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ABSTRACT

Along with increasing globalization, the management of international manufacturing networks is becoming increasingly important for industrial companies. This paper mainly focuses on the coordination of knowledge transfer within manufacturing networks. In this context, we propose the time-place matrix as a tool for mapping the distribution of knowledge within manufacturing networks. Using this tool, four important questions about the coordination of knowledge transfer within a manufacturing network are identified: know-where, know-what, know-when, know-how to transfer. The relationships among these questions are discussed, based on which a frame of thought is proposed that managers can use in their quest for network competitiveness.

Keywords: knowledge transfer, manufacturing network, coordination

INTRODUCTION

It is indisputable that business today is international. The role of manufacturing companies has changed from supplying domestic markets, via supplying international markets through export, to supplying international markets through local manufacturing. Hence, the research on international issues in manufacturing has evolved from local production, through global sales and marketing, into global manufacturing (Rudberg and Olhager, 2003). Consequently, a new paradigm has emerged in the field of international strategy that builds on the idea that a multinational company has to adopt a structure and an organization that allows the company to respond to different and possibly even conflicting demands from its international environment (Prahalad and Doz, 1987; Bartlett and Ghoshal, 1989). An important element of this new paradigm is its network approach to the study of the activities of multinational companies (Dunning, 1993). It is predictable that as competition is globalizing and the complexity of the environments in which companies operate is increasing, the management of integrated international networks will become increasingly important for manufacturing companies (Bartlett and Ghoshal, 1989; Ferdows, 1997). According to De Meyer (2000), many flows in manufacturing networks need to be coordinated. Among these flows, the knowledge flow is probably the most important, yet difficult one to manage.

The research presented in this paper focuses on the coordination of the transfer of knowledge within manufacturing networks. From a theoretical perspective, the general aim of this research is to build a frame of thought for directing knowledge transfer on the level of a manufacturing network which, then, provides the basis for analysis, theory development, and guidelines for both academic and industrial use. The paper is organized as follows. First, a literature review shows the importance of research on knowledge transfer within manufacturing networks. Second, a tool for mapping the distribution of knowledge within manufacturing networks is proposed. On the basis of this tool, the coordination of knowledge transfer is discussed. Four "know" questions are then identified and analyzed. Finally a frame of thought is proposed which can be used as the guideline for managers when they need to transfer knowledge within manufacturing networks. Throughout the paper, small empirically based examples are used to illustrate our arguments.

LITERATURE REVIEW

Within the decision-making process related to global manufacturing activities, two types of decisions can be distinguished: those concerning "configuration" and those related to "coordination" (Fawcett et al. 1993). Coordination is one of the management tasks. In the context of manufacturing networks, coordination primarily involves tactical level decision-making aimed at planning global activities efficiently and effectively. A fundamental issue to be addressed at this level is how to design and manage the flow of goods, people, technology, and information in international networks (Chakravarty et al., 1997). This aspect is also concerned with technology transfer and diffusion as well as "within network" learning (Galbraith, 1990; Flaherty, 1996) and, thus, knowledge transfer.

Bhatnagar et al. (1993) provide an extensive literature review of the models available for general and multi-plant coordination. The authors distinguish two broad levels of coordination: a general level (coordination of decisions of different functions) and a multi-plant level (dealing with decisions regarding the same function at different echelons in the organization). Das *et al*. (1998) propose an approach based on reinforcement learning to coordinate a multi-plant and multi-country facility network that spans manufacturing and distribution stages. The problem is modeled as a Markov Decision Problem and the optimal coordination policy is determined through reinforcement learning under an integration perspective. Recently some authors have addressed the coordination problem in global logistics through specific case studies (Kuutti, 1996; Clendenen *et al*., 1996; Arntzen *et al*., 1995; Lee and Billington, 1995). At the same time, several companies, such as Intel (Mlynarczyk, 1995), Ericsson (Rudberg et al, 1998), and Honda (Sonoda, 2002) also have created clear and standardized guidelines for manufacturing and related activities as a means to better coordinate their manufacturing network operations.

Most research has focused on planning the operations of manufacturing networks from a material flow perspective, using predominantly mathematical methods. Given the current (and future) competitive environment, too few scholars focus on knowledge. On the one hand, knowledge is considered more and more important. As heralded by Drucker (1993) and Nonaka (1994), a new economy or society, referred to as the "knowledge society" is developing, which distinguishes itself from the past in the key role that knowledge plays within society. The emerging knowledge based view of the firm (Kogut and Zander, 1992; Nonaka, 1994) suggests that the key role of the firm is in creating, integrating, storing and applying knowledge. On the other hand, it is impossible for manufacturing to withstand the globalization trend. Companies are establishing more and more factories globally.

