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MANAGEMENT OF DESIGN INFORMATION IN THE PRODUCTION SYSTEM DESIGN PROCESS

Jessica Bruch

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MÄLARDALEN UNIVERSITY
SWEDEN

Akademin för innovation, design och teknik

Abstract

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 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. Designing production systems in an effective and efficient manner is advantageous as it supports the possibility to achieve the best possible production system in a shorter time. One way to facilitate the design of the production system is an effective management of design information. Without managing design information effectively in the production system design process the consequences may be devastating including delays, difficulties in production ramp-up, costly rework, and productivity losses.

The objective of the research presented in this thesis is to develop knowledge that will contribute to an effective management of design information when designing production systems. The empirical data collection rests on a multiple-case study method and a survey in which the primary data derive from two industrialization projects at a supplier in the automotive industry. Each industrialization project involved the design of a new production system.

The findings revealed ten categories of design information to be used throughout the process of designing production systems. The identified design information categories are grouped in the following way: (1) design information that minimizes the risk of sub-optimization; (2) design information that ensures an alignment with the requirements placed by the external context; (3) design information that ensures an alignment with the requirements placed by the internal context, and (4) design information that facilitates advancements in the design work. In order to improve the management of the broad variety of design information required, a framework is developed. The framework confirms the necessity to consider the management of design information as a multidimensional construct consisting of the acquiring, sharing, and using of information. Further, the framework is based on six characteristics that influence the management of design information. These characteristics are information type, source of information, communication medium, formalization, information quality, and pragmatic information. Supported by the findings, guidelines for the management of design information are outlined to facilitate an effective and efficient design of the production system and thus contribute to better production systems. The guidelines are of value to those responsible for or involved in the design of production systems.

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ABSTRACT

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 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. Designing production systems in an effective and efficient manner is advantageous as it supports the possibility to achieve the best possible production system in a shorter time. One way to facilitate the design of the production system is an effective management of design information. Without managing design information effectively in the production system design process the consequences may be devastating including delays, difficulties in production ramp-up, costly rework, and productivity losses.

The objective of the research presented in this thesis is to develop knowledge that will contribute to an effective management of design information when designing production systems. The empirical data collection rests on a multiple-case study method and a survey in which the primary data derive from two industrialization projects at a supplier in the automotive industry. Each industrialization project involved the design of a new production system.

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SAMMANFATTNING

För tillverkande globala företag är högpresterande produktionssystem som bidrar till tillväxt och konkurrenskraft för företaget oumbärliga. Inom en rad olika branscher är det allt mer erkänt att en överlägsen produktionssystemsprestanda är avgörande för konkurrenskraft och framgång. Arbetet med att utforma produktionssystem har dock fått lite uppmärksamhet och dess potential att bidra till konkurrensfördelar försummats. Att utforma produktionssystemet på ett effektivt och ändamålsenligt sätt kan bidra till konkurrensfördelar eftersom det stöder möjligheten att uppnå det bästa möjliga produktionssystemet på en kortare tid. Ett sätt att underlätta utformningen av produktionssystemet är en effektiv hantering av designinformation. Utan att hantera designinformation effektivt i utformningsprocessen av produktionssystemet kan konsekvenserna bli förödande, till exempel genom förseningar, svårigheter i upprampning av produktionen, kostsamma omarbetningar, och förluster produktivitet.

Målet med forskningen som presenteras i denna avhandling är att utveckla kunskap som bidra till en effektiv hantering av designinformation när produktionssystem utformas. Den empiriska datainsamling vilar på en flerfallstudie och en undersökning där de primära uppgifterna kommer från två industrialiseringsprojekt hos en leverantör inom fordonsindustrin. Varje industrialiseringsprojekt omfattar utformningen av ett nytt produktionssystem.

Resultaten pekade på tio designinformationskategorier som skall användas under produktionssystemets utformningsprocess. De identifierade kategorierna kan grupperas på följande sätt: (1) designinformation som minimerar risken för suboptimering, (2) designinformation som säkerställer en anpassning till de krav som ställs från externa omgivningen, (3) designinformation som säkerställer en anpassning till de krav som ställs internt, och (4) designinformation som underlättar framsteg i utformningsprocessen. För att förbättra förvaltningen av den stora variationen av designinformation som krävs, har ett ramverk utvecklats. Ramverket bekräftar nödvändigheten av att beakta hanteringen av design information som en flerdimensionell konstruktion bestående av förvärvandet, delandet och användandet av informationen. Vidare är ramverket baserat på sex egenskaper som påverkar hanteringen av designinformationen. Dessa egenskaper är typ av information, informationskällor, kommunikationsmedium, formalisering, informationskvalitet och pragmatisk information. Med stöd av resultaten är riktlinjer uppdragna för hantering av designuppgifter för att underlätta en effektiv och ändamålsenlig utformning av produktionssystemet och därmed bidra till bättre produktionssystem. Riktlinjerna är av värde för de som ansvarar för eller deltar i utformningen av produktionssystem.

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It is with a bittersweet joy that I write the final lines of my thesis. Being a PhD student has been an interesting process, a twisted path with surprises. Sometimes it has been difficult to see the path and other times it has been very rewarding. All in all it has been a great experience! The path has been shared with many friends and colleagues who refined and contributed to the results of this thesis. I would like to express my gratitude to everyone who helped me make this possible.

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Jönköping in February, 2012

Jessica Bruch

APPENDED PAPERS

The thesis consists of two main parts: the summarizing chapter of this compilation thesis and the following six papers appended in full:

Paper I Bruch, J. and Karltun, J. (2009), Information Requirements in a Proactive Assembly Work Setting, Presented at the 3rd International Conference on Changeable, Agile, Reconfigurable and Virtual Production, 5-7 October 2009, Munich, Germany.

Paper II Bruch, J. and Johansson, G. (2011), Dual Perspective on Information Exchanges between Design and Manufacturing, Presented at the 18th International Conference on Engineering Design, 15-18 August 2011, Copenhagen, Denmark.

Paper III Bruch, J. and Bellgran, M. (In press), Design information for efficient equipment supplier - buyer integration, Journal of Manufacturing Technology Management, , Vol. 23, No. 4.

Paper IV Bruch, J. and Bellgran, M. (2012), Creating a competitive edge when designing production systems: facilitating the sharing of design information, Status: Re-submitted to International Journal of Service Sciences following one revision.

Paper V Bruch, J. and Bellgran, M. (2011), Managing design information in the production system design process, Status: First round of review in International Journal of Production Research.

Paper VI Bruch, J., Bellgran, M. and Angelis, J. (2011), Information Management for Production System Design with a New Portfolio Approach. Presented at the 21st International Conference on Production Research, 31 July – 4 August, 2011, Stuttgart, Germany.

Additional publications by the author, but not included in the thesis

Bruch, J., Johansson, C., Karltun, J. and Winroth, M. (2007), Considering design demands of a proactive assembly system: a position paper, Presented at the 1st Swedish Production Symposium, 28-30 August 2007, Gothenburg, Sweden.

Granell, V., Frohm, J., Bruch, J. and Dencker, K. (2007), Validation of the DYNAMO Methodology for Measuring and Assessing Levels of Automation, Presented at the 1st Swedish Production Symposium, 28-30 August 2007, Gothenburg, Sweden.

Dencker, K., Stahre, J., Bruch, J., Gröndahl, P., Johansson, C., Lundholm, T. and Mårtensson, L. (2007), Proactive Assembly Systems - Realizing the Potential of Human Collaboration with Automation, Presented at the IFAC-CEA: Conference on Cost Effective Automation in Networked Product Development and Manufacturing, 2-5 October 2007, Monterrey, Mexico.

Bruch, J., Karltun, J. and Dencker, K. (2008), Assembly Work Settings Enabling Proactivity – Information Requirements, Presented at the 41st Conference on Manufacturing Systems (CIRP), 26-28 May 2008, Tokyo, Japan.

Bruch, J., Karltun, J., Johansson, C. and Stahre, J. (2008), Towards a Methodology for the Assessment of Information Requirements in a Proactive Assembly Work Setting, Presented at the 2nd Swedish Production Symposium, 18-20 November 2008, Stockholm, Sweden.

Bruch, J. (2009), Information Requirements in a Proactive Assembly Work Setting, Licentiate thesis, Chalmers University of Technology, Gothenburg.

Bruch, J., Bellgran, M. and Johansson, C. (2009), Exploring requirement specification of the production system – a position paper, Presented at the 3rd Swedish Production Symposium, 2-3 December 2009, Gothenburg, Sweden.

Fasth, Å., Bruch, J., Stahre, J., Dencker, K., Lundholm, T., Mårtensson, L. (2009), Designing proactive assembly systems – Criteria and interaction between automation, information, and competence, Asian International Journal of Science and Technology in Production and Manufacturing (AIJSTPME), Vol. 2, No. 2, pp. 1-13.

Waefler, T., von der Weth, R., Karltun, J., Starker, J., Gaertner, K., Gasser, R. and Bruch, J. (2011), Control capability of Work Systems, In Waefler, T., Fransoo, J. C., Wilson, J.R. (Eds.) Behavioral Operations in Planning and Scheduling, Berlin, Germany: Springer-Verlag.

Bruch, J., Wiktorsson, M., Bellgran, M. and Salloum, M. (2011), In search for improved decision making in manufacturing footprint: A conceptual model for information handling, Presented at the 4th Swedish Production Symposium, 4-5 May 2011, Lund, Sweden.

Bruch, J. and Bellgran, M. (2011), The critical role of design information for improved equipment supplier integration during production system design, Presented at the 44th Conference on Manufacturing Systems (CIRP), 31 May – 3 June, 2011, Madison, WI, USA.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PART 1

SUMMARIZING CHAPTER

CHAPTER 1

INTRODUCTION

CHAPTER INTRODUCTION

The first chapter of this thesis establishes the importance of the research area – managing design information when designing production systems and framing it into a context. Based on a need for a more effective management of design information when designing production systems, the research objective is defined and the research questions are formulated. Further, the scope and structure of the thesis are presented.

1.1 GAINING AN EDGE THROUGH PRODUCTION SYSTEM DESIGN

Arguably the prerequisites for economic success of manufacturing companies have changed tremendously during the last two decades. Several uncontrollable forces have emerged including a growing international environment, fragmented markets with sophisticated customers, fast-evolving technology, and shrinking product lifetimes (Chryssolouris, 2006; Clark and Fujimoto, 1991; ElMaraghy and Wiendahl, 2009). As the competition in which the companies operate is increasing, frequently introducing new products to the market in time is crucial for business prosperity (Girotra *et al.*, 2007; Stalk Jr. and Hout, 2003). For example, Hendricks and Singhal (2008) point out that delays in product introduction have a substantial and negative impact on profitability. These negative consequences can be explained by customers that cancel orders, a reduced window for generating revenues, products faster becoming obsolete, or lower product prices (Hendricks and Singhal, 2008). Delays minimize a company's possibility to benefit from first-mover advantages and can lead to decreases in market share and sales growth as well as potentially strengthening the market position of competitors. Thus, being late with the introduction of a product can be devastating if competitors succeed in gaining a superior market position.

Hence the ability to identify the needs of the customer and to quickly create products that will meet these needs and that can be manufactured at low cost will have major implications on the survival, growth, and profitability of companies (Trott, 2008; Ulrich and Eppinger, 2007). This being said, extensive scientific and industrial attention has been devoted to finding the most efficient methods and tools in order to improve the product development performance of companies. The result is a substantial body of knowledge with a great deal of homogeneity concerning tools and methods that support the performance of structured and efficient product development. Cochran *et al.* (2001/2002) conclude that although the field of product development is still growing and dynamic, there is an agreement on what it means to develop a product. However, the success of many new products is highly related to the ability of integrating the development of production systems (Bellgran and Säfsten, 2010).

The area of production system development has generated far less excitement among academics and practitioners. This is perhaps not surprising as the western world has long been emphasizing the developing of products, while it was assumed that the manufacturing of products could be carried out in low-wage countries or by competitors with stronger operating competencies (Karlsson, 2009). The perception that industrial production is not a core competence and of no strategic use ignores the integrating role of production system development capabilities in new product development (NPD) performance. The real power of superior production system development 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). Further, the real value of the production system is not its often extremely costly production equipment but the intellectual capital embedded within its details such as assembly sequences or quality assurance (Hayes *et al.*, 2005). The knowledge relevant for creating these details resides in the heads of the people involved in the creation process and is thus difficult to observe and imitate by competitors.

