Characteristics affecting management of design information in the production system design process

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Although it has been argued that the design of production systems is crucial, there is a general lack of empirical studies analysing and identifying resources and capabilities required for an efficient production system design process. One of these resources is the critical role attributed to design information and one such capability how the design information is managed. To address this research gap, this paper reports the results from two in-depth case studies in the automotive industry focusing on the management of design information in the production system design process. Our results show that the management of design information needs to be understood as a multidimensional concept having three dimensions: acquiring, sharing and using of design information. By focusing on the three dimensions six characteristics affecting the management of design information when designing the production system are identified. The characteristics are information type, source of information, communication medium, formalization, information quality, and pragmatic information.

Keywords: design of production systems; manufacturing industry; information management; case study, characteristics

Subject classification codes: Original manuscript

Introduction

For manufacturing companies active on the global market, high-performance production systems that contribute to the growth and competitiveness of the company are essential. Among a wide range of industries it is increasingly acknowledged that superior production system design capabilities are crucial for competitive success. However, the process of designing the production system has received little attention, ignoring its potential for gaining a competitive edge. The real power of an efficient design process is not its contribution to reduced operating costs, but how it supports manufacturing companies in their attempts to achieve faster time to market, smoother production ramp-up, enhanced customer acceptance of new products, and/or a stronger proprietary position (Hayes et al., 2005, Pisano, 1997). The right design before implementation facilitates rapid commission of systems to allow for rapid repayment of the invested capital as well as bringing new products promptly to the market, thus reducing the cost for the manufacturing company (Wu, 1994).

A review of the literature shows a broad range of factors affecting design in either a positive or negative way. One factor frequently mentioned as one of the most valuable resources that a manufacturing company possesses is design information and how design information is managed. From a theoretical point of view, there are several reasons why the management of design information should be positively associated with the performance of the production system design process. First, in line with the arguments of Cohen and Levinthal (1990), this article assumes that the ability to recognize the value of information, process it and dispose of it, is critical to the company’s ability to create organizational knowledge. The second argument suggests that an effective management of information reduces uncertainty and equivocality (Daft and Lengel, 1986). The third argument lies in the fact that an effective management of information facilitates integration between functionally specialized departments and thus is very important for the development performance (Ottum and Moore, 1997, Souder, 1988). Overall, it can be concluded that the inability of managing design information may have severe consequences for production system design performance, i.e. if design information is not managed appropriately, it may lead to difficulties in creating effective and robust production systems and achieving fast time-to-volume, and it may cause delays, costly rework and a waste of resources.

Despite the benefits associated with an effective management of design information, there is a general lack of studies focusing on the management of design information when designing production systems. The purpose of this paper is, therefore, to identify characteristics affecting the management of design information when designing the production system.

Theoretical framework

Production system design

The production system design process is the process means the conception and planning of the overall set of elements and events constituting the production system, together with the rules for their relationships in time and space (Chisholm, 1990). The result of production system design is a detailed description of the proposed production system solution (Bellgran and Säfsten, 2010). Thus, production system design is only a part of a production system development process, which also includes the building and industrialization of the production system. However, the design process is an early step in the development work, and subsequent steps will be directly dependent on and influenced by the design work.

Design activities are usually carried out in a process describing the procedures that designers should follow. The literature about the design process describes various concepts of a general design framework (e.g. Bellgran and Säfsten, 2010, Cross, 2000, Pahl and Beitz, 1996, Roozenburg and Eekels, 1995, Ulrich and Eppinger, 2007, Wu, 1994). Although the design processes described have different points of origin (product or production system design), a majority of researchers agree that the design process starts with an analysis and ends with a detailed design. The overall production system design process can be divided into a preparatory design phase and a detailed design phase (Bellgran, 1998, Bellgran and Säfsten, 2010). In order to study the design process at a detailed level the two phases can be further separated into five subsequent steps, see Figure 1.

