The Effects on Knowledge Creation and Transfer in Production Process Verification due to Virtual Prototypes

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Abstract: The purpose of this article is to analyze how knowledge creation within production process verification units within companies and knowledge transfer between product development and production units are affected by the use of virtual prototypes. The analysis shows that the use of virtual prototypes has a negative effect on knowledge creation and transfer. However, increased degrees of acceptance regarding the new method combined with improved technical level are anticipated to reduce these negative effects.

Keywords: Final verification, virtual prototype, knowledge transfer, automotive industry.

1. Introduction

When companies develop new products they want to do this as inexpensively and quickly as possible, taking into account that their customers still want a high quality product. In any manufacturing industry, where the competition between manufacturers over the customers is fierce and the profit window is decreasing (Bullinger et al, 1995), this will be particularly true. The automotive industry is a good example of this situation. During the last two decades, there has been a lot of attention aimed at decreasing time-to-market (TTM) both within industry and the scientific community (Almgren, 1999).

One way of decreasing TTM is to perform the sub-processes within the product development process concurrently. To be able to do so, knowledge has to be transferred between different departments within the company. One way of doing this is to involve manufacturing representatives in the development work in order to use their knowledge to create a better product (Almgren, 1999).

The main phases during product development (in accordance with Hayes, Wheelwright and Clark (1988) in Wheelwright and Clark (1992, p. 33)) are presented in Figure 1.

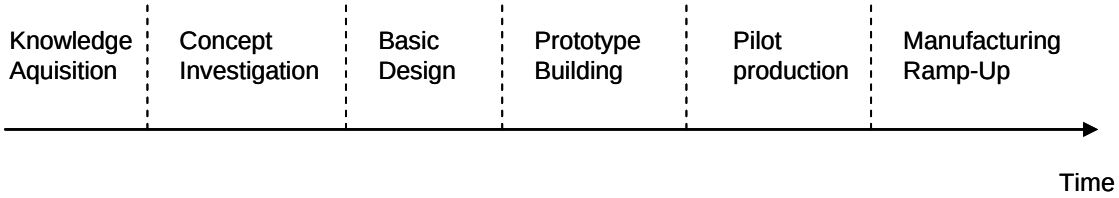

Figure 1: The main product development phases. Source: Hayes, Wheelwright and Clark (1988) in Wheelwright and Clark (1992, p. 33).

A lot of studies have been performed within the first three phases (D'Adderio, 2001) and there has been some attention to the last two phases (Almgren, 1999), but there has been little attention focused towards the Prototype Building phase (PB-phase). Thus, the processes included in the PB-phase have a clear improvement potential within the automotive industry since the costs for physical prototypes are high (Thomke, 1998).

One clearly visible trend in society in general and in product realization in particular is the increased use of computer-based tools (Poolton and Barclay, 1998; Rangaswamy and Lilien, 1997). In regards to this area, one apparent area of interest from some of the major actors in the industry (Thomke and Fujimoto, 2000; Östman, 1998; Gomes de Sà and Zachmann, 1999) is to use virtual prototypes (a virtual prototype should be understood as a computer-generated visualization of parts of (or entire) products.) instead of physical prototypes to verify the new product. The use of such prototypes is believed to have a positive impact regarding the outcome of the PB-phase. The studies performed to confirm this belief are scarce (Thomke and Fujimoto (2000); Nobelius (2001); Gomes de Sà and Zachmann, 1999) but the focus in these studies has neither been on the PB-phase, nor on knowledge issues.

Knowledge issues in product development have been studied to great extent (for example West and Burnes, 2000 and Lindkvist, 2001), but the focus on knowledge issues in the PB-phase is

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scarce. Some studies have been performed where the knowledge perspective has been applied (Thomke, 1998) but not in such detail. Other studies have been performed that deals with knowledge transfer issues due to virtual prototypes, but they only treat knowledge transfer within the early phases (D'Adderio, 2001).