Consequently, research into production system development is of high relevance when speed in NPD is a critical issue for manufacturing companies. In general, the process of developing a production system includes both the design of a production system solution and the implementation of the solution (Bellgran and Säfsten, 2010). Previous research reveals that the design process is the foundation of a competitive and profitable manufacturing business. For example, Bennett (1986, p. 2) points out that "the way in which a production system is designed will enable or preclude the possibility of achieving best results". The decisions made in the design phase have major implications on factors such quality, speed, dependability, flexibility, and cost of the production system (Slack *et al.*, 1998). Early design decisions are much more significant than later production decisions due to their impact on the downstream business activities by being technically feasible or practically viable (Barton *et al.*, 2001). Further, manufacturing companies that shift the identification and solving of design problems to earlier phases of the development process can enhance the overall development performance (Thomke and Fujimoto, 2000). The right design before implementation facilitates that systems can be rapidly commissioned to allow for rapid repayment of the invested capital as well as bringing new products to the market promptly, thus reducing the cost for the manufacturing company (Wu, 1994). The benefits associated with front-loading problem solving make the production system design process particularly interesting.

Although it has been argued that the design of production systems is crucial, there is a lack of theory supporting practitioners in their critical task of designing a production system. Concerns have been raised that research in production system design as one of the determinants of the effectiveness of operations and NPD is seriously underexposed (Ruffini *et al.*, 2000). As a result, production systems are generally designed relatively shortly before their installation (Chryssolouris, 2006; Duda, 2000), which limits the ability to evaluate the conceptual solution in a timely and financially sound manner. However, a poor conceptual solution can never be compensated for by the later phases in development projects (Cross, 2000). Therefore, this thesis considers the production system design process as a non-trivial problem that will incur a considerable amount of risk unless design activities are handled in an efficient and effective manner.

Many approaches to an effective and efficient production system design process originated before production systems needed to have the ability to continuously adapt and evolve. In the past, manufacturing companies could plan for relatively long product life cycles that more or less followed an s-shaped diffusion curve according to the intuitive logic of introduction, growth, maturity, and decline (Mata *et al.*, 1995; Powell and Dent-Micallef, 1997). One of the results was that both the time and the costs required for designing a new production system only represented a small proportion of its total lifetime and the unit's full cost (Hayes *et al.*, 2005). Today's dynamic markets, on the other hand, imply new types of life cycles and an enormous number of product models and variants (ElMaraghy and Wiendahl, 2009; Wiendahl *et al.*, 2007), causing an increasing divergence of the product and the production system life cycle (Keller and Staelin, 1987).

Reality shows that despite the introduction of tools that facilitate the integration of production issues in NPD, such as integrated product development or concurrent engineering (see, among others, Andreasen and Hein, 1987; Gerwin and Barrowman, 2002; Magrab *et al.*, 2010; Terwiesch *et al.*, 2002), the production system is often an obstacle to future product introductions. The introduction of new products and the increasing number of product variants trigger frequent changes in the production system, which often dictates costly and time-consuming changes to, for instance, jigs, fixtures, and machinery (ElMaraghy, 2009). Due to the high investment costs of new production equipment, many manufacturing companies even hesitate to introduce new products that would make their existing production equipment outdated (Hayes *et al.*, 2005). Thus there is clearly a need for a more effective and efficient production system design process resulting in better production systems.

1.2 THE CRITICAL ROLE OF DESIGN INFORMATION

The production system design process greatly affects NPD performance, which has contributed to improved knowledge about designing production systems in a systematic way based on a predefined structure (see, among others, Bellgran and Säfsten, 2010; Bennett and Forrester, 1993; Schuh *et al.*, 2009). Yet, there is a general lack of empirical studies analysing and identifying resources required when designing production systems and capabilities needed to deploy, integrate, and protect those resources.

Information is one important resource to be able to carry out the design process in an effective and efficient manner. Kehoe *et al.* (1992) regard information as the most valuable resource that a manufacturing company owns, beyond any doubt a powerful weapon. Drawing on the resource-based view, information can be considered as a strategic resource, i.e. a resource that includes all assets controlled by a firm that enable the firm to implement strategies to improve its efficiency and effectiveness (Barney, 1991; Barney *et al.*, 2001). A strategic resource leads to performance differences across organizations, and competitors find it difficult to substitute or imitate the resource without great effort (Hoopes *et al.*, 2003; Peteraf, 1993). In other words, a manufacturing company highly proficient in providing relevant and necessary design information that fits the needs of particular users on specific occasions might develop a competitive advantage over less skilled competitors.

Prior research has shown that approaching information from the resource-based theory can contribute to improved understanding of information in the development process (e.g. Frishammar, 2005; Mata *et al.*, 1995; Zahay *et al.*, 2004). To meet the general requirements of the resource-based theory and to allow for competitive advantages, information has to be heterogeneous across firms and imperfectly mobile (Barney, 1991). The design information in the production system design process has no intrinsic value; instead its value depends on the particular context and whether it enables necessary activities and decisions to take place (Galliers, 1987). Organizations also have a natural tendency to create a terminology and system of meaning of their own (Weick, 1969). Finally, most of the information required in the production system design process can only be found in the minds of experienced system designers (Bellgran, 1998). Thus, information is often unique and deeply embedded in the organization, by which it satisfies the demand to be scarce and difficult to imitate and substitute (Lewis *et al.*, 2010).

To fully use the potential of design information, manufacturing companies also need to have the capability to manage design information in an effective way. In fact, it has been argued that the managing of information "plays a pivotal role in determining the success or failure" of new products (Ottum and Moore, 1997, p. 258). The effectiveness of information management needs to be based on the capability to avoid situations in which the production system design process is either being subjected to information overload or getting information too late or not at all. Hence, capabilities are needed to deploy, integrate, and protect the design information resource. The term "capability" refers to tangible or intangible processes that are firm-specific and are developed over time (Makadok, 2001). Thus capabilities cannot easily be bought; instead they must be built within the organization (Teece *et al.*, 1997). Frishammar (2005) argues convincingly that the management of information is a capability that may allow for effective and efficient NPD and subsequently contribute to competitive advantages.

However, prior research offers insights and evidence that the capability of managing design information is challenging and all but trouble-free. For example, literature frequently stresses the paradoxical situation that, although there is an abundance of information available, it is extremely difficult for the people involved to obtain necessary and relevant information when such is needed (Edmunds and Morris, 2000). If too much information is provided, the person receiving information cannot use it effectively since he/she is burdened with a large supply of unsolicited information, some of which may be relevant (Butcher, 1998). Searching for and accessing design information can take up to 34 per cent of engineers' working time (MacGregor *et al.*, 2001). Furthermore, the inability to handle design information may have major severe consequences including delayed launch to market, exceeding the budget, corrections in operation, customer dissatisfaction, reduced market share, and the impossibility of accomplishing development projects (Baxter, 1995; Cooper, 1999). It has also been argued that an effective management of design information contributes to the innovation capability of the manufacturing companies (Frishammar and Hörte, 2005; Miller and Friesen, 1982). The reasoning above highlights the critical role of design information and its management for the success of the design process. Consequently, there is a need for empirical studies focusing on the management of design information when designing production systems.

1.3 RESEARCH OBJECTIVE AND RESEARCH QUESTIONS

The discussion so far can be summarized by stating two conclusions. First, the introduction shows that the design of production systems can create a substantial edge over less skilled competitors and contribute to a company's prosperity. Therefore, the effectiveness and efficiency in designing production systems can be a strategic weapon for competition in a global environment with sophisticated customers, fast-evolving technology, and shrinking product lifetimes. Second, the effectiveness and efficiency of the production system design process is largely dependent on the capability of managing relevant and necessary design information, thus bringing the research area in this thesis into focus.

However, although previous studies clearly contribute to the literature of improved management of design information, they do not focus explicitly on the implications for the managing of design information in the production system design process. The majority of theories on managing information originate from the field of product design and development, while theories in the production system design process rarely focus on the managing of design information. Addressing the gaps in the literature, the research objective was formulated as follows:

The objective is to develop knowledge to contribute to an effective management of design information when designing production systems.

This type of research is important to support the management of design information when designing the production system. An effective management of design information is seen as a means of contributing to and effective and efficient production system design process, thus supporting the creation of the best possible production system in a shorter time. To address the objective of the thesis, the thesis expands the analysis of the role of design information in the production system design process into two sub-areas, the type of design information required and the managing of design information. The former refers to the required resource to carry out design activities in an effective and efficient way, while the latter refers to the capability required to deploy design information resources. Therefore, the thesis focuses on two research questions:

RQ1: What design information is required when designing production systems?

RQ2: What characterizes the management of design information when designing production systems?

1.4 DEFINING AND DELIMITING THE RESEARCH AREA

In this thesis, the objective is to develop knowledge to contribute to an effective management of design information when designing production systems. To achieve this, calls for a structure that enables the assimilation and utilization of the developed knowledge. Therefore, a design information management framework will be created in order to visualize the findings of the research presented in this thesis and to support the management of design information when designing the production system.

NPD can be defined as "the transformation of a market opportunity into a product available for sale" (Krishnan and Ulrich, 2001, p. 1). This means that the term NPD as used in this thesis concerns both development and manufacturing of products. Consequently, NPD is employed to refer to a broader concept than only product development; NPD rather considers both product and production system development as integrated processes that are dependent on each other for successful NPD projects.

Production system design can be defined as 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 a production system design process is a detailed description of the proposed production system solution, while production system development as used in this thesis also includes the realization of the production system (Bellgran and Säfsten, 2010). Consequently, the focus of the empirical studies has been on the actual design task, which corresponds to the early phases of the development process, while the implementation and production start-up of the production system were excluded from the empirical data collection.

Further, in order to achieve the objective of the thesis, studying the design process of the production system is crucial. Despite the fact that a significant amount of design research has been carried out over the last decades, it is still questioned whether design can be a topic suitable for scientific investigations (Berglund *et al.*, 2001; Davenport and Prusak, 1998). Therefore, the way design is considered is of relevance for assessing the research. In the terms used by Cross (1999), "design science" and "science of design" refer to research that aims at improving our understanding of design and the development of support through the use of scientific methods during the investigation. The current thesis studies principles and practices of designing production systems as well as the relevance of development of support.

The empirical data were collected in the automotive industry. The automotive industry has long experience of combining novelty with complexity and thus frequently applies a concurrent development process (Terwiesch *et al.*, 2002) in order to develop a product in the best way regarding value-added time and resources. Therefore, the automotive industry was a natural candidate for the research presented in the thesis. However, the results of the thesis are transferable to other industries, where it is imperative to find more resource-efficient ways of designing production systems.

When designing a new production system, the degree of change, i.e. the extent of change required in relation to the properties of an existing production system, varies (Bellgran and Säfsten, 2010). Thus the extent of the changes in the production system can be seen as a continuum ranging from minor to major changes. At the one end of the continuum, it is possible to find production systems that largely possess the capabilities required for the introduction of new products, while at the other end of the continuum no actual production system can fulfil the required capabilities. The two industrialization projects[1] followed in this research required the design of a new production system, i.e. the new products could not be manufactured in the existing production systems and a new physical production system needed to be created. These projects were selected because the creation of a new production system demanded more work activities than a mere modification of the production system. This gave valuable insights regarding the management of design information. If there had not been so large changes, many of the insights gained would have been lost. However, it is important to note that an entire new production system design does not occur as frequently as changes. Even when new products cannot be manufactured in actual production systems, conceptual or technical solutions are often reused for the design of a new production system.

Finally, the managing of design information can be studied from different perspectives. The perspective taken in this research is what Frishammar and Ylinenpää (2007) call the "people-side" of managing information. As a result, the thesis ignores how the managing of design information could be organized by means of information technology. That is, the thesis does not address information technology aspects such as the retrieving, processing, and storing of design information or the use of management information systems. However, although the thesis emphasizes the "people-side" of design information management, information issues associated with cognition of information such as the perception and processing of information by individuals are not considered in the research. This does not mean that these issues are irrelevant, but they fall outside the scope of the thesis. Further, although the research presented in this thesis studied industrialization projects, the research does not focus on project management issues. The scope of the is research is on the management of design information when designing the production system and thus project management issues are only discussed in relation with the aspects where they affect the outcome of the design process.

1.5 OUTLINE OF THE THESIS

The thesis comprises two parts: (1) the summarizing chapter of this compilation thesis and (2) the appended papers

Part 1 consists of seven chapters. In the introductory chapter the overall importance of this research is motivated and the research objective and questions are defined. Chapter 2 outlines the frame of reference covering two main sections: production system design and design information management. Chapter 3 presents the research methodology, which starts with a description of the research approach. This is followed by a discussion of the research method, design, the process of

[1] To separate between the activities carried out during NPD, manufacturing companies use the term industrialization to refer to the process required to transfer a product design into production, thus including the design of production systems.

collecting and analysing data, concluding with an assessment of the credibility of the research. In Chapter 4 the results of the four case studies and the survey are presented. The analysis of the results is done in Chapter 5. The following chapter (Chapter 6) synthesizes the findings around the two research questions and brings them to the development of a design information management framework. Chapter 7 concludes the thesis and the research results are summarised and discussed. The chapter ends with recommendations for further research. Figure 1 outlines Part 1 – the summarizing chapter of this compilation thesis.