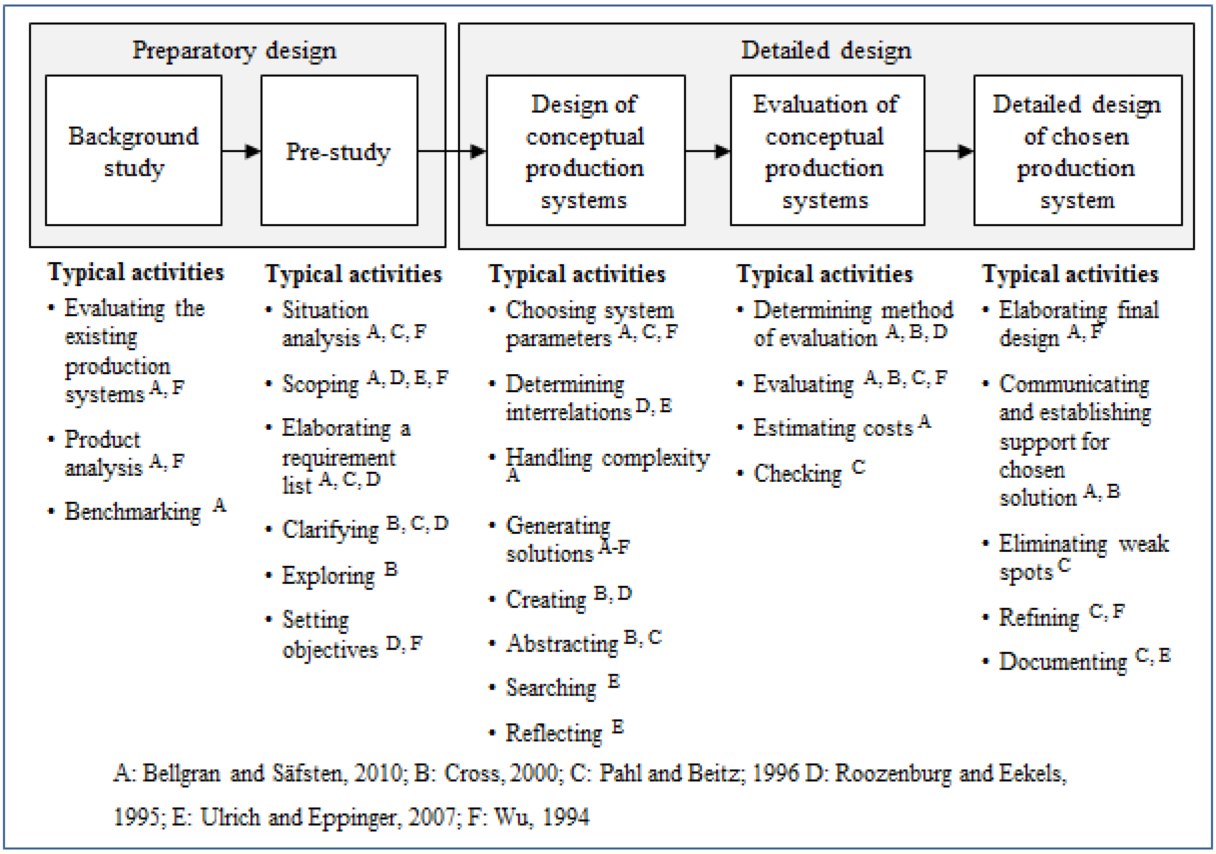

Figure 1. The production system design process with its inherent work activities.

The first and second phases include looking backwards and forwards to use gained experiences and capture the company's goals and strategies in the production system design process. The last three steps (steps 3-5) concern the design specification, which deals with activities important to create a complete and appropriate system solution. Thus, each step in the design process includes different activities that need to be carried out. Figure 1 reviews the activities that are carried out in each phase of the design process. For reasons of simplicity, the design steps shown in Figure 1 are illustrated in a sequential flow but are seldom clear and linear in reality; instead, the production system design process is an iterative process with many cycles and partly overlapping activities.

Design information in production system design

The term information is used in a variety of ways and is difficult to define. For instance, Rauterbeg and Ulich (1996) present six different interpretations of the term information. In general, it is seen that information is often defined in relation to the terms data and knowledge. Data, information, and knowledge can be arranged in a continuum (Davenport, 1997), where differences are based on the extent to which they reflect human involvement. Data on the one end of the continuum requires minimal human judgment, while knowledge on the other hand of the continuum requires maximum human judgement (Tsoukas and Vladimirou, 2002). Information can be found in between these two concepts. However, it is important to note that the provided description is a simplification of the reality and in practice the boundaries between data, information and knowledge are not clear.