This indicates a clear need to study the knowledge issues connected to the Prototype Building phase.

2. Purpose

The purpose of this article is to analyze how knowledge creation within production process verification units within the companies and knowledge transfer between product development and production units are affected by the use of virtual prototypes.

3. Theoretical framework

In this paper, a theoretical framework based on the five-phase model of organizational knowledge creation presented by Nonaka and Takeuchi (1995) is used. Some modifications will be done to better suit the problems identified. The basic reason for choosing Nonaka and Takeuchi is that it is a process including both explicit and tacit knowledge as well as both individual and organizational knowledge issues important in the studied cases.

The Nonaka and Takeuchi (1995) model includes five phases, which shows how the process of organizational knowledge creation spirals through the organization. This model is developed for product development and shows how the process moves cyclically and across levels. While the first four phases move horizontally, the fifth one moves vertically in the organization. In the fifth phase activities are created at different levels of the organization. The model is an ideal example, and it includes the following phases: sharing tacit knowledge, creating concepts, justifying concepts, building an archetype, and cross-levelling knowledge. The first phase is a socialization mode and the second is an externalization mode. In the second phase a concept is created, which then must be justified in the third phase. The organization decides whether or not to proceed with the concept. If the concept is accepted it will be converted into an archetype in the fourth phase. An archetype can be either a physical object such as a prototype, or an operating mechanism such as a new organizational structure. In the fifth phase the knowledge created in the previous phases is spread to other parts of the organization or even to parts outside, e.g. customers, suppliers, and partners. In this paper the phases will differ some from the original model as seen in Figure 2.
The following sections include descriptions of the different activities included in the theoretical model. Further on in this paper, this model will be referred to as KTVP (Knowledge Transfer in Verification Processes). In this model, there is no distinction made between different kinds of knowledge so the reader should interpret knowledge as including both explicit and tacit knowledge when not articulated explicitly.

There are four main factors that influence the difficulty of knowledge transfer: The characteristics of the knowledge transferred, the source(s), the recipient(s) and the context in which the transfer takes place (Szulanski, 1996). These four are combined in the initial knowledge flow. Szulanski (1996) discusses variables influencing these four factors. In this paper, only the variables specifically interesting for each phase are considered.

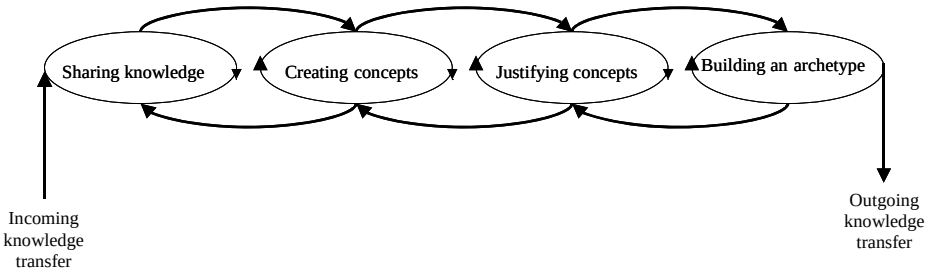

Figure 2: The developed version of the Nonaka and Takeuchi model; the Model of Knowledge Transfer in Verification Processes (KTVP), used in this paper as the theoretical framework

3.1 Incoming knowledge transfer and sharing knowledge.

Incoming knowledge transfer and sharing knowledge are discussed in the same section since these activities are closely related as well as prerequisites for being able to perform verification activities in the first place. Variables of particular interest when changing from physical to virtual verification are:

- Unprovenness, which is connected to the characteristics of the knowledge (the tacit knowledge of skilled workers needed for verification complicates the knowledge transfer).
- Lack of motivation with the participants is connected to both the source and the recipients.
- The incoming knowledge is not perceived as reliable. When new technology is used, people have a tendency to perceive the information provided from that source as less reliable.
- Lack of retentive capacity. If the recipients are not able to retain the knowledge transferred, the transfer is unsuccessful.
- Barren organizational context. If there are formal structures and coordination mechanisms that support knowledge transfer, the transfer process is facilitated.
- An arduous relationship between the participating individuals can be a negative influence on the knowledge transfer. For example, if the participants have not met before or if they have different cultural background this can put a damper on the openness and acceptance between the individuals.