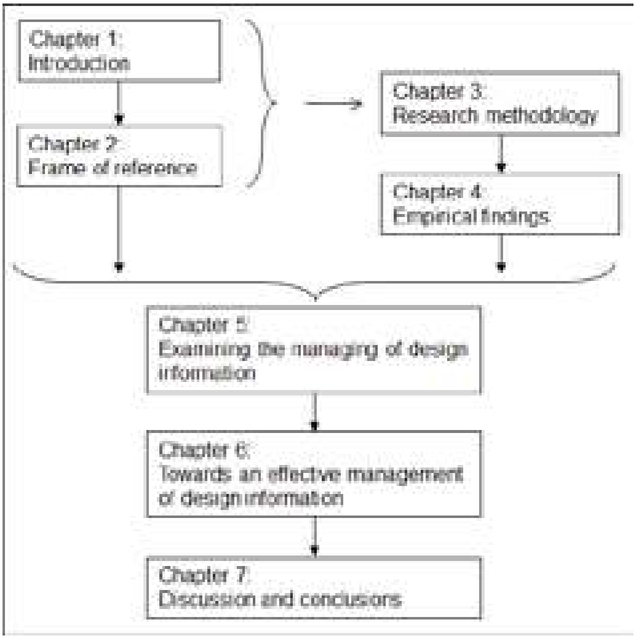

Figure 1. Outline of the summarizing chapter of this compilation thesis.

Part 2 consists of six papers produced during the PhD studies. Paper I summarizes the conclusions drawn in the licentiate thesis. Paper II examines the managing of design information between design engineers and production system designers, while Paper III focuses on the sharing of design information between manufacturing companies and external equipment suppliers. Paper IV investigates critical factors facilitating effective management of design information in the production system design process. Paper V focuses on the management of design information in the production system design process. Paper VI investigates the consequences for the managing of design information when there is a need to design production systems with a longer-term perspective.

CHAPTER 2

FRAME OF REFERENCE

CHAPTER INTRODUCTION

In this chapter, the frame of reference is summarized. The theoretical considerations are divided into two parts central to the research area: the design of production systems and the management of design information.

A recent trend in manufacturing industry includes an effort towards applying lean production to achieve greater efficiency and productivity (Liker, 2004). At the same time, companies have to cope with the demands to frequently introduce new products to the market (Girotra *et al.*, 2007; Stalk Jr. and Hout, 2003). While the concept of lean production has doubtlessly contributed towards the understanding that production can be a decisive tool for competiveness, it focuses predominantly on improvements in operational performance. The emphasis on improving production performance may appear efficient to manufacturing companies, but in the longer term, the process by which a production system is designed provides the largest potential of the most cost-effective solution (Bennett, 1986). The focus on lean production in manufacturing companies may thus not be enough to be responsive to changes in product design and demand patterns. The proposition underlying this thesis is that manufacturing companies need to pay increasing attention to the production system design process in order to obtain competitive advantages. Thus, this chapter starts by reviewing previous literature about the production system design process before addressing critical issues regarding the managing of design information in the production system design process.

2.1 THE PRODUCTION SYSTEM DESIGN PROCESS

2.1.1 Production systems

Before dealing with research concerning the design of the production system, it is essential to understand the underlying terms of the research. Since the meaning of terms varies among different authors, those adopted in this research are outlined below.

Production is regarded as *"the act or process (or the connected series of acts or processes) of physically making a product from its material constituents, as distinct from designing the product, planning and controlling its production, assuring its quality" (Chisholm, 1990, p. 736).*

This definition implies that production refers only to the process of converting input into desired products and services and thus production is seen as one of several activities required to put a product on the market, an activity which is regarded as manufacturing. Thus, manufacturing is transforming something of much greater scope than production.

The term **system** refers to a finite set of elements that have a relationship to each other and to the environment and that under well-defined rules should form a whole (Hubka and Eder, 1988). Hubka and Eder (1988) point out that systems constitute a hierarchy meaning that a system is always a constituent part of a super system, while at the same time it can itself be divided into subsystems. When adding the word system to production, it refers to the actual physical system in which the transformation from input into desired outputs takes place.

*A **system** can thereby be defined as "a collection of different components, such as for example people and machines, which are interrelated in an organised way and work together towards a purposeful goal" (Bellgran and Säfsten, 2010, p. 38).*

A system is a separate unit with system boundaries that can be drawn at different levels, and everything outside of the system boundaries can be considered as the external environment (Wu, 1994). In addition, a system can be either open or close. The former refers to a system that depends on and interacts with its surroundings, which is not the case in a closed system. The production systems studied in this research were open systems that depended on and were affected by the context, i.e. the production systems had to be adaptable to the changing context such as customer demands or volume fluctuation. It is important to note that although the environment influences the production system, the production system cannot influence the environment; for a more detailed discussion, see e.g. Churchman (1978).

Based on the discussion above it can be concluded that the production system can be seen as a subsystem of the manufacturing system, where the production system includes all activities and elements needed to transfer a set of inputs into products and services. The production system comprises a number of elements with reciprocal relations. To study the transformation process requires considering the totality of all subsystems and elements including the relationship between them and to their environment. Consequently, in this thesis the **production system** is considered as

"an interacting combination at any level of complexity, of people, material, tools, machines, software facilities, and procedures designed to work together for some common purpose" (Chapanis, 1996, p. 22).

The definition emphasizes the need for taking a comprehensive view of all subsystems, their elements and their relations when designing a production system in order to minimize the risk of suboptimization by having a one-sided focus on one of the production system subsystems. Groover (2008) identifies four subsystems of the production system:

- Technical system – represents the hardware that is directly linked to the production process including machines, tools, fixtures, etc.
- Material handling system – represents the hardware that is related to loading, positioning, and unloading as well as transportation and storage between stations.

- Human system – represents direct and indirect labour required to operate and manage the production system.
- Control system – represents the planning and control capabilities required to coordinate the other system elements.

2.1.2 A systematic design process

The introduction stated that the designing of production systems is important in order to achieve fast and effective product introductions to the market. Once the production system is in operation, the ability to make major changes is limited due to cost and time restrictions. The work of designing the production system is regarded as a process.

A **process** is *"a network of interrelated activities that are repeated in time, whose objective is to create value to external and internal customers" (Bergman and Klefsjö, 2010, p. 42).*

In contrast to the system perspective, which facilitates the understanding of the complex production system (Checkland, 1999), the process perspective supports the coordination of the work (Keen and Knapp, 1996). Thus, the production system design process is understood as a tool needed to manage and support the design activities. It is important to note that the task of designing a production system is often carried out in a project. A project refers to a temporary endeavour undertaken to solve a unique task such as the design of the production system within a well-defined time frame, which should be guided by the company's design process.

In general, the process of designing a production system can be divided into several distinct phases comprising all necessary activities from an analysis to a detailed design of the selected system solution. One way to structure the design activities is to separate between a preparatory design phase and a design specification phase (Bellgran, 1998; Bellgran and Säfsten, 2010). The former phase is very crucial for the possibility of designing production systems that suit the preconditions of each company and situation and mainly involves analysis, while the latter phase involves the utilization of both creativity and analysis.

Each phase can be further divided into subsequent work activities. The first and second steps are preparatory design activities and include looking backwards and inwards in order to bring obtained experience into forthcoming production systems but also looking ahead and outwards aiming at capturing the company's goals and strategies into the production system design. The latter 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 2 below reviews the activities that should be carried out in the different design phases as suggested by several scholars (Bellgran and Säfsten, 2010; Cross, 2000; Pahl and Beitz, 1996; Roozenburg and Eekels, 1995; Ulrich and Eppinger, 2007; Wu, 1994). The activities shown in Figure 2 are illustrated in a sequential flow. However, in order to achieve an effective and efficient production system design process, it is essential to emphasize the necessity for an iterative process with many cycles and partly overlapping activities.

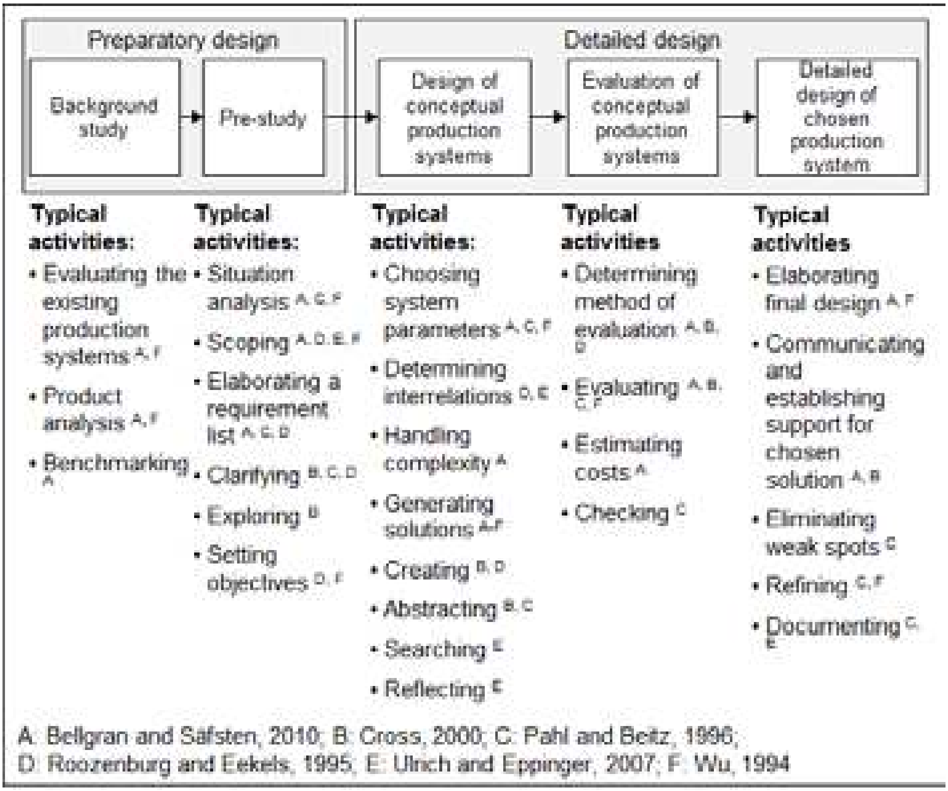

Figure 2 Typical work activities carried out when designing the production system.

Accomplishing the work activities specified in Figure 2 requires the involvement of different functions[2] that contribute with input and decision making. However, the manufacturing company does not need to be responsible for all work activities carried out in the production system design process; rather the manufacturing company has the choice among internal designers and external designers or a combination of both (Bellgran, 1998). By utilizing external expertise, the company can benefit in the design process from new and innovative ideas and detailed knowledge. One activity that is frequently carried out in collaboration with several industrial actors is the design and subsequent building of the production equipment, i.e. there is a general trend towards acquiring the production equipment from external equipment suppliers.

As early as the 1970s, Abernathy and Wayne (1974) pointed out that vertical integration expands and specialization in production equipment increases causing an increase in capital investment. Equipment suppliers are sources of major

[2] Since departments can include more than one function and also evolve over time, in this research the term function is used to denote responsibilities and work areas required to design the production system.

innovations in manufacturing technology for which the incentives are greater and adopted by the larger user firms (Hutcheson *et al.*, 1996; Reichstein and Salter, 2006). Further, it has been argued that equipment suppliers need to take more responsibility for refining existing technology and improving equipment reliability and capabilities (Hutcheson *et al.*, 1995). However, those companies that procure production equipment become dependent on the equipment suppliers' efforts to provide the equipment and to secure or improve the operating performance of the equipment (Lager and Frishammar, 2010). Thus, the design and building of production equipment is of significance for the manufacturing industry and often accounts for a fairly large share of costs in production development projects. Long-term collaboration between the manufacturing company and the equipment supplier is therefore of great value for successful acquisition of production equipment (Bellgran, 1998). In order to ensure long-term collaboration, efforts have been made to define a structured and systematic acquisition process for the production equipment (Johansson and Nord, 1999; Rönnberg Sjödin and Eriksson, 2010).

2.1.3 Different approaches to the production system design process

A distinction can be made concerning the approach taken to the production system design process, which affects the activities that are carried out by the manufacturing company. Expanding on Wu (1994) and Engström *et al.* (1998), Säfsten (2002) identifies three main approaches to the design of production systems:

- The concept-generating approach – The design process is driven by different constraints such as type of product, volume, and number of variants.
- The concept-driven approach – The design process is driven by something external such as a pre-existing design or the interest of an actor.
- The supplier-driven approach – The design process is driven by an external supplier suggesting possible alternatives based on more or less detailed requirement specifications.

The three approaches, see Figure 3, imply different degrees of involvement by the manufacturing company in the production system design process. Figure 3 illustrates that in a concept-generating approach the manufacturing company is responsible for all activities from the analysis of the situation to a complete production system in operation. On the other hand, in a supplier-driven approach, the supplier takes care of parts of the activities. In the most extreme case all work activities are outsourced to a supplier. However, even in situations where the design of the production system is completely outsourced to a supplier, it seems necessary to maintain certain competencies also within the manufacturing company. For example, Hobday *et al.* (2005) or Von Haartman and Bengtsson (2009) point out that to be able to benefit from supplier integration, manufacturing companies have to possess corresponding in-house competences.