Knowledge is a source for innovation and, thus, potentially providing a dynamic competitive advantage, provided that it is transferred and shared. Without that, geographically distributed plants would be knowledge islands and not contribute to the dynamic development of the network(s) they are part of.

So, it is relevant to discuss knowledge transfer within manufacturing networks. Currently, most research on knowledge focuses on the process of making available and amplifying knowledge created by individuals as well as crystallizing and connecting it to an organization's knowledge system (Nonaka et al., 2006). Knowledge theory has been used to explain phenomena in many disciplines, including organization theory and behavior, human resource management and leadership, innovation and technology management, strategic management, public administration and information management. Some of these disciplines have considered knowledge transfer as well. For example, Szulanski (1994) discusses intra-firm transfer of best practices. Tsai (2001) discusses knowledge transfer in intra-organizational networks by starting from the absorptive capacity and network position of manufacturing units. However, most of this research emphasizes the organizational level. Thus, connecting knowledge and manufacturing is needed. However, as Ferdows (2006) points out: "*… scholars in the field of operations management are almost absent in the knowledge management literature and our practitioners are often relegated to the back seat in their companies' knowledge management campaigns*".

Indeed, some scholars on manufacturing do pay attention to the role of knowledge. Corso (2002) enlarges the perspective of looking at product innovation as a continuous process of knowledge creation, embodiment and transfer, which extends to all phases of the product life cycle, including development, manufacturing, installation, consumption, and maintenance. Based on this, he maps the routes of knowledge in this, what he calls, process of continuous product innovation. Ferdows (2006) discusses the transfer of changing production know-how and identifies four zones for classifying production know-how according to the interplay between the level of codification and the rate of change of production know-how. But what needs to be stressed is that most research still focuses on how to codify or transfer tacit knowledge residing within individuals (Kogut and Zander, 1992; Nonaka, 1994; Szulanski, 1996) to other plants. Vereecke et al. (2006) discuss knowledge flows within manufacturing networks. They propose a new, empirically derived typology of plants in the international manufacturing network of multinational companies, which is based on knowledge flows between the plants. But they neglect to analyze how the knowledge is actually transferred within the manufacturing network.

Thus, it seems clear that the systematic and systemic thinking about knowledge *transfer* between *plants* in manufacturing networks is lacking. The purpose of this paper is to address exactly this.

TIME-PLACE MATRIX

Before we start considering how to coordinate knowledge transfer, we need to find out which knowledge we have and where it is. In other words, as a first step, we need some tool to map the type and distribution of knowledge in the manufacturing network. Certainly, such a tool should describe what is happening in the real world. Therefore, it is useful to develop them by starting from a practical perspective and study what is happening in industry.

Company A is the world leader in silicon innovation. It tries to develop technologies, products, and initiatives to continually advance how people work and live. Currently, it has 11 production facilities and six assembly and test facilities worldwide. It employs more than 7000 researchers and scientists in labs around the world. Taking one product as example, which was developed in the US: as from 2002, the product was produced at its plant in Oregon. Later, company A extended production to its plants in Mexico and Ireland.

Company B is a medium size Danish textile company, which chooses to position itself as an OEM supplier of medical textiles and has few, but very important, customers. It keeps manufacturing tasks that are central from a knowledge and competence perspective, at headquarters in Denmark. This involves two manufacturing halls: one is reserved for R&D; the other handles ramp-up tasks. Mass production takes place in company B's plants in Ireland, Slovakia and the US.

Actually, it is easy to find this kind of examples of companies, in all industries and of all sizes, that have new product development in one place, ramp-up manufacturing at the same site or elsewhere, and mass production in yet another location somewhere in the world. New product development, ramp-up, mass production, and also end-of-lifecycle production could be viewed as typical production processes, which also correspond to the four stages (introduction, growth, maturity and decline) of the product life cycle (Ryan and Riggs, 1996). During this process, not only the product and the market pass through a series of major stages, so does the production process used in the manufacturing of that product proceed from highly flexible, but not necessarily very cost efficient toward increasing standardization, mechanization, and automation (Hayes and Wheelwright, 1979) and back at the end of the life cycle. The knowledge on, for example, how and where to produce the product most effectively changes accordingly.