Another important area discussed here is the positive influence from the use of routines to improve the ability to adopt the incoming knowledge (Szulanski, 1996; Hellriegel and Slocum, 1974). In short, the more routine there is in a knowledge transfer, the easier it is for the recipient to adapt that knowledge.

The sharing knowledge phase includes, what Nonaka and Takeuchi (1995) calls the socialization mode of knowledge creation. When individuals share their experiences shared tacit knowledge, so called sympathized knowledge, is created out of the individual tacit knowledge. The process of sharing tacit knowledge can take place either through dialogue or through observation, imitation, and practice. To enable this mode, teams must be created where the socialization can take place.

3.2 Creating concepts

Within the verification process studied, the creating concepts phase can be exemplified with the discussions held to decide whether the planned manufacturing sequence is appropriate and the outcome from these discussions. The variables that are particularly interesting in this phase are:

1. Causal ambiguity. If there is ambiguity within the verification organization regarding the source of knowledge used for particular decisions, the knowledge transfer process is obstructed.
2. Not perceived as reliable. If the novelty in the virtual environment affects the individuals in a negative way due to low personal experience, there is a risk that the knowledge and information provided from the computers are perceived as being unreliable.
3. Barren organizational context. The cross-functional integration in the verification team creates a sound base for the amount of knowledge organizationally enabled in the verification teams.

A fourth variable not treated by Szulanski (1996) that should be included here is the concept of ba (ba means place). In this setting it is of interest to study the environment where the verification takes place. Do the participants previously know the environment? Do the participants have the possibility to communicate face-to-face? Nonaka and Konno (1998) emphasise face-to-face experiences as a key to conversion and transfer of tacit knowledge.

3.3 Justifying concepts

When justifying concepts, the main activities do not include knowledge transfer, so here different justification modes are presented.

To verify any product or process it is necessary for the participants in the verification process to be able to justify and by that, to accept that the results from the process are valid. There are several ways of justifying results and processes. The following discussion regarding justification is based on Tell (2001). He describes two different dimensions of justification modes where the endpoints (of a continuum) are described.

The four different kinds of justification are:

1. External justification
2. Internal justification
3. Justification by procedure
4. Justification by performance

External justification can be exemplified with the positivistic way of performing scientific studies. This kind of justification means that the individual accepts a proposition based on beliefs that originate ex somate. The foundation is that there are some things that are given and that from these things, truth originates.

Internal justification can be regarded as the opposite to external justification. In other words, the individual can only accept proposed solutions if they coincide with internal beliefs. These kinds of beliefs can be created within a social system,

which lead individuals included in this social system accepts rules that might seem strange for people outside of the system.
Justification by procedure is the kind of justification used to convince the reader that the conclusions are correct by describing the theoretical framework, presenting the method used to gather information and analyzing the information in a conventional way. If the appropriate approach to research is used, then the conclusions are justified.

Finally, when trying to justify by performance, the method is regarded as an obstruction to real progress. It is only when there is disorder and irrational behaviour is used that knowledge can be created. The results are the only thing that matters. They speak for themselves.

3.4 Outgoing knowledge transfer

This final phase is congruent with the mode of internalization, which is when explicit knowledge is turned into tacit knowledge (Nonaka and Takeuchi, 1995). The tacit knowledge created is called operational knowledge, i.e. tacit knowledge about such things as the feel for a correctly performed assembly sequence. Documents, manuals or oral stories are useful tools. To exemplify, the act of documenting helps individuals to internalize their experiences. Furthermore, documents can enable the transfer of explicit knowledge to others. In this mode the need for action is stressed. Training through activity instead of continuous reasoning is the key.