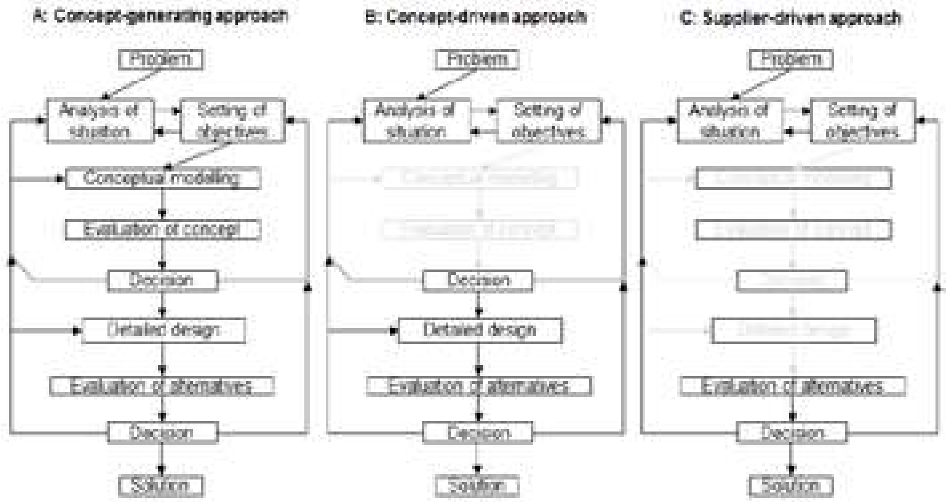

Figure 3 Three different approaches to the design process from the manufacturing company's perspective (adapted from Säfsten, 2002).

Further, it is widely acknowledged that product and production system design activities should be integrated in order to reduce the time required for introducing new products on the market (Andreasen and Hein, 1987; Magrab *et al.*, 2010). Gerwin and Barrowman (2002, p. 939) define integrated product development as "a managerial approach for improving new product development performance (e.g., development time), which occurs in part through the overlap (partially or completely parallel execution) and the interaction (exchange of information) of certain activities in the NPD process". As a result, several issues related to the development of the product are considered simultaneously rather than sequentially. However, in contrast to a non-overlapping and non-interacting development of products, an integrated approach also increases the need for coordination. One possibility to ensure a high degree of coordination of the different work activities is the ability to apply a product development process. A product development process describes the sequence of steps and activities the company has to deploy (Ulrich and Eppinger, 2007). Thus, the production system design process can be considered as a part of the new product development process. Prior research on product development best practices highlights that successful projects follow a formalized and structured cross-functional stage-gate model for the product development process (Griffin, 1997). Cooper (2008) describes that a stage-gate process in its simplest form consists of a series of stages which are followed by gates. In the stages the project team undertakes the prescribed work activities, while in the gates decisions are made on whether the project should continue or not. Including both the product and the production system design in the same process requires creating a balance between the two design processes by not solely focusing on either the product or the production system design.

Further, as the production system is hierarchical and consists of a number of interrelated elements, there are many similarities between the production system and a complex product. Hobday (1998, 2000) defines complex products as high-technology, business-to-business capital goods where each product is of high cost and made up of many interconnected, often customized parts, designed in an hierarchical manner and tailor-made for specific customers. Due to high costs, physical scale, and composition, complex products are typically produced within a recognizable, single project or small batches (Hobday, 1998, 2000). In line with a complex product, the production system is often a one-off that is highly adjusted to the requirements placed upon it and whose creation requires a high degree of knowledge. However, one should be aware that there is also a fundamental difference between a complex product and the production system. The production system is not a product that is used by humans; rather the human subsystem is a part of the production system (Bennett and Forrester, 1993; Groover, 2008). The implication of the difference is that although a great deal of related work can be found in the new product development theory, not all theory may be valid when designing a production system.

2.1.4 Difficulties in the production system design process

Although manufacturing companies have started to focus on production system design, many find it difficult to coordinate the production system design process and work in a structured and systematic way; see discussions by Bellgran and Säfsten (2010) or Cochran *et al.* (2001/2002). Multiple explanations for the difficulties in production system design are possible. First, the nature of the production system design process is not well defined, i.e. there are many different definitions and interpretations of the process and work activities involved (Cochran *et al.*, 2001/2002). Part of the reason is that companies have focused on the product design because they saw it as a way to achieve competitive advantages, while the production system design process is seldom seen as a means to achieve the best possible production system (Bellgran and Säfsten, 2010). Thus, although the term design process is well known in manufacturing companies, it is usually applied in the product design and not in the system required to produce the products. It is, however, important to note that "process development[3] is a technically difficult and organisationally complex activity on its own right, and operates in a much richer context than is generally portrayed in the simultaneous-engineering literature" (Pisano, 1997, p. 31). As a result, the design of production systems needs to trigger separate control and coordination of the specific set of activities required to move the project along from inception analysis to detailed design.

Second, a general implication of the definition of the production system is the need to extend the activities of the production system design process beyond those of production equipment, plant layout, and job design (Love, 1996). Applying a holistic perspective increases the complexity of the production system design process significantly, implies that the design itself is organizationally complex, and spans over multiple functions. Consequently, production system design processes require

[3] The term process development is defined as creating and refining an organization's capability to manufacture a product or set of products commercially, which is similar to the term production system design applied in this thesis.

setting up a project team with members from different specialized functions to handle both the required skills and the volume of the work involved (Love, 1996).

Third, Chryssolouris (2006) points out that at the time a production system should be designed, the objectives of a production system are neither well-defined nor aligned to changes. Further, information about the elements of the production system such as the production equipment or material handling system is imprecise at the beginning of the production system design process, particularly if there is a need to handle a high degree of novelty (Chryssolouris, 2006). In order to minimize the degree of novelty, it is suggested that production system designers should reuse and retain as many thoughts and concepts as possible of previously designed and implemented systems (Hubka and Eder, 1988).

Finally, the production system design process is interdependent with the company's manufacturing and business strategy (Bennett and Forrester, 1993; Pisano, 1997). Thus, the decisions made in the production system design process should strive for the achievement of both an internal and external (environmental) fit (e.g. Choudhari *et al.*, 2010; Miller, 1992; Ruffini *et al.*, 2000). An internal fit ensures that the elements of the production system are mutually supportive and that the decisions about the production system design align properly with the company's operational goals and objectives, while an external fit provides consistency between the capacities and capabilities of the production system and the context. However, accomplishing an internal fit among the different subsystems of the production system poses challenges due to the large number of design variables and their interdependence. As has been argued by Bozarth and McDermott (1998), to accomplish an internal fit one must consider simultaneous, complex interactions among a wide range of interdependent variables when designing the production system.

On the other hand, in order to obtain an external fit requires that the capability of the production system corresponds to the competitive priorities of the company (Miltenburg, 2005). One possibility is to consider the market and context, manufacturing strategy, product concept, etc. (Bennett and Forrester, 1993; Duda, 2000). As the conditions change over the product life cycle, it is also necessary to identify order winners and order qualifiers for each phase of the product life cycle. For example, Aitken *et al.* (2003) and Slack and Lewis (2008) illustrate the importance of considering different competitive strategies during different phases of the product life cycle. Cost, for example, may in the introduction and growth phase be an order qualifier, while it can be an order winner in maturity and market saturation phases. However, any change in the external fit may also demand suitable modifications to the production system design to provide an internal fit.

Although one key requirement in the production system design process is to achieve internal and external fit, there is the possibility that the demand can cause conflicts as when efforts to maintain environmental fit prevent or destroy internal complementarities, or when the emphasis on internal consistency detracts managers from changes outside the organization (Miller, 1992). Thus, achieving internal and external fit is not an easy task. Further, concerns have been raised whether there is more than one production system design that can represent the best fit, as different production systems may result in similar performance (Ruffini, 1999). Similar results have been found by Draaijer and Boer (1995), who found that on the one hand similar market demands were satisfied although manufacturing companies had organized the production systems very differently, and on the other hand very different sets of market demands were met by similar production systems. Thus, it is not possible to point out an exact way of how a manufacturing company should design its production systems; instead there are multiple, equally effective ways in which a manufacturing company can achieve internal and external fit (Van de Ven and Drazin, 1985). As has been argued by Bellgran (1998), the resulting production system is the product of how people, influenced by the organizational and historical context, apply the available options to design the production system.

Overall, it can be concluded that the literature reviewed so far provides many important insights into the production system design process and challenges that need to be met. However, the above-discussed research provides only limited insights into how those challenges can be handled by critical resources such as design information. This thesis contributes to the important work conducted by Bennett and Forrester (1993), Ruffini (1999), and others by investigating the critical role attributed to design information in the production system design process.

2.2 THE MANAGEMENT OF DESIGN INFORMATION

2.2.1 Defining design information

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. 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; Kahn *et al.*, 2002), where differences are based on the extent to which they reflect human involvement.

Information is defined as *"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. In this thesis, 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. 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 in spite of being acquired and shared (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, 2005; 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 4.

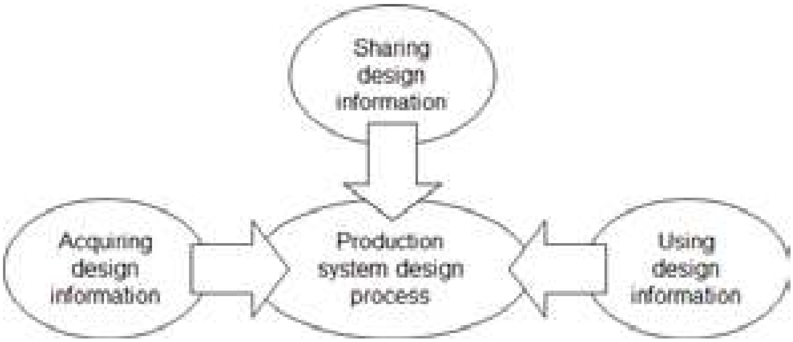

Figure 4. Model of the three dimensions of managing design information in the production system design process (based on Frishammar and Ylinenpää, 2007).

2.2.2 Acquiring design information

Acquiring of design information refers to the gathering of relevant and necessary information required to make the design process more effective and efficient (Frishammar and Ylinenpää, 2007). In general, the definition of the production system and the identified activities carried out in the design process imply that multiple types of design information need to be considered in the design process ranging from strategic to operational information. The need to differentiate between strategic and operational information is confirmed by Bruzelius and Skärvad (1989), who categorize information into broad and deep information. The former concerns the strategic more general information required, while the latter refers to the operative information and is often deep in details. Information may also be classified as operational or background information (Petersson and Petersson, 1992). The purpose of operational information is to facilitate fulfilment of the task. Background information, on the other hand, aims at providing a better context for the decision making and strengthening the motivation of the employees.

In addition, Frishammar (2003) and Häckner (1988) classify information into hard (quantified) and soft (qualitative) information and discover that companies usually rely on a combination of both hard and soft information. Hard information regards numerical information that can easily be quantified and processed with the help of analytical models, whereas soft information refers to images, visions, ideas, and cognitive structures (Häckner, 1988). In addition, soft information may be characterized as broad, general, and subjective, as it concerns holistic images of reality and is linked to individuals (Shrivastava, 1985).

It has been argued that the type of information required depends on task complexity and previous experience (Byström, 1999; Fjällström, 2007). Task complexity refers to whether the event is planned or unplanned, and previous experience refers to whether the handling of the event is known or unknown, see Figure 5. Fjällström (2007) found that when a routine problem occurred, domain information, i.e. information about facts, concepts, and theories in the domain of the problem and problem solving information was available, while in cases of novel problems this had to be figured out by the people dealing with the problem.

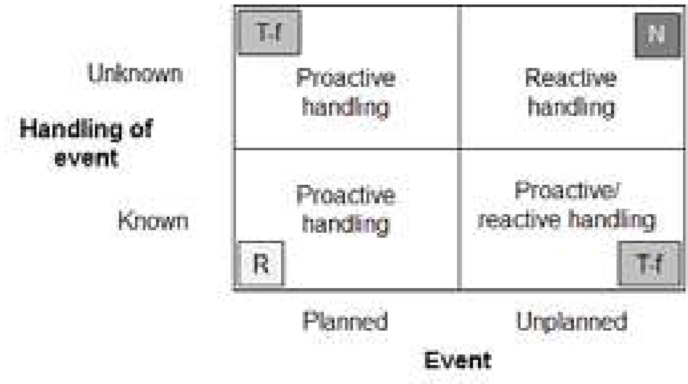

Figure 5. Task complexity and earlier experience (R = routine problem, T-f = trained-for problem, N = novel problem) (based on Fjällström, 2007; Säfsten *et al.*, 2008).

