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Four types of manufacturing process innovation and their managerial concerns

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Abstract

Manufacturing process innovation (MPI), an organization-wide effort involving radical redesign of manufacturing related processes and systems to achieve dramatic improvements in critical manufacturing performance measures, encompasses various kinds of activities. Some MPI initiatives focus on technological innovation and others may intend to change work processes and organizations' behavioral routines. Some organizations adopt new technological solutions or work methods that are externally available, while others may develop and adopt novel technologies or organizational routines which are new to the state of the art. Different focus in MPI initiatives requires different approaches and preconditions for achieving desired outcomes. However, MPI has been mostly treated as one type of innovation in literature and further classifications of MPI have not been made. This paper presents four types of MPI and discusses what managers can expect and prepare for each type of MPI. Basic strategic directions in terms of what type of MPI can be conducted at a specific organization is also discussed. The four types of MPI is developed through a literature review of various research fields, for instance manufacturing strategy, process innovation, organizational innovation, typology of innovation, and new product development.

Keywords: Manufacturing; process innovation; typology; manufacturing strategy

1. Introduction

Severe competition in a global arena requires manufacturing companies to continuously develop their manufacturing functions for greater efficiency and speed. Moreover, in a business environment characterized by fast-paced change, it is hard for manufacturing functions to sustain operational competitiveness as long as the speed of improvements is moderate. The functions must have a capacity to undertake large-scale improvements of a radical and innovative nature, as a complement to incremental improvements. This paper features innovation in manufacturing related processes that is referred to as manufacturing process innovation (MPI).

MPI encompasses a wide range of activities. Some MPI initiatives focus on technological innovation, for instance adopting new technologies or installing new pieces of equipment at factories. Some other MPI initiatives may involve changing work processes, material and information flows, or organizations' behavioral routines in factories. In MPI, a manufacturing organization may adopt new technological solutions or work methods that are externally available, or it may develop and install novel technologies or work routines which are new to the industry.

Different types of MPI exist, and the different types may require different approaches and preconditions in order for an organization to achieve desired outcomes in MPI. Although a number of researchers have discussed typologies of innovation in literature [1, 2], they have not paid much attention to different types of MPI, nor have they discussed what approaches and preconditions can be needed to achieve different types of MPI.

The purpose of this paper is to propose types of MPI and to discuss possible approaches and important factors that managers need to consider for each type of MPI. A basic strategic direction in terms of what type of MPI

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can be conducted in a specific manufacturing organization is also discussed. The types of MPI have been developed through a literature review of research fields such as manufacturing strategy, process innovation, organizational innovation, and innovation management.

2. Conceptualization of MPI

In this section, MPI is conceptualized in more detail. Manufacturing process innovation can be defined in various ways, but in this paper it is defined based on the well-known definition of process innovation suggested by Hammer and Champy [3]; an organization-wide effort that involves fundamental rethinking and radical redesign of manufacturing related processes and systems to achieve dramatic improvements in manufacturing performance measures such as cost, quality, service, and speed. In MPI, changes are made not only in the processes of transforming raw materials into products, but also other support processes and systems related to, for instance production planning, logistics, purchasing, administration, engineering, and management [4]. Since MPI is an organization-wide effort, it is usually conducted in a form of a project or an initiative. This paper focuses on factory-level MPI. Some researchers describe MPI as an abrupt step change, while others discuss that MPI does not necessarily mean one big jump but can be a result of many smaller changes that occur in concert and reinforce each other toward a radically new form [5].

A life cycle of MPI, here termed as a process of MPI, has been analyzed by a numbers of researchers. Various life cycle models of MPI have been presented in the literature [6, 7]. These models are different at a detail level but in general they contain three phases that can be called, preparation, design, and implementation. Each phase involves different activities as shown in Table 1.

Table 1. Phases in a process of MPI

Phase	Activity
Preparation	Securing management commitment, identifying processes to be improved, aligning with corporate and business strategies, establishing process vision, setting stretched targets, forming a promotion organization and/or a steering committee, formulating projects, providing education
Design	Analyzing focused processes, exploring alternatives, designing new processes, prototyping and evaluating new processes
Implementation	Implementing new processes, training employees, monitoring performance measures, continuing improvements

Some researchers advocate a normative and liner process of MPI, based on the assumption that that a change can be managed and controlled through well-thought-out and analytical-driven planning exercises. The mentioned kind of approach toward a change is often called deliberate approach [8]. Some other researchers advocate another kind of approach so called deliberate-emergent approach [8, 9, 10]. In the deliberate-emergent approach, MPI is initiated and its targets are set by the management, but how to achieve the targets are largely left to employees to discover through experiments and learning.

