s behavior, learning curve effects and relevant managerial leverage points to control the industrial technovation process have to be included in following steps of model development.

The significance of technological and organizational product-process integration in the focus of manufacturing strategy and corporate strategy is recognized in recent literature. In these investigations
it is verified that manufacturing units focusing on integrated product-process development with a regimen of policies, practices and structures are more successful. In contradiction to these approaches sometimes the notion that manufacturing units’ product and process development capabilities are mutually exclusive can be found in the literature.

Empirical results indicate that integrated strategies—if implemented in a coordinated and coherent manner—can boost both the manufacturing unit’s product development capabilities and its process development capabilities. Success is significantly correlated to early and tight manufacturing involvement in product taking into consideration the constraints as showed above.

Further development stages of the model are likely to provide substantial support for the generation of more effective decisions in manufacturing units. In a next step practices for an achievement of compressed technovation implementation cycles by integrated product process strategies will be investigated.