In this paper information is considered as "… the collection of data, which, when presented in a particular manner and at an appropriate time, improves the knowledge of the person receiving it in such a way that he/she is better able to undertake a particular activity or make a particular decision" (Galliers, 1987, p. 4). Galliers refers to the difference between data, information, and knowledge, which has two important implications. First, information is enlightening and has real meaning in a given context or situation, i.e. information is contextual and enabling (Galliers, 1987). Second, because knowledge is valuable information from the human mind (Davenport and Prusak, 1998), it consists of truths and beliefs, perspectives and concepts, judgments and expectations, methodologies and know-how. To effectively use such assets requires the user of information to acknowledge and apply information during the production system design process. Or to put it in the words of Nonaka and Takeuchi (1995, p. 58) "information is a flow of messages, while knowledge is created by that very flow of information". In this paper, the term design information is used to denote the information needed to carry out the necessary design activities.

In general, manufacturing companies need to have the capability to deploy, integrate, and protect the design information resource in an effective way, i.e. they need to manage design information. Since information can be handled more or less effective, previous research (e.g. Frishammar and Ylinenpää, 2007, Zahay et al., 2004) propose that information has to be considered as a resource and should be approached from a resource-based view of the company. The resource-based theory suggests that resources are heterogeneous across companies and imperfectly mobile leading to higher levels of performance and thus to competitive advantages (Barney, 1991, Peteraf, 1993). In the context of production system design, information clearly is a resource and hence manufacturing companies must have the capability of managing relevant and necessary design information in an effective way.

Three reasons have been found why design information is not incorporated in the design process:

1. Information is not acquired (Cooper, 1975, Omar et al., 1999).
2. Information is not shared among different specialized functions (Sivadas and Dwyer, 2000, Souder, 1988).
3. Information is not used (Deshpande and Zaltman, 1982, Zahay et al., 2011).

Based on these conclusions, prior research in new product development points out that management of information should not be considered as a single one-dimensional construct; rather the managing of design information is a multidimensional construct consisting of the three dimensions acquiring, sharing, and using (Frishammar and Ylinenpää, 2007, Ottum and Moore, 1997). For the designing of the production system, it means that the management of design information should be considered from three dimensions, see Figure 2.

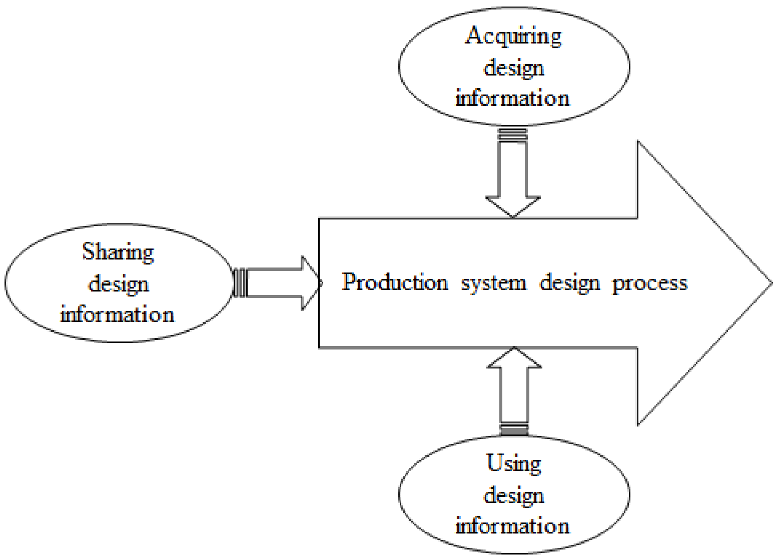

Figure 2. Model of the three dimensions of managing design information in the production system design process (based on Frishammar and Ylinenpää, 2007).