3. Approach toward classifying MPI

One of the purposes of this paper is to classify MPI into a few types. To meet this purpose, the present study adopted an approach including three steps;

- Undertaking a literature review to gather models, frameworks, discussions, etc. that can be relevant to classifying MPI,
- Analyzing the gathered information to identify appropriate dimensions of classifying MPI, and
- Constructing a model that presents types of MPI.

3.1. Literature review

The literature review started with searching with keywords such as “innovation and type”, “manufacturing, innovation, and type”, “process innovation and type”, “manufacturing, strategy, and type”, in online databases for instance Web of Science, Google Scholar, Emerald, etc. The articles and books that included models and frameworks classifying various kinds of changes or innovations were selected for the review. The selected articles and books were from various research fields, such as innovation management, process innovation, manufacturing strategy, organizational innovation, and new product development.

3.2. Analysis of the collected models and frameworks

The models, frameworks, and discussions in the reviewed literature classified changes or innovations in one or more of following three dimensions; scale of change, subject of change, and innovativeness of change.

The scale of change refers to at which system level a change occurs. A change can happen at a subsystem (e.g. a small part of a factory) or across the whole system (e.g. the whole factory) [11]. This dimension is less relevant to the classification of MPI, because MPI is related to a large-scale change.

Another dimension is the subject of change. It concerns what is mainly intended to be changed or

created. Researchers have proposed different classifications of innovations in this dimension. Examples are product or process innovation [12], administrative or technical innovation [13], and organizational, management, production, or marketing innovation [14]. According to those who proposed these classifications [12, 13, 14], MPI is process, technical, and production innovation. These classifications treat MPI as one of the innovation types but do not categorize MPI into different types. A useful classification in this dimension was found in the research field of manufacturing strategy. Wheelwright [15] identified several manufacturing decision categories composing a manufacturing strategy. Wheelwright further classified these categories into two groups namely, structural and infrastructural (Table 2 shows a slightly modified version of these groups). The Wheelwright's classification was selected as a basis for classifying MPI in the dimension of the subject of change because;

- the decision categories were comprehensive and they could be regarded as subjects of change in MPI,
- basic changes in one or more of the decision categories could be considered as MPI, and
- characteristics of the groups that Wheelwright describes influence ways to achieve MPI. For instance, basic changes in the structural group tend to require a substantial capital investment and thus entail an attentive budgeting process.

The third dimension is the innovativeness of change. It concerns the degree of novelty involved in a change or creation. The most common classification of innovation in this dimension is a binary classification of incremental and radical innovation. In manufacturing, incremental innovation is commonly considered equivalent to incremental improvement that involves extension or reinforcement of existing processes and systems without changing their essential concept [16]. Radical innovation is a fundamental change and involves development of new processes and systems that are distinctly different from the existing ones [16]. According to the classification described above, MPI is an approach within the category of the radical innovation. In addition to the binary classification, Tidd et al. [11] and Kleinschmidt and Cooper [17] have identified a moderate innovation that can be placed between the incremental and radical innovation. According to these authors, the moderate innovation involves generation of outcomes that are new to the company but not new to the industry, while radical innovation relates generation of outcomes that are new to the industry, in other words, new to the state of art. The classification and the terminology of the moderate and radical innovation suggested by Tidd et al. [11] and Kleinschmidt and Cooper [17] is useful for our purpose because it enables to classify MPI in the dimension of innovativeness of change.

3.3. Constructing a model that represents MPI types

The analysis described above has indicated that adopting the classifications of structural and infrastructural manufacturing decision categories, and moderate and radical innovation are appropriate for classifying MPI types. Cooper [2] suggests that it is beneficial to treat innovation as a phenomenon that consists of multiple dimensions at the same time. Therefore, a model of MPI types is constructed by combining the mentioned two classifications together.

4. A model of four types of MPI

A model of four types of MPI is shown in Fig. 1. The horizontal axis of the model represents the classification of MPI in terms of its innovativeness. Two levels of innovativeness are defined in below.

Locally innovative: this paper refers to the moderate innovation mentioned in the previous section as local innovation. The locally innovative MPI occurs when MPI largely involves adoptions of solutions that are new to the specific company but not new to the industry.

Radically innovative: The radically innovative MPI occurs when MPI largely involves adoptions solutions that are not only novel to the specific company but also new to the industry in other words new to the state of the art. The solutions are developed internally and/or in cooperation with external partners during MPI or in separate development projects.