Another classification is made by Zahay *et al.* (2004), who distinguish between different information types according to their origin, i.e. whether the design information was internally developed or obtained from the external context. Consequently, design information may be obtained from different sources. A source is expected to contain the relevant design information required for performing a work activity. Sources cannot only be divided into internal and external sources, but also into personal and impersonal sources (Aguilar, 1967; Daft *et al.*, 1988). The former include direct human contact, while the latter regard written/non-verbal sources of design information. A more detailed classification of impersonal sources has been provided by Johansson (1999) and Harlin (2000) who separate process and documentation as impersonal sources. Documentation refers to any type of written information, while process regards information that can be obtained by analysing existing production systems. Aguilar (1967) found that although the receiver of information often depends on a combination of information sources, personal sources far exceed impersonal sources in importance. Similar results have been provided by Fjällström (2007) and Hertzum and Pejtersen (2000), who state that personal sources are the preferred choice. Further, the results of previous research indicate that internal sources are favoured in contrast to external sources. For example, Aguilar's (1967) study shows that even in cases of external information, i.e. information about the company's outside environment, managers tend to rely almost as much on inside sources than on outside sources. This phenomenon may be partly explained by the fact that perceived source accessibility is positively related to the frequency of usage (Sawyerr *et al.*, 2000).

2.2.3 Sharing design information

To Frishammar and Ylinenpää (2007), information sharing is the transfer of information across specialized functions. The sharing of design information is a key for successful development since it reduces uncertainty and equivocality among participants in development projects (Daft and Lengel, 1986) and allows for integration between the specialized functions (Moenaert and Souder, 1990; Turkulainen, 2008).

A key implication from prior research is that the management of uncertainty and equivocality has different information needs (see e.g. Daft and Lengel, 1986; Frishammar *et al.*, 2011). Uncertainty can be defined as "the difference between the amount of information required to perform a particular task, and the amount of information already possessed by the individual" (Galbraith, 1973, p. 5). Consequently, uncertainty requires the provision of additional/new information to close the information gap causing uncertainty. The assessment of uncertainty is based on aspects such as clarity and the amount of detail that is available (Galbraith, 1973). Daft and Lengel (1986) propose that in order to reduce uncertainty, companies have to ask a large number of questions and gather additional information to seek answers to the questions. They conclude that to support the amount of information needed to deal with uncertainty and achieve desired task performance, it is possible to implement specific structural mechanisms. Overall, the reduction of uncertainty requires the provision of new but target-oriented information (Moenaert *et al.*, 1995).

Equivocality, on the other hand, is primarily associated with ambiguity, i.e. multiple and conflicting interpretations among project participants (Weick, 1995). In order to reduce equivocality among project members, the exchange of subjective information is required. In situations of high equivocality, the key is to construct or enact a reasonable interpretation that makes previous action sensible and suggests how to proceed (Daft and Weick, 1984). Thus, additional information does not contribute to the resolving of misunderstandings; rather equivocality is resolved by defining or creating an answer (Weick, 1995).

It has, therefore, been suggested that the communication medium, i.e. the medium by which information is transferred, has to be carefully chosen since the applied communication medium has consequences on the capacity to process information. For example, Hertzum and Pejtersen (2000) point out that written information such as documents lack information about the surrounding context, i.e. they miss explanations about why specific decisions are made as well as what purpose is served. Therefore, in situations of high equivocality the processing of rich information, i.e. information that will change understanding in a timely manner, is crucial (Daft and Lengel, 1984, 1986). Consequently, there is a need to use a communication medium that allows for immediate feedback, debate and clarification such as face-to-face meetings. On the other hand, when the aim is to minimize uncertainty, a less rich medium is recommended, i.e. a medium that can transfer rather large amounts of information such as documents (Daft and Lengel, 1984, 1986). This category is effective for the processing of well-understood messages and data since it involves fewer cues and thus restricts feedback. The discussion above is summarized in Figure 6, which illustrates the different structural characteristics a company can implement to facilitate the sharing of either rich or less rich information.

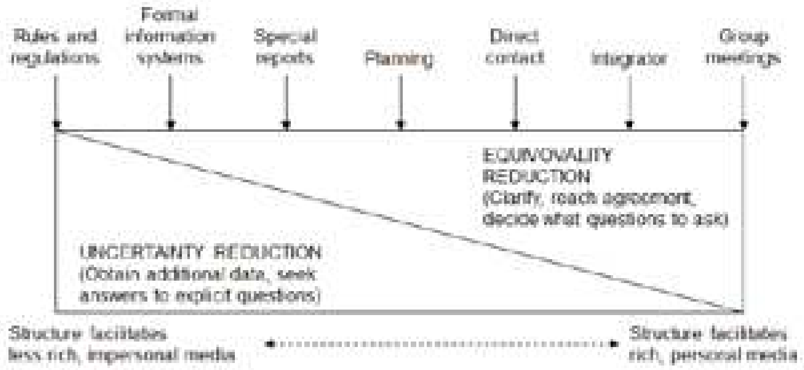

Figure 6. The different needs of information sharing to cope with uncertainty and equivocality reduction (adapted from Daft and Lengel, 1986).

Furthermore, it has been argued that a company's ability to effectively integrate cross-functional activities is based on the process of sharing real-time information in order to identify and solve problems (Moenaert and Souder, 1990; Wheelwright and Clark, 1992). Nevertheless, although the transfer of information is essential, research by Ottum and Moore (1997) shows that the information collected by one function is not automatically shared with other functions. The diversity of functions implies a high degree of differentiation and interdepartmental differences causing problems in the sharing of information (Lawrence and Lorsch, 1986; Vandevelde and Van Dierdonck, 2003). Griffin and Hauser (1996) argue that subtle terminology difference between different functions may imply vastly different solutions. The terminology and detail used can cause frustration when people with different expertise and skills share information (Vandevelde and Van Dierdonck, 2003). In general, it becomes more difficult to share information among people with different functions and backgrounds the more abstract the information is (Jacobs, 1996). For people with the same background and knowledge it is much easier to understand the shared information.

Prior research emphasizes the important role dedicated to external equipment suppliers in the production system design process (Reichstein and Salter, 2006; Skinner, 1992). However, the sharing of information should become even more challenging when external competencies such as equipment suppliers are included in the design process. Several studies illustrate that distance and organizational bonds have an impact on information exchange (e.g. Dankbaar, 2007; Vandevelde and Van Dierdonck, 2003). These studies argue that physical proximity, i.e. a short distance, is beneficial for the exchange of information. For example, Allen (1977) points out that the frequency of information sharing among people normally decreases in line with increased physical separation. It has been highlighted that people working in dispersed teams are more likely to 'drop' members who are distant (Mortensen and Hinds, 2002). With an increase in distance, informal and face-to-face communication becomes inconvenient (Vandevelde and Van Dierdonck, 2003). Another reason why the sharing of information should become even more challenging is organizational bonds. These bonds can hamper the sharing of information because of a lack of clarity, roles, and responsibilities (Gupta *et al.*, 1987).

Based on the discussion above, it can be concluded that there is a correlation between the sharing of information and the integration of specialized functions. Interaction and collaboration are two important elements of integration between different functions. Interaction is associated with structural and formally coordinated activities including routine meetings, planned teleconferencing, and the flow of standard documentation (Kahn, 1996). Collaboration, on the other hand, refers to the unstructured, affective nature of relationships between different functions and stresses the importance of mutual understanding, common vision, shared resources, and achievement of collective goals in a process where several functions work together in a mutual/shared process (Kahn, 1996). Frishammar and Hörte (2005) argue that although interaction is primarily concerned with the sharing of information, also collaboration is an appropriate measure of information sharing since the underlying foundation for a high level of collaboration is a good flow of information between the different functions. Consequently, integration is approached as an information-sharing phenomenon, where shortages occur due to a lack and asymmetry of information or an inability to share information (Turkulainen, 2008).

Further, it can be concluded that integration can be promoted by structural and formal coordination activities among functions and through a more unstructured informal coordination process that stresses continuous relationship (Frishammar and Ylinenpää, 2007). Coordination can be defined as "all informal and formal mechanisms that establish and integrate the roles of project participants and it involves the timing and frequency of activities that are required to meet the product goals" (Olausson and Magnusson, 2011, p. 283). Formalization concerns the degree to which rules or standard operating procedures are used to govern interaction between different functional areas (Ruekert and Walker, 1987). Expanding on Thompson (1967) and Adler (1995), Vandevelde and Van Dierdonck (2003) discuss four categories of formal coordination:

- Standards or rules
- Plans and schedules
- Formal mutual adjustments
- Dedicated teams

In a study of the design-manufacturing interface in the UK automotive industry, Twigg (2002) found that those coordination mechanisms can also be applied when company bounds are crossed. Informal coordination mechanisms, on the other hand, concern formless relations that cut across formal structures or informal communication supplementing formal (Martinez and Jarillo, 1989). Overall, it has been argued that information obtained through informal paths is far greater than the information obtained through formal paths (Bruzelius and Skärvad, 1989).

2.2.4 Using design information

Using design information in this thesis is regarded as responding to or taking appropriate actions on the acquired and shared information (Frishammar and Ylinenpää, 2007). In general, it is important to ensure that the information is of high value to the user, i.e. the user has to perceive information as useful for the task at hand to actually employ the information in his/her work activities (Eppler, 2006). One way of establishing a high degree of information utilization in the work tasks is to focus on quality and not quantity, meaning that manufacturing companies should start to focus on information quality instead of gathering enormous amounts of information. The goal has to be to improve the usefulness and validity of the available information rather than to overwhelm people with information. Several studies, such as those by Kahn *et al.* (2002), Lesca and Lesca (1995), and Strong *et al.* (1997), have been undertaken to investigate the origin and consequences of deficiencies in information quality. It is clear from these studies that information quality is a multidimensional construct that considers several qualitative criteria that information should fulfil to effectively meet user requirements. Eppler (2006) suggests sixteen dimensions of information quality, which are summarized in Table 1.

Table 1. Information quality dimensions and their definitions (Eppler, 2006)

Dimensions	Definitions
Comprehensiveness	Is the scope of information adequate (not too much nor too little)?
Accuracy	Is the information precise enough and close enough to reality?
Clarity	Is the information understandable or comprehensible to the target group?
Applicability	Can the information be directly applied? Is it useful?
Conciseness	Is the information to the point, void of unnecessary elements?
Consistency	Is the information free of contradictions or convention breaks?
Currency	Is the information up-to-date and not obsolete?
Correctness	Is the information free of distortion, bias, or error?
Convenience	Does the information provision correspond to the user’s needs and habits?
Timeliness	Is the information processed and delivered rapidly without delays?
Traceability	Is the background of the information visible (author, date, etc.)?
Interactivity	Can the information process be adapted by the information consumer?
Accessibility	Is there a continuous and unobstructed way to get the information?
Security	Is the information protected against loss and unauthorized access?
Maintainability	Can all the information be organized and updated on an on-going basis?
Speed	Can the infrastructure match the user’s working pace?

If problems in information quality are not handled adequately, there is a risk for difficulties such as the inability to find the right information or to use the information in the task at hand. Therefore, Eppler (2006) proposes an empirically-based framework for information quality, see Figure 7. The framework focuses on improving information quality in knowledge-intensive processes, i.e. non-routine processes with demanding requirements in terms of continuous learning and innovation; processes that rely on the individual's expertise and personal contribution in the form of information. The information quality framework illustrated in Figure 7 comprises four elements (Eppler, 2006):

- The first element consists of the four information quality levels: relevant information, sound information, optimized process, and reliable infrastructure.
- The second element consists of four phases and concerns the life cycle of information from a user's perspective: information is searched and found (identification), evaluated, adapted to a new context (allocation), and applied.
- The third element consists of the sixteen identified information quality criteria, which are placed along the phases according to their importance for the different phases.
- The fourth element consists of the management principles that can be applied to improve the quality of information in every phase: integration, validation, context, and activation.

In Figure 7 the four information quality levels are further divided into content quality and medium quality. This is done in order to emphasize that the first two levels, relevance and soundness, relate to the actual information itself, while the lower levels, process and infrastructure, relate to the adequateness of the channels by which information is transported (Eppler, 2006).