Research method

Due to the lack of empirical studies of how to manage design information in the production system design process, a case study methodology consisting of two real-time studies was adopted. As the interest of the present study is the understanding of the phenomenon (here the management of design information in the production system design process), a case study methodology was appropriate for depth of observation. A case study can be defined as a research strategy that aims at understanding the dynamics present within a single setting (Eisenhardt, 1989). In situations with limited understanding, studying the phenomenon at first hand is expected to improve the researcher's pre-understanding of the problem studied (Voss et al., 2002). The case study company is a global supplier in the automotive industry with responsibility for the entire development of new products including technological renewal and product and production system development. Since the foundation of the company, it has moved from developing and manufacturing one single product to offering innovative technological solutions in a broad variety of products. The two production system design projects studied belonged to two different divisions of the company and were carried out at two different manufacturing sites, one in Sweden and one in England.

The research is founded on two in-depth case studies of the production system design processes (henceforth referred to as Case A and Case B). In order to understand the context of the production system design process, Case A was studied for 37 days and Case B was followed for 34 days. Data were gathered by multiple sources of evidence including observations, semi-structured interviews and document studies (see Table 1). In addition, daily informal conversation took place, which often served as an update to the project studied (i.e. progress, changes and challenges) or gave more detailed background to the company (i.e. practices, standards, rules, etc.). During the data collection, documents were studied in order to get a basic insight into the background, scope and status of the projects. The document study also included various departmental documents such as the technical requirement specification and the new product development model allowing for reconstruction of previous ways of working in the production system design process.

Table 1. Overview of the data collection techniques applied in the case studies.

	Case study A	Case study B
Study location	Sweden	England
Days at the company	37 (November 2009 – August 2011)	34 (February 2011 – April 2011)
Passive observations	37	24
Participant observations	13	9
Semi-structured interviews	24 (ranging between 40-90 minutes)	14 (ranging between 30-80 minutes)
Informal conversation	Daily	Daily
Documentation	Full access	Full access

The case study referred to as Case A has been carried out at in Sweden and relates to the introduction of a new product. The case study company had 15 years of product development and production experience but was a minor player in the studied product segment on a market with rather tough market conditions. The new product development project was initiated to strengthen the market position and to lead to a positive cash flow in the product segment.

Case B was carried out at a business unit with a different product segment from that in Case A, which implied different prerequisites for the creation of a production system. In the studied product segment, the case study company was the technology leader and one of the world's leading suppliers with a long track record of successful innovation and new product development. Market share was 30 to 40 per cent depending on product variant and market. However, the case addressed a new product that was not available on the market from any supplier in the studied market segment. Consequently, the new product development project had to handle new challenges and situations without any previous experience, which had major implications for the manufacturing complexity.

Another source of data was 35 face-to-face interviews that were conducted ranging from 30 minutes to 90 minutes in time. The production system design process includes the involvement of different functionally specialized departments, some of which were affecting the design process and some of which being affected by the design process. The different respondents represented both the strategic and operational levels of the manufacturing company and included vice presidents, managers (plant, project, marketing/sales, facility and production engineer), engineers from various functions (production engineering, R&D, maintenance, quality, logistic, purchasing), a lean coordinator and assembly operators. The interviews were used to gain an in-depth picture of the situation.

During data collection attention was placed on data triangulation to strengthen the internal validity of the research results (Yin, 2009). Consequently, the conclusions drawn are not only based on one source of information such as interviews, since then the conclusions would have been based only on individuals' reports. In practice, this often meant that the same problem or fact was addressed by more than a single source of evidence. For example, one observation revolved around difficulties of equipment suppliers to understand the information provided. In order to understand why the problem existed and its consequences, the existing documents were studied, inquiries during interviews were made and relevant meetings were observed.

The data analysis was conducted in an iterative way following the guidelines provided by Miles and Huberman (1994) and Eisenhardt (1989). During the case studies, data were continuously analysed. Observations were daily recorded in a diary and each interview and the findings of the documents studied were summarized and transferred into a case study record. As a next step, each case was analysed separately (within-case analysis) before conducting a cross-case analysis. Finally, the results of the analysis were compared with the propositions found in the literature.

Results

The results presented below have been observed in both cases unless otherwise indicated in the text.

Acquiring design information

In both cases studied, one of the more notable challenges in the acquiring of design information was the need to base the design process on a holistic view, in order to ensure an internal and external fit of the production system. In general, the easiness of acquiring design information relied on the information type. In previous production system design projects, the focus was on the design information related to the technical subsystem of the production system, i.e. design information related to the production equipment. Therefore, problems had occurred when the people involved in the production system design process were supposed to acquire additional and new design information contributing to a more holistic view. There was a general agreement on certain critical design information types that needed to be acquired in the design process on an overall level, but there was an uncertainty about the detailed content of each of these information types. The results of Case A however showed that more and more information types become important as the project progressed leading to a more holistic perspective in the detailed design phase.