4. Method

This paper is based on studies performed within the automotive industry, since it is an industry where intra-organizational knowledge transfer combined with virtual verification is widespread today. In this paper, Volvo Cars and SAAB Automobile were utilized for the empirical material. Within these companies, the most labour-intensive part of the manufacturing process was chosen for the study. This was also the area where most radical changes were made in the verification process, since computer-based tools have been used for years regarding automated assembly lines (cf. robot simulations).

4.1 Selection of research methodology

Since the character of the main questions in this paper is “how” in combination with the exploratory nature of the study, this implies (Yin, 1994) the use of the case study approach. The use of case studies is strengthened by the fact that the author had little control over the events.

4.2 The case studies performed

This paper is based on several studies performed during a four-year period. The three main studies are presented briefly below:

1. Study 1 was performed during the production ramp-up phase of a product development process (PDP), where physical prototypes were used during the verification process. In this study, the outcome from that development process was collected and analyzed. To add supplementary details, a retrospective study was performed after the completion of the development process.
2. Study 2 was performed during the prototype-building phase of a PDP where virtual prototypes were used instead of physical. This study was aimed at describing the changes in outcome from PDP’s with a varying degree of virtual prototypes used. Here, historical data from two earlier PDP’s was compared with the results from the contemporary PDP.
3. Study 3 was performed during the same PDP as Study 2. This study was aimed at mapping the work processes, the organizational design and communication patterns during the verification process.

4.3 Research methodology used in the studies

A case study approach was used in all of the studied cases but the detailed design differed some between the studies (see descriptions below).

The studies performed have included verification processes of two different products. These processes were separated in time and were performed after each other. The research procedures have differed due to the fact that the process focused during Study 1 had already been performed when the studies begun, while during Study 2 and 3 the verification process was studied in real time. Therefore, the data collected during Study 1 consists mainly of historical data. Supplementary interviews were performed and informal discussions were held in order to receive a better understanding of the work method and organization used during Process 1 (The verification process studied in Study 1 is called Process 1. The same logic applies for Studies 2 and 3.)

During Study 1, own observations were used in combination with supplementary interviews with skilled workers, pre-production engineers and project leaders to receive as accurate information as possible. Due to the informal nature of the

supplementary interviews, notes were taken during the interviews and transcribed afterwards. In total, ten interviews regarding the verification process were performed during Study 1. The average length of each interview was approximately 60 minutes. The interviewees were asked about the verification method and organizational structure used. An interview template with open-ended questions developed for this particular study was used.

During Study 2 and 3, information was collected using observations (participation during four different verification series), interviews (to gather information regarding process descriptions and work methodology between the verification series) and collection of company internal performance data. The interviewees were selected depending on their degree of participation and on their previous experiences from earlier verification processes. Interviewees were also selected so that at least one representative from all organizational parts involved in the verification process cover was formally interviewed. In total 14 people were formally interviewed. An interview template with open-ended questions was used. The procedure performed during and after the interviews as well as the extent of each interview was similar to Study 1. In addition to the interviews, informal discussions were held with other people directly involved in the verification series. Participating observations were made both by attending meetings where different aspects on verification were discussed, and by attending four verification series. During the observations, the other participants were notified of the presence of a researcher. In addition to the oral sources, company internal databases were used as an information source at the same time as the structure of the information stored was studied to be able to describe how the information was handled.

4.4 Validity and reliability

The initial question that needs to be addressed is whether the study has construct validity or not. The knowledge transfer processes were not initially in focus, but as time went by they became central. The changes in effect of the knowledge transfer efforts performed was impossible to measure objectively since it was not possible to perform measurements regarding the verification of physical prototypes. Instead, information regarding the knowledge transfer processes during the verification process was gathered in order to use a theoretical model to analytically get to the effects. The construct validity in that case is therefore depending on the validity of the theoretical model used.