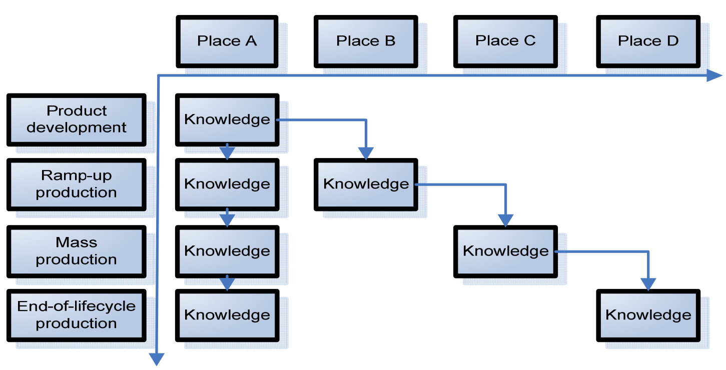

Figure 1: Time-place matrix for mapping knowledge transfer in manufacturing network[1]

[1] This model takes its outset in vertically integrated mass producers. In companies that do not mass produce, between one and four phases can be distinguished: product development (possibly), ramp-up production (possibly), one-off or small batch production, end-of-lifecycle production (possibly).

The time-place matrix shown in Figure 1 captures the major changes taking place. Time is represented according to the four life-cycle stages, namely product development, ramp-up production, mass production and end-of-lifecycle production. The locations of R&D centers and plants make up the place dimension. By using the time-place matrix, it is easy to map out the existing knowledge in manufacturing networks. This is the static way of using it. Furthermore, this matrix could also be used dynamically to show the possibility of knowledge transfer among different phases and/or places.

COORDINATING KNOWLEDGE TRANSFER IN MANUFACTURING NETWORKS

Taking the time-place matrix as the starting point, 5W1H (why, who, where, what, when, how) thinking could be used for coordinating knowledge transfer within manufacturing networks. The ***know-why*** question aims at understanding and improving the contribution of knowledge transfer to the performance of the whole manufacturing network. The ***know-who*** question is covered by the know-where question, as shown below. Therefore, we will pay attention only to ***know-where, know-what, know-when, know-how*** questions on the basis of the time-place matrix. In the following, we will introduce them separately, and then open up the relationships among them.

Know-where

Know-where means where to transfer to. But considered in the context of a time-place matrix, it should go beyond only discussing “where to transfer”. Essentially, know-where in this context means identifying the knowledge sender and receiver, which could be the nodes in the matrix positioned by two dimensions (time and place), i.e. know-where refers to places and phases knowledge transfer taking place. Based on observations of several case companies, it is possible to generalize three routes of knowledge transfer in the time-place matrix.

Firstly, knowledge transfer could emerge in the same production phase but at different locations. Knowledge transfer in the same production phase, but between different places, is non-directional, which means that different places could be knowledge senders as well as knowledge receivers. This is quite different from knowledge transfer between different production phases which is discussed in the following. Generally speaking, this type of knowledge transfer mainly happens in the product development and mass production phases, and less so between plants engaged in ramp-up and end-of-lifecycle production. Company C provides an example.

Company C is a medium sized textile company offering high quality woven textiles to industrial customers. It has two research centres placed in Europe and China respectively. The research staff in the two centres exchange their knowledge using video-conferencing, visits, and phone calls. With regard to the mass production phase, company C outsources most of its production activities. This means that its partners operate the mass production phase of company C. However, it has its own engineers who visit different partners and acquire new knowledge from them. Afterwards, these engineers give courses to other partners to make sure that knowledge is transferred and used to improve performance.

Secondly, knowledge transfer could emerge in the same place but among different production phases. Generally, this occurs when a company keeps the whole production process in the same place, from product development to end-of-lifecycle production. But as globalization progresses, fewer companies choose to do this. Instead, ever more companies disperse their production processes.

This means that the third type of knowledge transfer, namely between different phases located in different places, increases. Knowledge transfer within company A and company B are of this type. In company A, the product is developed and ramped up in the US, but mass produced in Mexico and Ireland. Company B has kept its development and ramp-up activities in Denmark, but moved its mass production activities to Ireland, Slovakia and the US.

What needs to be stressed here is that knowledge transfer among different production phases, irrespective of place, is directional. Obviously, it is normal for knowledge to be transferred from product development all the way through to end-of-lifecycle production. This process could be viewed as the evolution of knowledge about the product, which will be discussed in detail later. Also, there exists the possibility that knowledge is transferred from product development to mass production directly without via ramp-up, for example in the form of product modifications. On the other hand, there is also the possibility of reverse transfer, namely knowledge transfer from mass production to ramp-up, from ramp-up to product development, and from mass production to product development directly.

Know-what

Know-what mostly means which knowledge needs to be transferred. As there exist different kinds of knowledge in the manufacturing network, all of which can be transferred, it is important to find the answer to the know-what question, which could be one of the bases for discussing knowledge transfer.