As a broad range of information types needed to be acquired in the production system design process, design information was collected from different information sources. The results of the cases show that overall, personal sources, i.e. direct human involvement were by far the preferred source of design information. However, the use of personal sources created a heavy dependence on individuals. If the relevant person was not available, the required design information could not be obtained. In addition, functions were dependent on each other for design information in real time even though the design information was not new or equivocal and could easily have been transferred by impersonal sources. The available documented design information was preliminary concerned with the acquisition of the production equipment and the overall new product development project.

Another identified challenge was the need to also acquire design information from external sources. There was a lack of clear strategies supporting the acquisition of design information outside the company's boundaries. Further, external sources were not as easily accessible as sources within the manufacturing company. For instance, in Case B it was deemed important to study production systems of other companies that had found solutions concerning the handling of the raw material. However, the study visits required several weeks of planning, while in Case A a similar production system was at the same plant and thus could be studied without any planning. Consequently, in Case B decisions concerning the production system were delayed as it took time to acquire the relevant design information.

Sharing design information

When it comes to the sharing of design information, such information was shared either by documents or direct human involvement such as meetings, telephone or conversation. In other words, different communication media were selected for the sharing of design information in the two case studies. In Case A the choice of communication media relied on the prerequisites, i.e. how information was shared was not dependent on the content but on the previous documentation. For instance, although not all functions involved in the production system design process had skills in reading product drawings and would have needed additional clarification, product information was usually transferred by drawings, while information about the human subsystem was generally not documented and thus transferred face-to-face. In Case B the information was mainly shared by means of a rich communication medium, i.e. face-to-face since documentation and knowledge regarding the production system design process was limited. In general, the way information was shared in both case studies was also dependent on the timeline of the production system design process. The farther the design process progressed, the more effort was placed on documentation, which led to more sharing of design information by means of documents later in the production system design process.

In both cases, the production system design process itself had led to challenges in the sharing of design information. Although production system design was a vital part of the overall new product development stage-gate model, the model was created from a product perspective and no formal production system design process was available. Further, the project studied in Case B was one of the first projects using a stage-gate model, which had not been tested previously. As a consequence, routines still needed to be established and the details concerning production system design were even less comprehensive compared with other stage-gate models used at the case study company. As a result, the production system design process lacked formalization in both Case A and B, which influenced an efficient sharing of design information negatively. Contributing to this effect was the fact that the overall new product development process did not support a more individual project control of the functions involved in the production system design process. For example, the production system design process was shared in the overall new product development group since there was no structure for separate meetings between the functions that were concerned with the production system design process. By appointing a separate industrialization project manager, some of these difficulties were resolved in Case A. The industrialization project manager created a cross-functional industrialization team that met on a more regular and frequent basis and allowed for additional interpretation and discussions related to the design of the production system.

There were often situations when information sharing was facilitated by physical proximity, i.e. when the different functions were located in the same office. However, not all functions were co-located, leading to an unbalance in the sharing of design information and conflicting views. There was a higher awareness and better understanding of the needs of those functions that were located close to each other as there was an ability to spontaneously discuss critical issues. As soon as functions were not located at the same place the frequency of spontaneous information sharing decreased in both case studies.

Use of design information

The findings of the case studies reveal that the production system design process was not supported by a tailor-made IT system, which led to challenges concerning the information quality. There was no natural place to document and summarize the design information on a central database, which caused problems when information needed to be accessed. Design information from previous design projects could have been of value in the actual production system design process, but since it was not documented, the work needed to be redone. The provided design information also became dependent on individuals involved in the production system design process and their background, experiences and interests. Furthermore, the lack of a tailor-made IT system led to difficulties in knowing if one was using the relevant information when several persons created similar design information relevancy and timeliness was difficult to judge. The lack of support prevented people from perceiving information as useful even though it would have been of significance to use the shared design information.