The second question to be addressed the reliability issue. To create reliability several sources can be used and triangulation of the gathered information can be performed. In this case, interviews were supplemented by written descriptions of the processes and by participating in discussions regarding development of the methodology used. These complementary sources strengthen the reliability in the descriptions as well as they contribute to the overall understanding of the studied field.

5. Results

5.1 Incoming knowledge transfer

For both of the processes studied in this phase, the most prominent differences are included. The different team members express their opinions regarding the proposed design and assembly solutions. The basis for their contributions is their individual mental models (for example, the proper assembly sequence). One of the subsidiary purposes of the verification process is to develop shared mental models, since the assembly staff participating will pass on this knowledge to the rest of the assembly staff (approximately 5% of the total number of assembly staff participates during the verification series). To transfer the same knowledge, shared mental models have to be created.

During Process 1, shared mental models were created as follows: Initially the product preparation engineers presented their proposed assembly sequence. After that, all of the team members gathered around the new product and the assembly staff tried to assemble the product according to the proposed sequence. If they detected any problems, it was discussed and the product preparation engineer went back to his/her workplace and changed the sequence. Each verification series consisted of several prototypes so that the assembly staff could practice every assembly sequence and in some cases even introduce the new, improved assembly sequence at the end of a series. Consequently, during Process 1, the work method created opportunity to use all of the proposed activities (dialogue, observation, imitation and practice) to create shared mental models.

During Process 2, two of the proposed activities were not used. Imitation and practice was not performed because of the use of computer-created images. The assembly staff could not test the assembly sequence by actually assembling the products. Instead, they had to evaluate the proposed assembly sequence only by studying the images on the computer screen. A lot of the

assembly staff complained about the difficulties doing a satisfactory job when they could not use their other senses to evaluate the propositions. To make the task even more difficult, this was the first time the verification teams used this verification method. The participants had to learn to work in the computerized environment besides the work evaluating the new product.

This indicates that virtual verification alone is not the answer. Polanyi (1966) supports this conclusion through his statement that explicit integration cannot replace its tacit counterpart. In the studied case, the use of computer-created images does not create opportunities for the assembly staff to express their tacit knowledge by actually showing the other participants what they mean. Instead they have to verbalize their knowledge, which in many cases is difficult (and in some even impossible).

5.2 Creating concepts

During Process 1, the prerequisites for an effective externalization mode were met. The team members could draw analogies from their previous experiences from other verification series, since the verification environment was similar to what they were used to. During Process 2, the prerequisites were not met, since the assembly staff had clear difficulties expressing their individual tacit knowledge due to the inability to use physical objects. We have already mentioned the difficulties for the assembly staff to create metaphors or models during Process 2 to some extent. Since this mode holds the key to knowledge creation, the following knowledge transfer activities (for example knowledge transfer to the other assembly workers) during Process 2 were influenced by the lowered efficiency in this mode.

5.3 Justifying concepts

One major challenge when making changes in crucial parts of a process is to convince the participants that the new method leads to improved results (whether the results aimed for are internal or external to the participant).

One important observation is that during the initial virtual series a lot of the participants expressed their uncertainty, and thereby their lack of acceptance, regarding the new work method. This uncertainty and non-acceptance of the method can be concluded to have an influence on the outcome from the process.

5.4 Building archetypes

The differences between the two processes studied are not substantial regarding the building of archetypes. The only major difference was the increased use of databases to store the information created in the verification series so that every interested party was able to have access to all of the information during Process 2. During Process 1, the normal procedure was to produce paper documents that were distributed to the team members. This meant that everybody did not have access to all of the information, but at the same time there were not as many documents circulating in the organization. If the structure of documents in a database is easy to follow, this tool can be a powerful enabler in the third mode. In the case studied, the structure was not satisfactory according to the users, which affected the final outcome.