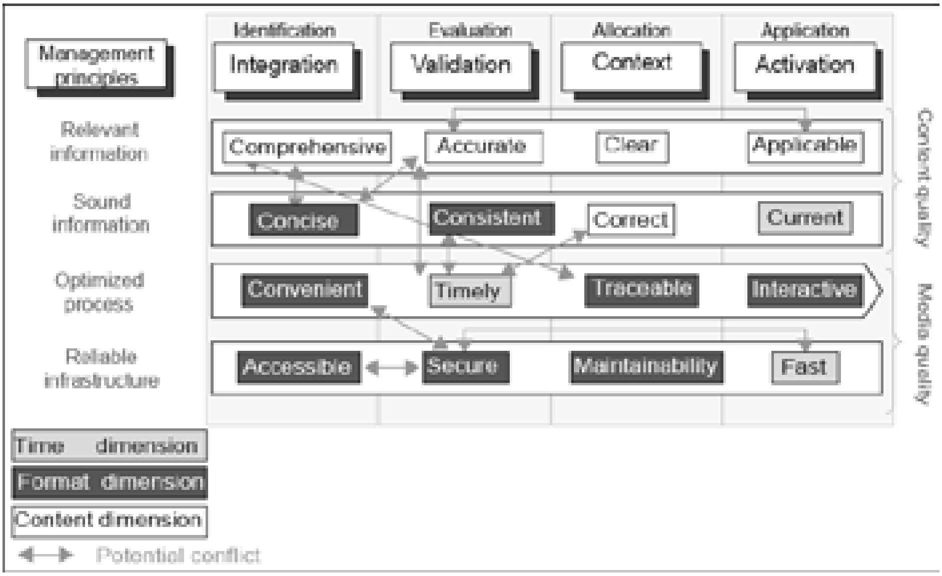

Figure 7. Information quality framework (adapted from Eppler, 2006).

It is important to note that using information can be particularly challenging in projects where tasks are often processed in parallel, i.e. concurrent engineering (Terwiesch *et al.*, 2002). Johansson (2009) discusses in detail the consequences of concurrent engineering for information quality and concludes that the need to work with overlapping activities seems to affect several information quality criteria. One explanation is the need to use partial/preliminary information in development projects with overlapping activities, i.e. one cannot expect to receive the same type of information with the same accuracy in development projects with overlapping activities compared to projects that are carried out in a sequential flow (Smith and Reinertsen, 1998). Previous research points to a general reluctance among engineers to release early information on the one hand and to use incomplete information on the other hand (e.g. Clark and Fujimoto, 1991; Hauptman and Hirji, 1996). In the traditional more sequential development process, where tasks often proceeded in a sequential order, information could be finalized before it was shared with other functions. However, the need to shorten the time to market requires engineers to release and use preliminary information, which influences the precision and stability of the information (Terwiesch *et al.*, 2002).

Another aspect that facilitates the use of information is the pragmatic level of the information (Fjällström *et al.*, 2009; Von Weizsäcker, 1974). Pragmatic information adds new knowledge to the receiver by combining pre-knowledge of the matter (confirmation) with novelty, i.e. new aspects that the receiver did not already know. For information to be understood, it has to relate to pre-understanding and contain confirmation. When no confirmation exists, the receiver is not able to relate the information to any meaning and thus no understanding is possible (Von Weizsäcker, 1974). On the other hand, information also has to make a difference to the previous knowledge of the receiver, i.e. people expect to receive information that contains some degree of novelty (Alm and Fjällström, 2003).

2.3 SUMMARY OF FRAME OF REFERENCE

The frame of reference reveals that there is only a small amount of research that explicitly focuses on the critical role of the design information resource in the production system design process. The major part of research concerns either the production system design process or the management of information in new product development. Thus, there is a need for further research with respect to at least two areas when designing production systems: the required design information and the managing of design information.

The presented frame of reference does not only define the focus of the research and its limits; it is also a central tool that guides the data collection and analysis. To avoid ending up in a situation where the evidence does not address the initial research questions requires a framework of reference that directs the data collection (Yin, 2009). In addition, the frame of reference is also used during the analysis of the data, which is a continuous interplay between theory and data (Eisenhardt, 1989). Going into details regarding the research methodology is the theme of the next chapter.

CHAPTER 3

RESEARCH METHODOLOGY

CHAPTER INTRODUCTION

This chapter describes the research methodology adopted starting with a discussion about the research approach. Thereafter follows a description of the case study method including a discussion about research design, data collection, and data analysis. The chapter concludes with a discussion about the credibility of the research.

The research process of the PhD studies started in January 2007 and the research can be divided into two phases. The first phase of the research process aimed at identifying and analysing information that supports a proactive behaviour of assembly operators. The focus of the research was on operational information, i.e. the information required by the operator to plan, control, and execute the work activities that need to be carried out once the production system is in operation. This phase was finalized by the presentation of the licentiate thesis "Information Requirements in a Proactive Assembly Work Setting" (Bruch, 2009); the findings are summarized in Paper I (Bruch and Karltun, 2009) appended to this thesis.

A final conclusion from the research presented in the licentiate thesis was that it is necessary to provide operators with so called 'why information' to enable proactive behaviour[4] (Bruch, 2009; Bruch and Karltun, 2009). This means that operators need to get access to information that is related to a longer time horizon such as information about the introduction of new products leading to changes in the production system. However, the study also revealed that the manufacturing company had difficulties identifying and providing relevant and necessary information related to the design and implementation of production systems. Based on the conclusions drawn, a further literature review was conducted, which confirmed a lack of knowledge concerning the design information required and how to actually manage the design information when designing the production system. In addition, the literature review revealed the potential benefits that manufacturing companies can gain by focusing on the design process compared to the management and control of an existing production system. As a result, the research of the second phase, which started in mid-2009 after the presentation of the licentiate thesis, has

[4] For a more detailed discussion about the findings of the research presented in the licentiate thesis, see Bruch (2009) and Paper I (Bruch and Karltun, 2009) appended to this thesis.

a changed focus and thus the research methodology and findings presented in this thesis represent the second phase of the research process. However, the activities carried out during the first research phase provided a relevant background to the information management area.

3.1 RESEARCH APPROACH

The objective is to develop knowledge to contribute to an effective management of design information when designing production systems. Understanding knowledge as a contribution also needs admitting that knowledge is cumulative, i.e. the expanding of knowledge in an area may go through different phases depending on the existing knowledge (Karlsson, 2009). Both the management of information in new product development (NPD) and the production system design process have been studied previously but there is a lack of studies focusing on the management of information when designing the production system. Therefore, it was found necessary to have an explorative research approach. This means that the study is more directed towards know-what research rather than to understand how things work (know-how) or why it is so (know-why).

Even if the production system design process is usually carried out in a project with a defined goal and time frame, it can be considered as a complex process. Not only are the numerous elements and subsystems of the production system interrelated, but the activities carried out in the design process are also related. Further, the production system design process requires input from various specialized functions including those not directly involved in the industrialization project and is subject to influences from the external context. This makes it difficult to explicitly isolate the process of designing the production system from its surroundings. Therefore, the research problem has been approached from the system perspective, which means that the industrialization project, where the design of the production system is performed, is thought of as a system. Applying a system approach in this research has some consequences to the results of the research. Although the system approach assumes the existence of an objective reality, the findings of a system study do not result in absolute theory (Arbnor and Bjerke, 2009). Thus the system approach sees reality as consisting of components that are mutually dependent on each other but cannot be summed up. It is important to note that the description of the system is always an interpretation and simplification of the reality studied but has to be based on a study of the real system (Arbnor and Bjerke, 2009).

While the system approach determines the conception of reality, the research approach is also influenced by the reality that is studied. This thesis can be categorized as applied research, meaning that the knowledge produced in the research should not only be of scientific relevance but also of industrial usefulness. One approach emphasizing the contribution to practical use and useful research for practitioners concurrent with theory development is the interactive research approach. Interactive research emphasizes the need for collaboration between research and practice and aims at joint learning and critical knowledge production between the participants and the researcher (Svensson and Nielsen, 2006). Interactive research should not be considered in terms of the methods used; rather it is an approach towards a certain way of understanding and conducting research, namely to do research together with, not on, the participants (Larsson, 2006).

Therefore, the research was influenced by the interactive research approach. The interaction with the employees at the manufacturing company was based on the common interest in understanding the production system design process in more detail as a foundation for improvements. The collaboration with the manufacturing company took place over four periods: (1) introduction, (2) preliminary feedback, (3) participation in development activities, and (4) evaluation and feedback, which are described in more detail in Section 3.4.1.

In interactive research, new knowledge is created during various types of meetings and close interaction between the researchers and practitioners. However, despite the importance of cooperation that benefits both parties, the necessity of academic independence for interactive research is stressed (Svensson and Nielsen, 2006; Wigren and Brundin, 2008). Although interactive research aims at coming as close as possible to the phenomena studied, it does not point out the importance of distance for reflection. Thus, although the research process has been collaborative to a very high degree, the process of writing the present thesis and summarizing the academic results has been an individual one.

3.2 RESEARCH METHOD

In order to answer the two research questions presented in Chapter 1, it is important to select a suitable research method. The research method represents a way to plan for, collect, and analyse empirical data. Larsson (2006) argues that in interactive research different research methods can be used depending on the situation and the research questions. For the present research, the case study method was chosen. The first rationale for choosing the case study method was the need to gather a rich set of data from actual practice in order to facilitate the understanding of the phenomenon studied (Voss *et al.*, 2002). The lack of empirical studies exploring the management of design information when designing production systems called for a more flexible design strategy. Having a flexible design approach implies rigorous data collection procedures but the detailed framework of design emerges during the research progress (Robson, 2002). By taking a flexible approach, the research was not restricted by the clear-cut and linear research design used in fixed studies; instead, there was the possibility for the research questions to evolve, and data collection options could develop or be abandoned during the research process. The second rationale for choosing the case study method was the ability to study the entire production system design process from both the strategic and the operational perspective. An investigation of the process only for a given moment in time would not have reflected the dynamics of the process. As Leonard-Barton (1990) points out, a case study allows for the investigation of past and current phenomena from multiple sources of evidence.

3.3 RESEARCH DESIGN

Once the research method had been selected, the next step was to plan and organize the research, i.e. to design the research. The research design guides the researcher in collecting, analysing, and interpreting the observations made in the case study and thus works as a plan for how the researcher should go from initial questions to the conclusions answering the questions (Yin, 2009). Based on the conclusions drawn in the licentiate thesis and on another review of the academic literature, the initial research questions were formulated. Gaining pre-understanding about general constructs and categories that are of relevance for the research is a prerequisite when using a case study method (Voss *et al.*, 2002).

Although it is important to formulate research questions and develop a theoretical construct, it is common that the research questions evolve over time and that the theoretical constructs become modified. In addition, doing applied research of a dynamic process makes it difficult to plan for the research process in detail. Making adjustments to the observations made was also necessary in the current research to be able to give a comprehensive description of aspects that played an important role regarding the management of design information. The inherent flexibility of the research design can be a strength but should not be an excuse for inadequate specifications of research questions or constructs nor should it lessen the rigour with which case study procedures are followed (Voss *et al.*, 2002; Yin, 2009). In the present research design, minor changes were made due to the need to pursue new leads. These changes did, however, not require a change in the overall research design nor in the research objective.

Besides formulating the research questions and developing a general understanding of the area studied, the research design involves making a number of decisions. In the following, five aspects are discussed: number of cases, real-time versus retrospective cases, case selection, unit of analysis, and mixed method research.

3.3.1 Number of cases

The research is performed in the belief that the management of design information when designing production systems is influenced by the specific situation. Rather than there being one best way of managing design information, manufacturing companies have to adjust the management of design information to the context of the industrialization project. As a result, it was found necessary to study multiple cases highlighting the diversity of the phenomenon studied. In this, it was possible to minimize the risks often related to a single-case study such as misjudging a single event, misinterpretation of the repetitiveness of the case, observer biases and limits in the ability to generalize the case study results (Voss *et al.*, 2002; Yin, 2009).

3.3.2 Real-time or retrospective cases

To study the managing of design information in the production system design process, either retrospective or real-time cases can be used. The results of the thesis are based on a combination of real-time and retrospective cases. Two real-time case studies following two different industrialization projects were conducted. By following the two projects in detail, possible negative effects such as participants not recalling critical events were avoided, while at the same time the pre-understanding of the problem studied increased (see, among others, Leonard-Barton, 1990; Voss *et al.*, 2002). However, doing a real-time case study requires a considerable amount of time both for the researcher and the participating company, which needs to provide access during the entire research. Therefore, concurrently with the two real-time studies, two retrospective studies were conducted to increase the external validity of the findings. In addition, this reduced the issues of time and access – two issues that are critical and pervasive in real-time studies (Cross, 2000; Robson, 2002; Voss *et al.*, 2002).

3.3.3 Case selection

In order to identify a reference population of possible cases that could be included in the data collection, a theoretical sampling was used. The objective of theoretical sampling is to identify cases that replicate previous cases or extend emergent theory (Eisenhardt, 1989). In the present research, four different sampling criteria were used: 1) automotive industry, 2) responsibility for product and production system design, 3) stage-gate product development model, and 4) production system type.

1. The automotive industry has to handle shrinking product life cycles combined with an increasing number of product models and variants, which has major implications on investment costs and cost per manufactured/sold product (Asnafi *et al.*, 2008). Consequently, the automotive industry has to have the ability to effectively and efficiently design production systems.
2. The companies selected for the case studies should be responsible for both product and production system development. The criterion is related to the high interdependency of these two functions, where product design engineers process large amounts of relevant and necessary design information.
3. Since the focus of this research is the management of design information rather than the improving of the actual design process, it was important to select companies that had an understanding of the work activities to be performed in the design process. Another motive is that companies applying a stage-gate model are also obliged to integrate the work activities of different functions and thus the managing of design information between different functions is crucial to carry out the work activities of each phase.
4. Designing a production system requires a holistic perspective. Therefore, the production system of the company had to include people and production equipment of various degrees of automation, i.e. the focus was on semi-automated production systems.