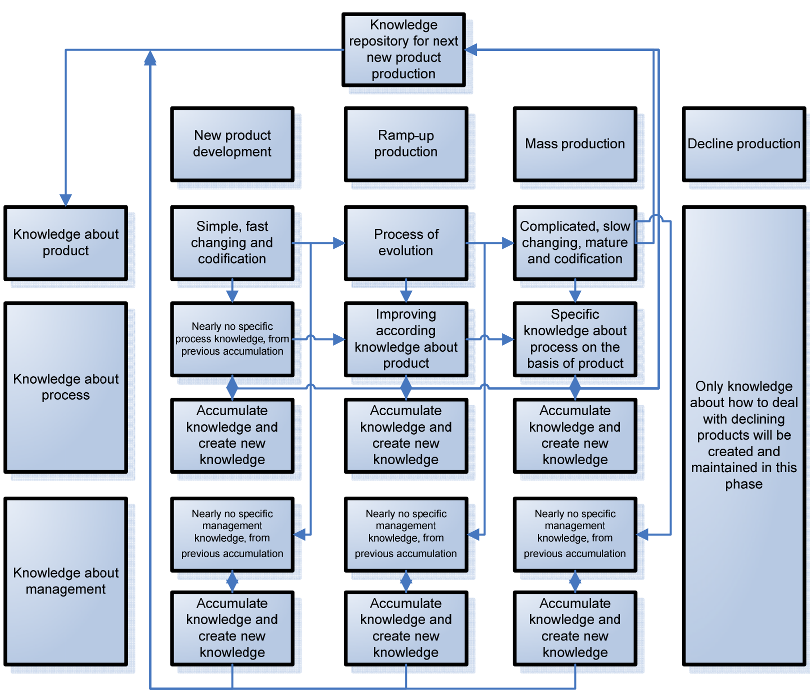

Figure 2: Three types of knowledge transferred in the manufacturing network

Generally speaking, three types of knowledge are transferred in manufacturing networks, namely: 1) product knowledge; 2) process knowledge; and 3) management knowledge. This division of knowledge mainly originates from the structural and infrastructural decisions, which are the two core elements of content research of manufacturing strategy (Adam and Swamidass, 1992). We will introduce the three types separately and discuss their relationships in the context of the time dimension (the product lifecycle), as shown in Figure 2. To some extent, this figure is inspired from Corso's (2002) research, as he also maps the routes of knowledge transfer in the process of continuous product innovation, which involves all the major phases of product life cycle, in the context of a single product or at a product family level. However, there obviously exist some differences between his research and what is shown in this paper. Firstly, Corso discusses knowledge transfer in the product life cycle while this paper discusses it in the manufacturing process cycle. Secondly, he starts his discussion on the basis of single product or product family level, while the research shown in this paper takes outset on manufacturing network level.

Product knowledge – Knowledge about the product mainly includes product specifications and product-specific process and management knowledge. In fact, the process from product development to mass production could be viewed as an evolution of knowledge about the product. Moreover, this evolution process does not end up with the mass production. It will be included in the company's knowledge repository and may be used again in future product development activities. Company D's transfer of knowledge from Denmark to China is an example in place. However, as the Chinese engineers go to Denmark to learn how to make the valve, it is obvious that what they learn also includes knowledge about how the product is made (process) and how that process is managed (management).

Company D is one of the largest industrial companies in Denmark. It has mass-produced one type of valve in Denmark for a long time. Recently, the company found there is a large demand for the valve in the Chinese market. Therefore, it prepares to move the production to China. Chinese engineers go to Denmark to learn how to make the valve, after which they go back to China to organize the ramp-up on the basis of what they have learnt in Denmark with the necessary modifications for the Chinese market. This could be viewed as the case for knowledge transfer from mass production to ramp-up. Furthermore, through every new production process, workers keep accumulating knowledge about the process for different phases, which in turn provides new opportunities for them to create new knowledge to be used in the next product development.

Process knowledge – Knowledge about the process mainly refers to production know-how, including manufacturing technology but also operating knowledge stored in the heads and hands of the operators. Generally, it could be analyzed from two angles, as shown in Figure 2. On the one hand, along with the evolution of knowledge about the product from product development to mass production, knowledge on how to produce the product changes correspondingly. Again, this actually presents product-specific process knowledge. On the other hand, through producing a range of products over time, non-product bound experiential knowledge about the process is accumulated about each of the production steps and phases, and about the entire process. Moreover, according to Nonaka's knowledge spiral (1994), new process knowledge could also be created in this environment. Knowledge thus accumulated and/or created becomes part of the knowledge repository available for next product developments (whether that knowledge is used adequately is another issue). Company C is an example to illustrate this type of knowledge transfer.