5.5 Outgoing knowledge transfer

After each series, the discovered problems regarding the manufacturing process were brought back to the engineering teams, while the manufacturing representatives returned to their normal work at the assembly line. This resulted in a hampered learning process and that some of the knowledge assimilated by the manufacturing representatives was forgotten.

Outgoing knowledge transfer includes both internalization of the required knowledge by the participants and transfer to other individuals or groups within the organization and to external interested parties. The internalization activities are, in the cases studied, identified as activities such as writing verification series reports, writing assembly manuals and tutoring perform by the assembly workers during the latter parts of the verification process. The use of computer-created images does not influence the efficiency in this mode directly. The efficiency in the internalization mode during Process 2 decreased according to the assembly workers. It is probably because of the decreased efficiency in the preceding modes.

For organizational knowledge creation to take place the knowledge conversion process must go beyond the individuals that perform the interaction between tacit and explicit knowledge (Nonaka and Takeuchi, 1995). The process should “spiral” through the organization, that is, the knowledge must be shared with others in groups or within divisions.

There were methods in both Process 1 and 2 that supported the spiralling of knowledge. But, there is one interesting observation that must be illuminated here. The use of computer-created

images creates interesting possibilities for the tutors to show their "students" how to perform the assemblies, for example by introducing Virtual Reality (VR) in the tutoring situation.

In Table 1 below, the main disadvantages for each phase are summarised.

Table 1: The main disadvantages in each phase of the KTVP due to the use of virtual prototypes.

Phases	Disadvantages with virtual prototypes
Incoming knowledge transfer	Imitation and practice was not performed.
Sharing knowledge	No opportunity to express tacit knowledge by showing the other participants.
Creating concepts	Difficulties in expressing individual tacit knowledge due to the inability to use physical objects.
Justifying concepts	Lack of acceptance regarding the results due to the unexperienced participants
Building an archetype	No substantial differences were found.
Outgoing knowledge transfer	No substantial differences were found.

6. Conclusions

The following conclusions can be drawn:

- In the studied cases, the introduction of virtual prototypes in the verification process resulted in clearly changed prerequisites for knowledge transfer and creation.
- These changes arose mainly regarding incoming knowledge transfer, creating concepts and the justification phases, but the efficiency in the other modes were also affected by this introduction.
- The use of computer-created images obstructed the creation of shared mental models during incoming knowledge transfer since the participants had difficulties utilizing imitation and practice to strengthen the tacit knowledge.
- The participants' lack of experience regarding working in a virtual environment affected their efficiency. However, the team members' inability to externalize their individual tacit knowledge must be regarded as the primary reason for the difficulties experienced during the verification process.
- The new method is not accepted by all of the participants. There is a need for a greater focus on justification activities. The possibility for the assembly staff to learn the new assembly sequences has decreased since the skilled workers participating in the verification process did not have the same possibility to practice the assemblies as the were used to.

7. Future research

An area where the final results have not been available to study yet, are the effects this new work method has on the learning activities when other influencing parameters come into play. The effects due to language and/or cultural barriers within verification teams or between verification teams (the knowledge creators) and the receivers of the knowledge (for example, suppliers or own employees abroad) are two important examples. Naturally, it is of great interest to study the effects on verification performance when the method has been adapted and accepted. What is the outcome of the verification process when the participants have got used to the virtual environment?

Another area of interest is, to study how the continuous technology development influences virtual verification in the future. Here, several alternative directions of interest can be identified. The effects when using VR as an outgoing knowledge tool and/or the effects when using databases and/or virtual communication (such as e-mail) in the knowledge transfer has been identified two areas influencing knowledge transfer. Another direction is the effects of improved computer capacity on the outcome of the verification process. How will the outcome be affected by more lifelike visualizations or by more rapid changeovers from engineering drawings to verification simulation

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