The three selected companies and the cases studied are summarized in Table 2.

Table 2. Overview of the companies selected and the cases studied

	Company I		Company II	Company III
Company type	First-tier supplier		Original equipment manufacturer	Original equipment manufacturer
Study location	Sweden	England	Sweden	Sweden
Case type	Real-time	Real-time	Retrospective	Retrospective
Referred to as	Case B	Case P	Case E	Case T

In addition, to select cases, boundaries were set related to the research questions and the research framework to determine where the problem of the research could be studied. The focus was on finding cases that allowed for comparison between the collected data but still allowed for generalization of the findings. This is in line with the recommendation by Yin (2009) to use a replication and not a sampling logic for the selection of cases. The goal was to select cases that captured the widest possible coverage of activities, challenges, and strategies for the managing of design information, i.e. what Pettigrew (1990) calls polar types, in which the phenomenon studied is clearly observable. If the number of cases studied is relatively small, it is preferable to choose cases that highlight the differences (Pettigrew, 1990). However, it is important to note that the case selection was also influenced by the industrialization projects that could be studied, i.e. the real-time studies had to fit the timeline of the research.

Based on the choices of the cases involved in the data collection, the cases represent different attributes including scope of the new production system, investment costs, newness of the product, different divisions, and the location. As the research progressed and the data collection continued, it became clear that the cases were of polar types. The differences were not only traceable to the different attributes discussed above, but also to other factors that became clear during the data collection such as previous documentation of design information and organization of the industrialization projects.

3.3.4 Unit of analysis

The unit of analysis refers to the fundamental problem of what the case is and should be related to the way the initial research questions have been posed (Yin, 2009). In the research presented in this thesis a different unit of analysis was selected for the real-time case studies compared to the retrospective case studies.

The design of production systems is often carried out as part of the industrialization project at manufacturing companies and therefore the industrialization project was chosen as the unit of analysis for Case B and Case P. This means that the industrialization project is used to study all activities that are performed to achieve the objective of designing a production system. It is important to note that since the industrialization project has a broader scope than the design of a production system, the focus of the case study was on the early phases of the industrialization project. The context of the industrialization project is the company and the new product development project (see Figure 8). The numerous activities of the industrialization project are carried out by representatives from different functions of the manufacturing company and even external equipment suppliers perform parts of the project tasks. The external equipment suppliers do not necessarily need to be included in the project organization; nevertheless the activities carried out by the equipment supplier and those related to the acquisition of the production equipment have a substantial impact on the conceptual production system solution. Since it is possible to have more than one level of analysis in a case (Yin, 2009), the activities carried out when designing the production system and acquiring the production equipment are regarded as subunits of the analysis.

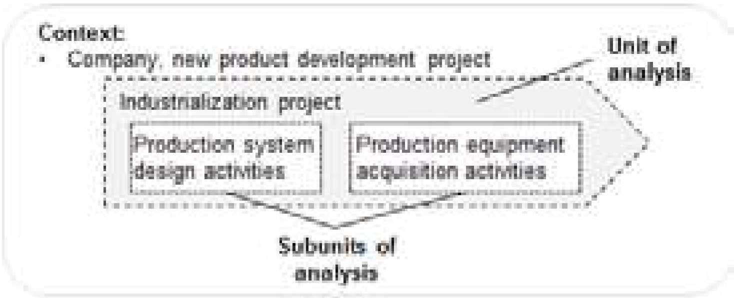

Figure 8. The industrialization project as the unit of analysis of Case B and Case P.

The retrospective case studies are based on the common need to acquire production equipment from an external equipment supplier. Therefore, the production equipment acquisition process is the unit of analysis for Case E and Case T. The context of the production equipment acquisition project is the company (see Figure 9). Although different units of analysis were selected, the data of the retrospective case studies can be compared with the data of the real-time case studies since the subunit of analysis in Case B and Case P is similar to the unit of analysis in Case E and Case T.

Figure 9. The production equipment acquisition project as the unit of analysis in Case E and Case T.

Mixed method research

In the research presented in this thesis the case study method was combined with a survey method, which provides several advantages and benefits. The survey method was selected to gather further information about the management of design information concerning the external equipment supplier involved in industrialization projects and is hereafter referred to as Survey S. The case study method and the survey method can complement each other and when used in a combination can expand the scope and breadth of the research, giving a more detailed understanding of a specific situation and leading to more precise and generalized results (Miles and Huberman, 1994). In a similar way, Yin (2009) argues that the use of mixed method research can contribute to the collection of a richer and stronger array of evidence than can be accomplished by any single method alone. Thus, by combining the case study method with the survey method it was possible to combine the perspectives of both the manufacturing company and the equipment supplier.

3.4 DATA COLLECTION

The research presented in this thesis is based on four case studies and one survey with different characteristics: Case B and Case P – two real-time studies, Case E and Case T – two retrospective studies, and Survey S. The studies partly overlapped; Figure 10 illustrates the data collection process in a chronological order. Since the research context and structure were different, the process for data collection varied between the different empirical studies. Therefore, this section describes in detail the research context and data collection. The data collection for the real-time case studies, the retrospective case studies, and the survey, respectively, is described in more detail in the following subsections (3.4.1-3.4.3). In general, during the case studies different techniques for collecting data were triangulated.

Figure 10. Data collection process.

3.4.1 Case B and Case P: Real-time case studies

Both real-time case studies were carried out at Company I. Company I is a global supplier in the automotive industry and is responsible for delivery of the finished product, product development, and continued technological renewal. The industrialization projects studied in Case B and Case P belonged to two different divisions of the case study company.

In general, events and actions were observed first-hand at the company for a total of 37 days in Case B and 34 days in Case P. In Case B, data collection started in November 2009 and finished in August 2011; the entire industrialization project was studied but the focus was on the preparatory and detail design phases. Data collection in Case P reflected the preparatory design phase and took place from February 2011 to April 2011. Overall, being at the company was important for the data collected. For example, on several occasions, project members discussed critical aspects and possible problem solutions at greater length during the lunch break than in project meetings.

Data were collected from multiple sources of evidence aiming at data triangulation (see Table 3 for Case B and Table 4 for Case P). In practice, this means that during data collection the same problem or fact was addressed by more than a single source of evidence. For example, one observation revolved around the fact that design information was differently managed depending on whether the information was shared among functions within the manufacturing company or with the equipment supplier. In order to understand why the differences existed and their consequences, the documented design information was studied, inquiries during interviews were made, and relevant meetings were observed.

During the data collection, a diary was kept with observations and impressions after each day spent at the manufacturing site. The information recorded in the diary included also methodological aspects such as the persons met and the content and duration of the meetings. During data collection, the tentative results were continuously discussed with the two supervisors, who could reflect on the findings from a distance and gave valuable input for the next steps that should be taken in the collection of data.

Both case studies started with an introductory meeting to discuss the proposal and scope of the research. At the meeting, representatives from different organizational levels of the company as well as one of the supervisors were present, and suitable industrialization projects were selected. It was agreed to take a more holistic approach in the industrialization projects studied. As the research progressed, the nature of the data collection changed. As described in Section 3.1, the collaboration with the manufacturing company was carried out in four periods: (1) introduction, (2) preliminary feedback, (3) participation in development activities, and (4) evaluation and feedback.

The introduction period aimed at becoming familiar with each manufacturing site and the studied industrialization project. Therefore, serial project meetings were attended and numerous informal conversations with people from different functions that were active in the NPD project took place. The conversations were structured to the extent that the content of the discussion concerned the specific issues of the function in the NPD project. Furthermore, in order to become familiar with the particular project and to understand underlying assumptions, background, and scope of the industrialization project, documents were studied. Together with the employees responsible for the industrialization project, suitable respondents who affected or were affected by the industrialization project were identified. With the respondents (ranging from top-level management top operators) semi-structured interviews were conducted regarding

- Respondents' role in the studied industrialization project
- Specific issues and aspects related to the function of the respondent, which should be considered in the studied industrialization project
- Applied work methods and standards in the industrialization project in NPD
- Information handling in the studied project

During the second period, i.e. the preliminary feedback period, findings from the introduction period were presented resulting in a list of issues to be considered in the current project. The feedback was used as a basis to identify suitable development activities and two development activities were established. The first activity concerned the methods and standards used in the industrialization project and the second activity related to the documentation of experiences.

In the participation in development activities period, the researcher became part of a group that aimed at improving the quality of the technical requirements specification.[5] Thus, the development activities were related to one of the standards used in the industrialization project. As a group member, the researcher took part in the discussions concerning the structure and overall content/aspects that should be included in the technical requirements specification, while technical experts were responsible for the specification and detailed content of the requirements. The researcher reviewed and gave feedback on the proposed revised technical requirements specification. The second development activity was carried out without the involvement of the researcher. For example, in Case B a so-called ‘white book’ was developed, a report that documented experiences and lessons learned from the industrialization project.

In addition, as part of a development activity, semi-structured interviews were conducted and project meetings were followed. The interviews included questions regarding the development activities, progress, and changes in the industrialization project and information handling.

The fourth period – evaluation and feedback – consisted mainly of reflections on the collected data. Less time was spent on-site but contact continued by mail and telephone to follow up the progress in the industrialization project. Further, the results were presented to the company at feedback seminars, and in Case B a final evaluation of the industrialization project four months after the start of production was made. The ability of dissociating oneself from the studied research objective was important for reflection and drawing academic conclusions.

[5] The technical requirements specification is an important tool when designing production systems; it contains a detailed description of requirements that should be met in the design and subsequent building of the production equipment.

Table 3. Overview of the data collected for Case B during 37 days between November 2009 and August 2011

Technique	No.	Duration (minutes)	Types of primary data that were collected
Passive observations:			
NPD group	9	30-45	Status and progress of the NPD project, information sharing between the different functions.
Industrialization group	11	30-90	Status and progress of the industrialization project, coordination between logistics and production
Equipment supplier	6	90-600	Technical equipment development, identification of information to be included in the technical specification
Various meetings	11	30-180	Information about the product, working routines, project status
Participant observation:			
Workshop	4	75-120	Manufacturing strategy, identification of order winners, order qualifiers, and order losers
Lessons learned, feed-forward	5	60	Preliminary findings/propositions, continuous work
Technical specification review	5	40-60	Feedback, potential improvement
Face-to-face interviews	24	40-90	Roles, responsibilities, problems, and requirements that should be included in the future system
			<u>Respondents</u>: Manager Production Engineering, Project Manager Industrialization, Project Manager Advanced Engineering, Program Manager, Operations Manager, Facility Manager, Quality Assurance Engineer, Purchaser, Logistics Manager, Maintenance Engineer, Vice President, Product Manager, Production Engineer, Workshop Manager, Team Leader, Assembly Operator
Informal conversation	Daily		Wide range, e.g. opinions, status, on-going activities
Documents	Full access		

Table 4. Overview of the data collected for Case P during 34 days between February 2011 and April 2011

Technique	No.	Duration (minutes)	Types of primary data that were collected
Passive observations:			
NPD group	5	45-75	Status and progress of the NPD project, information sharing between the different functions
Manufacturing engineering group	9	20-90	Status and progress of the production development project
Various meetings	10	30-300	Information about the product, working routines, project status
Participant observation:			
Preparation for workshop	1	180	Structure and content of a production system design model
Workshop	1	120	Structure and content of a production system design model
Lessons learned, feed-forward	4	50-70	Preliminary findings/propositions, continuous work
Technical specification review	3	35-60	Feedback, potential improvement
Face-to-face interviews	14	30-80	Roles, responsibilities, problems, and requirements that should be included in the future system
			Respondents: Production Engineering Manager, Advanced Engineering Project Leader, Quality Manager/Program Manager, Business Area Manager, Sales Director, Operations Director, Global Engineering Director, Jig and Tool Designer, Senior Development Engineer, Prototype Operator
Informal conversation	Daily		Wide range, e.g. opinions, status, on-going activities
Documents	Full access		

3.4.2 Case E and Case T: Retrospective case studies

The two retrospective cases Case E and Case T were based on the common need to acquire production equipment in industrialization projects. Particular emphasis was placed on how to facilitate the acquisition of more environmentally sustainable production equipment by formulating environmentally sustainable requirements in the technical requirements specification, which is used for the acquisition of production equipment.[6] The data collected were somewhat dissimilar with respect to the amount of data collected in each company (see Table 5 and Table 6). The data collected primarily derived from open-ended, semi-structured interviews but were supplemented by document studies. Most of the interviews had two respondents at the same time due to time restrictions. During Case T, one of the environmental managers also observed the remaining interviews. The interview guide was divided into several areas:

- Overall acquisition process
- Content and use of the technical requirements specification in production system development projects
- Respondents' responsibilities and involvement in the acquisition and the work with the technical requirements specification
- Consideration of environmentally sustainable requirements in the technical requirements specification
- Environmentally sustainable production systems
- Key performance indicators

The data analysed in the present research mainly relate to the first three bullets, while the remaining aspects were not the focus of the analysis but provided some valuable background and context. All interviews were face-to-face interviews and included several follow-up questions depending on the context-specific answers of the respondents. Further, the interviews were done by two interviewers, but it was agreed that one person should conduct the interview, while the other observed and took notes. All interviews were recorded and transcribed.