The need to use preliminary design information has its roots in the fact that coupled design activities were carried out in parallel. The different functions were forced to start their work activities even if not all required design information input was available. Problems occurred later in the process when it turned out that the used information was wrong, and this required (costly) rework. There was a lack of clear strategies for how the preliminary information should be used by the downstream parties and what design information needed to be exchanged at what moment in time. In addition, there were no clear rules about how changes in the design information should be communicated, which led either to misunderstandings (uncertainty of what information was relevant) or delays with regard to applying the updated information (people continued working with out-dated information as they were not aware that the design information had changed). To ensure that all functions involved in the production system design process became aware of changes in the product design, in Case A a formal change order process was introduced.

Another challenge that arose concerned the degree of novelty of the design information provided. For example, in Case B there was no obvious assembly sequence or testing procedure for the product due to the properties of the new raw material. In addition, there were concerns regarding how the raw material could be supplied to the manufacturing site without causing any damage or harm. The employees involved in the production system design process could not solve these issues by themselves, although there was no doubt about the general properties of the new raw material. There was a lack of previous knowledge of the matter, which made it difficult to predict how the raw material would behave in serial production, i.e. no pragmatic information was provided. The problem was solved by contacting experts in the area. These experts had experience of how the raw material could be handled and thus transferred their previous experience into a new context (application). Table 2 summarises the two cases including both similarities and differences.

Table 2. Overview of the companies studied.

Dimensions	Characteristics	Case A	Case B
Acquiring design information	Information type	Towards a holistic perspective	Focus on the technical subsystem
	Source of information	Mainly personal sources	Mainly personal sources Difficulties in acquiring information from external sources
Sharing design information	Communication medium	Rich (face-to-face) and low (documents, e-mail) The choice dependent on previous documentation	Mainly rich (face-to-face)
	Formalization	Medium	Low-medium
Using design information	Information quality	Medium	Low-medium
	Pragmatic information	Combination of novelty and confirmation	High degree of novelty

Characteristics affecting the management of design information in the production system design process

Six characteristics shaping the management of design information when designing the production system were found. They were found through studying the two case studies on the three dimensions of managing information outlined in the literature and making a cross-case analysis of the data found. They were information type, source of information, communication medium, formalization, information quality, and pragmatic information. The characteristics will be elaborated on in this chapter, for a summary see Table 3.

The first characteristic is the information type that needs to be acquired when designing the production system. The production system design process is likely to benefit from applying a holistic view on the acquisition of design information. Following this recommendation leads to the need to acquire various types of design information. Previous research has frequently emphasized the importance of having a holistic perspective when designing the production system (Bellgran and Säfsten, 2010, Bennett, 1986). Thus, facilitating the acquiring of a broad variety of design information is of crucial importance, as the generated production system solution should rely on a comprehensive view going beyond that of emphasizing the technical subsystem.

However, one should be aware that having a holistic view implies that a tremendous amount of design information needs to be acquired. This involves the risk of information overload, while at the same time the acquired information needs to be understood. Therefore, it is important to acquire a combination of hard and soft design information, of which hard information facilitates the handling of large amounts of design information and soft information provides the contextual description (Häckner, 1988).

The second characteristic regards the source of the required design information. The empirical findings suggest that the acquiring of the required design information should not be limited to the own organization. Nevertheless, personal and internal sources were by far the preferred choice for acquiring design information, which is in line to previous research (Aguilar, 1967, Frishammar, 2003). Personal sources are important to interpret unclear issues (Daft et al., 1988); this may be particularly important in the design phase. In addition, internal sources are perceived as more easily accessible and thus often more important than external sources (Sawyerr et al., 2000). Accessing external sources might be more time consuming and more difficult to achieve, but they offer significant potential. For example, acquiring design information from the external environment is vital for the innovation capability of the manufacturing company (Utterback, 1994). Ignoring the potential of impersonal or external sources can lead to dissipated resources, missed opportunities and less competitive production system solutions.