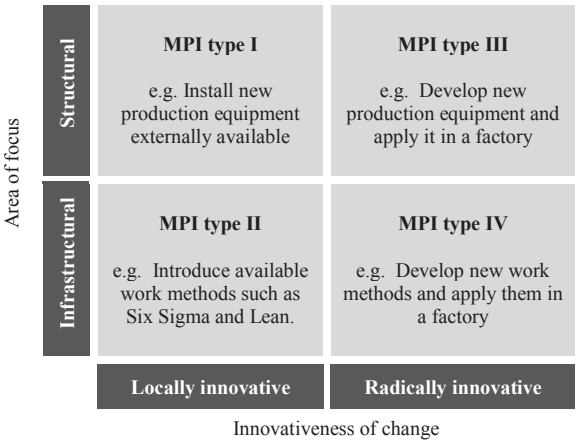

Fig. 1. A model of four types of MPI

The vertical axis of the model represents the classification of MPI in terms of area of focus. Inspired by the classification of Wheelwrights [15], two kinds of MPI are defined in below.

Structural: Basic changes mainly take place in the structural area shown in Table 2. For example, basic changes are made on the capacity of a factory and manufacturing technologies used in the factory.

Infrastructural: Basic changes mainly take place in the infrastructural area shown in Table 2. For instance, major changes are made on production control systems, material flows, and organizations.

Table 2. Structural and infrastructural area, inspired by Wheelwright [15]

Structural area
• Production capacity - volume per year
• Plant network design - size, location, focus
• Production technology - equipment, automation level
• Vertical integration - direction, extent
Infrastructural area
• Human resource - pay system, evaluation system
• Production planning/control - inventory, order system, batch size
• Quality control - defect prevention, monitoring
• Cost control - cost accounting, cost planning
• Material control - flow, layout
• Maintenance - routine, monitoring
• Organization - structure, culture

Four types of MPI are defined as follows.

MPI type I (structural - locally innovative): The primary focus in this type of MPI is to bring about basic changes in the structural area. This MPI type largely involves adoptions of solutions that are externally available. For instance, increasing the level of automation in a factory by adopting off-the-shelf technologies belongs to this type of MPI.

MPI type II (infrastructural - locally innovative): The primary focus is to bring about basic changes in the infrastructural area. This MPI type mostly involves adopting solutions externally available. A typical example is importing packaged company-wide improvement initiatives such as Lean manufacturing and Six Sigma.

MPI type III (structural - radically innovative): Basic changes occur in the structural area and new-to-the-state-of-the-art solutions are adopted in a factory. An example of this type is novel automation systems being developed and applied in a factory.

MPI type IV (infrastructural - radically innovative): Basic changes occur in the infrastructural area and new-to-the-state-of-the-art solutions are adopted in a factory. In this type, novel work processes, production flows, or other kinds of unique solutions related to the infrastructural area are created and used in a factory.

5. Discussion

The model of MPI types can help to discuss several managerial issues related to each MPI type. In the subsequent subsections, possible approaches and important factors that managers need to consider for each type of MPI are discussed. Later, basic strategic directions in terms of which type of MPI can be conducted at a specific company are discussed.

5.1. Possible approaches and important factors for achieving each type of MPI

MPI type I: According to Wheelwright [15], basic changes in the structural area tend to require substantial capital investment in physical assets, be difficult to reverse or undo once they are in place, and thus have long term impacts. Because of the 'strategic nature' of these changes, capital budgeting process is considered important. The above notion of Wheelwright [15] implies that an analytical-driven and well thought-out planning is critical in this type of MPI. A MPI process can be formal, systematic, and dominated by the deliberate approach. The process is likely to be conducted by a limited number of people often at a strategic level of an organization, such as senior managers, strategic planners, and senior production engineers. Manufacturing companies have developed project models to structure activities for procurement and installation of manufacturing equipment [18]. Such formal project models seem to be a beneficial way to support this type of MPI.

MPI type II: In this type of MPI, changes are more related to operating aspects of a manufacturing organization than ones in the previous type of MPI. Major changes in the infrastructural area tend not to require a large capital investment in a single point of time, but rather require constant investments during the course of the changes [15]. A cumulative impact of on-going efforts tends to lead to a major change. In this type of MPI, investments are made in not only physical assets but also organizational procedures and intangible assets such as knowledge, skill, motivation, leadership, and alignment of people in the organization [19]. Due to the investments in the intangibles, the cost and benefit of this type of MPI is hard to evaluate with traditional calculation methods such as return on investment [20]. Furthermore, this MPI type tends to involve major changes of the way of working for a large number of people in the organization. This means that political and cultural changes are likely to be necessary in this type of MPI [20].

It seems that a process of this type is less abrupt than the first type of MPI. A MPI type II can be a result of

many smaller changes that occur in concert and reinforce each other toward a radically new form. The deliberate approach can be applied to this type of MPI, but many researchers claim that this type can be less managed or controlled especially when a cultural change is involved [21]. These researchers instead advocate the deliberate-emergent approach in which a process of MPI may appear a series of learning cycles rather than predefined steps to be followed. Since most of the solutions to be adopted are externally available, implementation can be a critical part of a MPI process. In addition, the difficulty in calculating the return on investments in intangibles implies that the top management's belief, commitment, and patience play an important role in accomplishing a MPI of this type.