As there are two ways of analyzing knowledge about process, it is better to discuss the transfer of this type of knowledge separately. Product-specific knowledge is normally transferred between different phases which are possibly located at different places, along with the evolution of knowledge about product. Accumulated and created knowledge on a specific production phase (mainly product development and mass production) is transferred between different locations – see company C.

Management knowledge – This third type of knowledge mainly concerns the management of different production phases, including how to organize production systems, cooperate with other functions, and develop relationships with partners. In the majority of situations, this type of knowledge focuses on specific production phases. To some extent, it is also part of the knowledge repository for new product development. The transfer of this type of knowledge mainly happens among different places involved in the same production phase.

Know-when and know-how

After having considered the know-where and know-what questions, it is now relatively easy to understand know-when and know-how. Know-when means when to transfer, namely when knowledge is qualified for being transferred. Companies use to set performance standards to control know-when. Once standards are reached, knowledge could be transferred to the next phases or to other locations. Take company C as an example. In the product development phase, the new product is designed by a project team. The prototype of the new product will be made by the partners. In most cases, this gives rise to adjustments in the product specifications. This adjustment process usually takes several turns.

Several standards can be used to decide whether the product (and the knowledge coming with and embodied in the product, is ready for transfer to mass production, including cost, quality and manufacturability. Exactly what standards prevail varies from company to company and product to product.

Relationships among the four knowledge questions

On the basis of above analysis, the inherent relationships among know-what, know-where, know-when, and know-how can be found, as shown in Figure 3. Furthermore, these relationships show the consideration paths for managers if they start considering knowledge transfer within the manufacturing network.

Generally speaking, know-what is the first thing to be considered. It is the starting point for discussing knowledge transfer within manufacturing network. The other three knowledge questions can be decided on the basis of know-what. However, before making know-when and know-how decisions, know-where needs to be decided because it can have important impact on know-when and know-how. Therefore, two levels can be distinguished for the four knowledge questions. Know-what and know-where are in the first level. Know-when and know-how represent the second level, as they are decided on the basis of know-which and know-where.

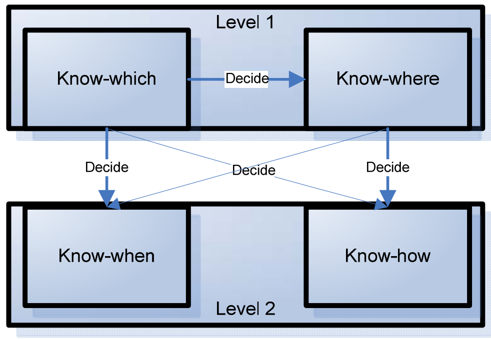

Figure 3: relationships among four knowledge questions

Thus, Figure 3 provides a framework to managers involved in organizing and coordinating the transfer of knowledge within their company's manufacturing network. Indeed, there could be many different factors affecting the decisions of four knowledge questions. For example, know-where decisions are affected by corporate strategy, the maturity of the potential knowledge receiver(s) and the knowledge senders, and the quality of the knowledge to be transferred. Each of these factors are also likely to affect the know-when and know-how decision-making. Furthermore, various different mechanisms many be used to actually transfer knowledge to other stages and/or locations. Ferdows (2006), for example, mentions four mechanisms that could be used to transfer production operations: moving people, projects, manuals, and joint development. Whether this list is exhaustive is not clear.

CONCLUSION AND FUTURE RESEARCH

This paper mainly focuses on the transfer of knowledge within manufacturing networks. The paper makes three contributions: 1) by reviewing the literature on manufacturing networks and knowledge research, we exploit the importance of discussing how to manage knowledge transfer within manufacturing networks; 2) the time-place matrix is proposed as a tool for mapping the distribution of knowledge in the manufacturing network; 3) taking the matrix as the starting point, four questions about coordinating knowledge transfer are generated: ***know-where, know-which, know-when, know-how***. These knowledge questions are introduced, analyzed and discussed separately. Moreover, by analyzing the relationships among the four knowledge questions, a framework is developed for managers facing knowledge transfer questions in manufacturing networks.

Through the time-place matrix, the four knowledge questions, and the framework about coordinating knowledge transfer, this paper attempts to view knowledge transfer within manufacturing networks systematically. Further research is needed to support each of the decision categories, for example: standards underpinning the know-when question and decision and the transfer mechanisms used to support the know-how issue, and the roles of strategy and maturity in the know-where discussion.

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