The third characteristic refers to the communication medium applied when design information is shared. Sharing design information through personal interaction has several positive consequences such as the ability to process rich information, interpret unclear issues, and allow for enactment and clarification (Daft and Lengel, 1986). However, the choice of using a rich communication medium was not always based on the fact that there was need for enactment or clarification but simply that there was no choice due to the limited documentation. Further, there are risks involved in relying heavily on personal interaction for the sharing of design information. Since not all project members are always involved in direct interaction, it is challenging to ensure that information is shared with all functions that would benefit from the information. Therefore, ne strategy would be to support the development of standard documents since documentation is generally more comprehensible than oral communication (Moenaert and Souder, 1996) and correlates with a smooth production start-up (Vandevelde and Van Dierdonck, 2003). These documents are valuable for the sharing of well-understood design information that does not need any further clarification.

The fourth characteristic is based on the formalization of the process of designing the production system. The degree of formalization seems to have a key role for the sharing of design information. Using a formally structured process can create more inter-functional harmony (Souder, 1987) and can increase information utilization (Cooper, 1999). Since the process of designing a production system is very complex and needs to involve various functions and departments, major benefits of assigning a project manager responsible for the production system design process and a dedicated team are observable. Overall, the results indicate that the sharing of design information can be improved by mechanisms that contribute to a clear and structured production system design process, i.e. formalization, which is in line with previous research (i.e. Frishammar and Hörte, 2005, Vandevelde and Van Dierdonck, 2003). It is worth noting that, although formalization tends to improve the sharing of design information, the value of more informal mechanisms allowing for spontaneous discussions should not be underestimated. The sharing of design information can be improved by formal as well as informal coordination mechanisms (Frishammar and Ylinenpää, 2007). Informal coordination mechanisms are particularly valuable when employees with different backgrounds and training need to share information.

The fifth characteristic identified is information quality, which influences whether the design information is used or not when designing the production system. Major imperfections in information quality have numerous negative consequences such as confusion, distraction, and delays. On the other hand, high information quality facilitates that the design information is actually used in the task at hand and thus provides comprehensive justifications for each decision. Hence, efforts are needed to accomplish high information content quality (relevant and sound information) and high information media quality (optimized process and reliable structure). However, as each imperfection has different causes, several but complementary approaches are required to obtain high information quality (Eppler, 2006).

The final and sixth characteristic refers to the need for information content to be a combination of confirmation and novelty, i.e. pragmatic information. Studies in this research (Case A and Case B) together with Fjällström's (2007) research show that pragmatic information is important when using information since the information has to be understandable, while at the same time it should be different from previous knowledge. The need to handle a broad variety of design information increases the risk that the novelty parts dominate the information content, which may prevent understanding of the design information. As a result, a project team responsible for the design of the production system should include representatives from different functions with different backgrounds and training in order to ensure that the design information can be understood and thus utilized in the design of the production system.

Table 3. Characteristics and their affect on the management of design information.

Characteristic	**Affect on the management of design information in the production system design process**
Information type	Different types of information need to be acquired to achieve consistency and avoid sub optimization in the conceptual production system solution.
Information source	The access to sources affects if relevant and necessary information is acquired or not.
Communication medium	The more documentation the more information can be shared by a media with less richness. However the choice of the communication media needs to be carefully chosen depending on the situation.
Formalization	The degree of formalization affects the sharing of information. It is important to use both formal and informal means.
Information quality	The higher the information quality the higher the likeliness that information will be used.
Pragmatic information	The combination of novelty and confirmation in the information content affects the use of information.

Conclusions

Returning to the purpose of the paper, i.e. to identify characteristics affecting an effective management of design information when designing the production system, the study has revealed some interesting findings. Through two in-depth case studies we reveal the importance of considering the management of design information as a multidimensional construct consisting of the three dimensions; namely the acquiring, sharing, and using of information. Important to note is that the acquiring, sharing, and using of design information has to be performed continuously throughout the production system design process, i.e. in each phase of the production system design process relevant and necessary information needs to be acquired, shared and used among the project members, see Figure 3.

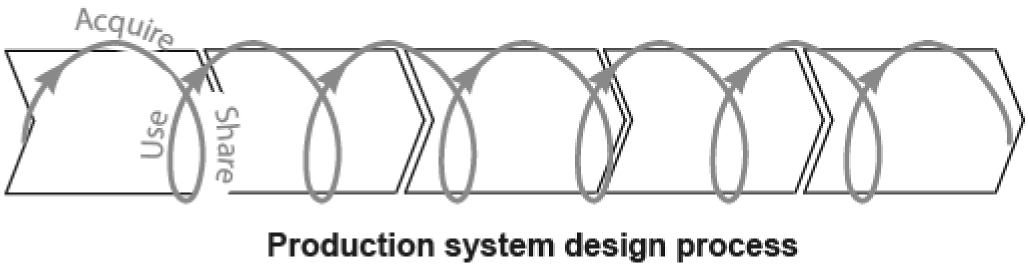

Figure 3. The management of design information should be viewed as a looping of acquiring, sharing, and using of design information with a high dependency between the three dimensions.