The above discussions are about generic managerial issues for MPI type II. For more specific MPI initiatives such as introductions of Six Sigma and Lean manufacturing, there are numbers of articles and books describing how to implement these initiatives.

MPI type III: Generally there is less literature describing this type of MPI than the earlier types. Since MPI type III involves basic changes in the structural area, it shares similar features to the ones of MPI type I. Type III tends to require a large capital investment at a single point of time, thus a careful planning is a critical part of a MPI process. A process of MPI tends to be formal and systematic and a limited number of people in the organization activity participate in the process.

A notable difference from type I is that type III requires significantly more development kind of work, especially when a MPI effort includes development of solutions that are new to the state of the art. A development phase of a MPI process can be similar to an early phase of new product development process that is less structured and liner and more iterative, emergent, and learning oriented [22].

In addition, researchers have argued that an organization setting is influential in achieving radical innovations. Researchers have identified characteristics of organizations conductive to radical innovations [23]. Examples are management's strong intent, commitment, and support for radical innovations, extensive external knowledge gathering of employees, cultures of experiment and risk-taking, and openness and trust among people in the organizations. Establishing these characteristics is an important condition to achieve the type III of MPI. There is also a study particularly focusing on characteristics of manufacturing organizations supportive to radical innovations [24]. The study has identified some characteristics related to production engineering functions. They are; management's setting highly stretched targets on production engineering functions (e.g. doubling productivity, halving manufacturing areas, halving investment cost for pieces of equipment, etc.); substantial amounts of financial and human resources being allocated to development kind of work in production engineering; and the production engineering functions having close cooperation with product development and operations functions. These characteristics related to production engineering functions can also be important to achieve the type III of MPI.

MPI type IV: Similar to type III, a limited amount of knowledge has been accumulated for type IV of MPI. Type IV shares similar characteristics to type II because they both involve major changes in the infrastructural area. Changes tend to be more gradual than those in the structural area. Both type II and IV tends to require active participation of a large part of people in an organization.

However, a process of type IV can be different from type II because type IV involves generation of radically new solutions. Such solutions can be developed by a few specialists but also emerged as a result of high-level participation of people in the organization in innovation efforts [25]. MPI involving such an emergent innovation can be initiated by the management with stretched targets but how to achieve these targets largely relies on people's ability to discover solutions through organizational learning.

Similar to type III, establishing an organization setting supportive to radical innovation is an important precondition to achieve the type IV of MPI. The characteristics of organization mentioned in the discussion of type III are also relevant to type IV.

5.2. Basic strategic directions concerning what type of MPI can be conducted

The model of four types of MPI can also be used to discuss basic strategic directions in terms of what type of MPI can be conducted at a specific company. Two basic directions can be discussed.

First, improvements or innovations in the infrastructural area should be conducted before initiating major changes in the structural area. Several practitioners and researchers have mentioned this direction. For instance, Harrington [26] state that work processes need to be reformed before increasing the level of automation, otherwise the investment in the automation is hard to produce desirable effects on the productivity in proportion to the amount of the investment. However, this strategic direction may not be appropriate for manufacturing functions at fast-developing countries. Considering that technological progress strongly affects the speed of development in

production and that there is usually a gap in technological advancement between the developed and developing countries [27], active and effective absorptions of externally available technologies can be a more appropriate strategy for manufacturing functions at fast-developing countries.

The other direction is that local innovations should precede radical innovations. As far as better solutions are externally available, it is reasonable to adopt them. When a company has arrived at the state of the art in manufacturing, radical innovation in manufacturing can be considered.

6. Conclusions

This paper has proposed a model of four types of MPI. MPI encompasses a wide range of activities from technological innovations to major changes of work processes and cultural changes of an organization. Although researchers have discussed different typologies of innovation in literature, MPI has been classified as one type of innovation among other types and further classifications within MPI have not been made. The proposed model helps to understand different kinds of MPI in a more structured way. Another benefit of the typology of MPI is that academics can narrow their focus on a specific type of MPI and investigate the relationship between organizational variables and a specific type of MPI.

It should be noted that generally a typology of innovation has innate problems arising from the fact that no innovation is isolated, and that an innovation of one type is likely to be associated with other types of innovation [1]. The classifications in the proposed model are conceptual. In reality a MPI initiative can be categorized into one or more of MPI types but is likely to include some aspects of other types in smaller degree.

This paper has also discussed possible approaches and important factors that need to be considered for each type of MPI. Although the discussion has been at a generic level, the discussion can help practitioners to consider what to expect and prepare when conducting different types of MPI.

Finally, the study presented in this paper has found that limited knowledge has been accumulated on the types of MPI related to radical innovation. More work can be conducted in the areas related to these types of MPI.

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