Further, the research shows that the management of design information is affected by at least six characteristics that can be attributed to the three dimensions. These characteristics are the information type, source of information, communication medium, formalization, information quality and pragmatic information. Figure 4 shows a model of the characteristics affecting the management of design information when designing the production system.

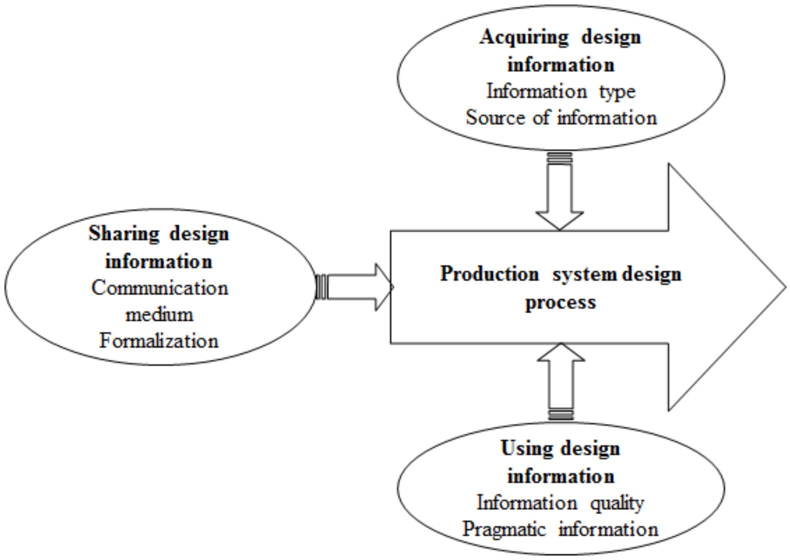

Figure 4. Overview of the identified characteristics affecting the management of design information when designing the production system.

To a background where the management of information is a critical capability for successful production system design, it is justified to elaborate on the managerial implications of the findings. To learn from previous mistakes but also to facilitate the design work documentation is crucial. Each project related to the design of a production system need to be documented in a standardised way highlighting lessons learned. But manager should also support the development of standardised documents, which can be applied when designing the production system such as a comprehensive requirement specification.

Further, the design of a product system affects and is affected by several functions but not all functions/ departments are aware that they own relevant and necessary information or have time to contribute with the required information. Our recommendation would be to dedicate resources by selecting functions that should be part of a cross-functional project team. By having a cross-functional working team, it will be easier to include different types of information in the conceptual design and thus to apply a holistic perspective.

Further, to help project members in their work of designing a production system a formalized production system design process should exist. The process needs to be applicable to all projects and there should be a possibility to integrate a production system design process with the overall new product development project model. To ensure a high level of recognition, the production system design model may also consist of stages and gates similar to a stage gate process. Such a process can lead to more information exchange and multifunctional discussions. In addition, managers should aim at co-locating employees working with the design of the production system as it supports more spontaneous and faster sharing of information.

One limitation of this study is that the identified characteristics seem to be interrelated. For example, the information types acquired can initially have to do with the accessibility to information sources. Future research should therefore focus on how these characteristics are interrelated. It would also be interesting to investigate how design information can facilitate production system design based on a life-cycle perspective. The research presented in this article has been focused on the design of the production system for the current product generation. However, modern global manufacturing companies more often need to design dynamic production systems that can easily be changed in accordance with customer requirements. This would be interesting to investigate as well since a higher degree of preliminary information should have an impact on the management of information.

Even though the empirical findings are supported by previous and well-recognized literature, there is still a need for developing knowledge about the management of information in the production system design process. Thus, a promising avenue for further research is to study the phenomenon in more organizations, preferably in different types of industries in order to make more general conclusions possible.

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