Table 5. Data for the semi-structured interviews during Case E

No. of respondents	Position of respondent(s)	Interview date	Duration (minutes)
2	Environmental Manager Quality Environment, Safety Manager	20 Sept 2010	70
2	Two Maintenance Engineers	21 Sept 2010	94
1	Production Engineering Manager	28 Sept 2010	62
2	Project Leader Production Development Strategic Purchaser	29 Sept 2010	88
1	Team Manager Industrialization	29 Sept 2010	39

[6] The acquisition included hardware and software and, in the following, 'production equipment' will refer to both.

Table 6. Data for the semi-structured interviews during Case T

No. of respondents	Position of respondent(s)	Interview date	Duration (minutes)
2	Two Environmental Managers	5 Oct 2010	88
2	Engineering Manager Environmental Coordinator	5 Oct 2010	62
2	Machine Purchasing Expert Environmental Coordinator	5 Oct 2010	64

3.4.3 Survey S

The focus of the survey method was to investigate the management of design between equipment suppliers and manufacturing companies and to identify success factors facilitating production equipment acquisition. The preliminary results from Case B were the foundation for the formulation of a questionnaire to be answered by equipment suppliers. The random sample included 46 equipment suppliers. Twenty-eight respondents returned the survey, of which three answers were invalid. It is important to note that the survey was of a descriptive character and was based on a non-probabilistic sampling of the companies. A descriptive survey tends to use a significant amount of qualitative data and aims at identifying trends rather than making statistical inference (Forza, 2009; Tanner, 2002).

The questionnaire contained 13 questions concerning design information and its management as well as 19 potential success factors. The importance of the success factors was measured on a seven-point Likert scale with 1 indicating that the dimension was not at all important for the performance, i.e. 'disagree', and 7 indicating that it was of crucial importance, i.e. 'strongly agree'. The five intermediate values represented a sequence including the option 'undecided'. The respondents could also choose the alternative 'don't know'. Further, the respondents were asked to rank the five most important factors and could state other success factors for a smooth production equipment acquisition that were not included in the survey.

3.5 ANALYSIS OF THE EMPIRICAL DATA

The analysis of the collected data followed the guidelines provided by Miles and Huberman (1994), who define data analysis as consisting of three concurrent flows of activity:

- Data reduction, which consists of selecting, focusing, simplifying, abstracting, and transforming the data that appear in written-up field notes or transactions
- Data display, which is an organized, compressed assembly of information that permits conclusion drawing
- Conclusion drawing/verification.

The data analysis process can be divided into six different steps and is characterized by a continuous interplay between theory and data, see Figure 11. The starting point for the research (Step 1) was the review of the academic literature relevant for the present thesis resulting in an overall analysis model, which is based on the assumption that the management of design information consists of the three dimensions acquiring, sharing, and using as has been argued in Figure 4.

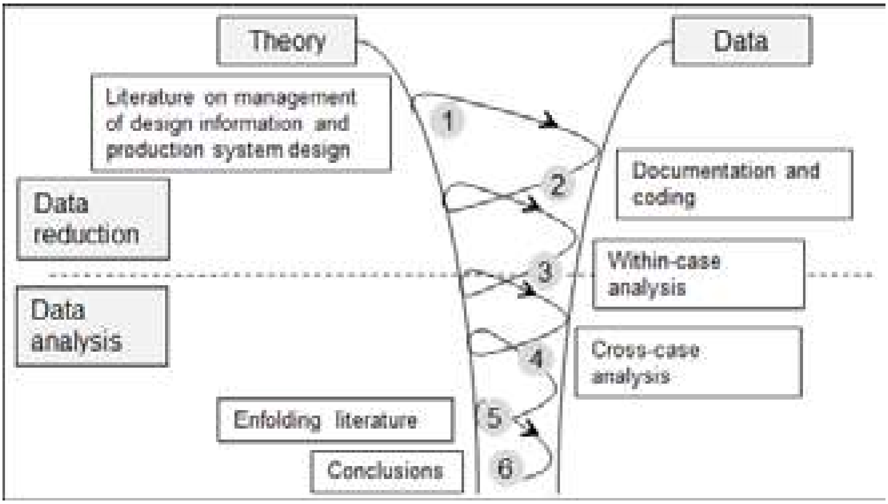

Figure 11. The data reduction and analysis process based on a continuous interaction between theory and data (based on Richtnér, 2004).

During data collection data were documented and coded in a case study database (step 2). In the present research, data collected during the case studies were in two categories: (1) case study notes, i.e. expanded notes of problems, challenges, and reflections documented in field notes and a diary as soon as possible after the case visit and (2) case study documents, i.e. the data collected in connection with the interviews and observations as well as internal company documents. The coding, i.e. the categorizing of the collected data into key variables derived from the theoretical framework, is vital for case research (Miles and Huberman, 1994). As a first step, data were categorized according to the two research questions, required design information (design information categories) and management of design information.

Step three concerns the within-case analysis, which aimed at becoming familiar with each case and to identify unique patterns for each case (Eisenhardt, 1989). Therefore, a detailed description of each case was developed, which means that a total of four case write-ups were created. The case write-ups followed the research variables design information categories, acquiring, sharing and using design information, and enabled to put the same facts from different sources together. As the analysis of the collected data advanced for each case study, recurrent patterns of the management of design information started to emerge for each case. Based on the emergence of these patterns new subcategories had to be added to the categories originally used during the coding of the material. Further, the identified patterns guided the creation of matrices about the design information needed in design activities and how this information was managed.

In the next phase a cross-case analysis was done, i.e. general patterns across cases were searched for (step 4) in order to go beyond initial impressions (Eisenhardt, 1989). The cross-case analysis used several techniques such as clustering, comparisons, and noting relations between variables (Miles and Huberman, 1994) and built on the case-write ups of the single-case analysis. First, each part identified as belonging to an information category or one of the three categories acquiring, sharing, and using was coded into the relevant category and then further broken down into subcategories. All together the four main categories had 14 subcategories. Second, the findings were matched against the different phases of the production system design process. Based on these two steps it was possible to compare the findings across the cases and to identify patterns. It is relevant to emphasize that the data of the different case studies were not simply agglomerated, rather the analysis was done under a common category in order to ensure that each case kept its interdependence in the analysis. This is in line with Miles and Huberman (1994), who argue that it is important to understand each case by its particular dynamics.

In the fifth step, the results from the analysis were compared with and related to the existing theory, i.e. enfolding the literature. Eisenhardt (1989) points out that reviewing literature involves asking what is similar, what is different, and why. The comparison with literature allowed identifying literature that concurred with the results of the empirical studies but also identifying literature that was rather conflicting. In the sixth and final stage conclusions were drawn.

3.6 JUDGING THE CREDIBILITY OF THE RESEARCH

Even though the different methods applied were chosen consciously, there is a need to question and discuss the quality of the research in order to establish credibility in the research results. The quality of the case study research can be judged on four criteria: construct validity, internal validity, external validity, and reliability (Yin, 2009).

3.6.1 Construct validity

Construct validity is about establishing operational measures that are reasonable measures for the concept studied. However, since researchers often fail to establish operational measures and case study research often rests on subjective judgements, to establish construct validity is especially problematic in case study research (Yin, 2009). The use of multiple sources of evidence, i.e. data triangulation, increases the validity of the research (Voss *et al.*, 2002; Yin, 2009). As previously described, in all four cases multiple sources of evidence were used (see Tables 2-5). Although the retrospective cases (Case E and Case T) mainly used semi-structured interviews as a means to collect information also company documents were used. Further, in Case E and Case T, the interviews were generally conducted with two respondents, thus minimizing the risk that questions remained unanswered.

During each case, more than one person was interviewed from different functions and levels of the organization. Besides analysing the documents provided by the companies, business press and official company documents (e.g. company websites, annual reports, etc.) were also reviewed before, during, and after the case studies. Thus it was possible to get complementary views on the research variables. Further, questions to ask and the choice of suitable respondents were modified during progress in Case B and Case P when the understanding of the design process increased.

To avoid or at least minimize the impact of the personal view of the researcher, the theoretical framework guided the construction of the operational measures. However, problems regarding the applicability during data collection were encountered. Although constructs seemed to be valid, they were not necessarily usable by the respondents. For example, information can be provided in a variety of ways, such as visual, auditory, kinaesthetic, or tactile (Vincent and Ross, 2001). Many respondents found it challenging to indicate how different types of design information were provided. Often different types of information were provided simultaneously using different means, which made it impossible to construct absolute scales. However, the use of multiple-case studies with dual types of cases provided a better opportunity to construct validity, as the stability of constructs can be validated beyond the immediate case (Leonard-Barton, 1990).

In the real-time case studies only notes were taken during the interviews increasing the risk of misinterpretation. However, the project descriptions of the real-time case studies were reviewed by insiders. Further, since the real-time case studies were performed over several months, there was the possibility to go back to the relevant employees once more to recheck notes. In addition, the results were presented and discussed, which increased the understanding, and the feedback received was used to update results.

3.6.2 Internal validity

Internal validity means the process of establishing causal relationships (Voss *et al.*, 2002). Internal validity is strengthened by using real-time case studies as they enable the researcher to trace the cause-and-effect relationship (Leonard-Barton, 1990). In Case B and Case P, data were collected first-hand and were not dependent on participants recalling critical events correctly after the event had happened. Further, the problem of post-rationalization was minimized; the interpretation of reconstructed events may differ from that made by participants at the time the event occurred (Voss *et al.*, 2002). Reflecting on the observations as soon as possible after the fieldwork made it easier to recall and remember critical aspects observed. There was also the possibility to validate and discard the causal relations found due to the received feedback on the propositions.

During analysis attention was paid to identifying differences when comparing empirical data with theory, which is in line with Christensen's (2006) recommendation. The discovery of differences is a prerequisite for less ambiguity in descriptions and improved theory. Further, the enfolding of literature was an important step in the analysis and thus increased the validity of the findings (Eisenhardt, 1989; Voss *et al.*, 2002). It has also been discussed that internal validity relates to the credibility and authenticity of the research results (Miles and Huberman, 1994). Interviewing more than one respondent at the same time in Case E and Case T could reduce the internal validity as the respondents might influence each other when answering. However, all case studies are based on data triangulation and the results have been discussed with research colleagues. Further, at the beginning of each interview, the perspective chosen, background, and assumptions were explained to the participants. These activities are in line with means suggested by Merriam (1994) and should thus strengthen the internal validity.

3.6.3 External validity

External validity is about whether the conclusions drawn from the data and context of the research study can be trusted and applied in different contexts as well (Christensen, 2006). Thus, external validity is about generalization outside the case. In case study research, external validity cannot be established through tests using different data sets (statistical generalization); rather in case study research external validity can only be established through analytical generalization (Yin, 2009).

Retrospective cases strengthen external validity (Leonard-Barton, 1990) as they allow for a more controlled case selection according to critical parameters of a study (Voss *et al.*, 2002). Two retrospective cases were included in the research presented in this thesis. Since particular focus was on how to facilitate the acquisition of environmentally sustainable equipment, Case E and Case T were selected based on their general interest in accomplishing more environmentally sustainable production systems. In addition, the management of design information in production system design is not something unique to the cases examined. Although the unit of analysis was the industrialization project, it can be argued that few industrialization projects are completely unique. Instead, the industrialization project may be considered as a repetitive means with similar activities even though the specific production system is unique. Therefore, parallels might be drawn to comparable organizations in similar situations, particularly as the case studies were selected based on the replication logic as suggested by Eisenhardt (1989) and Yin (2009). Further, by expanding the research to include equipment suppliers representing a relatively high variety of contexts and backgrounds by means of a survey, the research was able to offset some of the lack of external validity of the case studies.

3.6.4 Reliability

Reliability refers to the ability with which another researcher can replicate the case study and arrive at similar findings and conclusions (Yin, 2009). Miles and Huberman (1994) mention dependability and auditability as related to the reliability of case study research. Thus it is important to describe the research process in necessary detail, which is required in order for the reader to follow the process. In the present research, the data collected are well documented in field notes, diary, and document studies. Further, all interviews in Case E and Case T have been transcribed. To minimize the risk of memory failure, in Case B and Case P data were documented continuously in a diary (e.g. Patel and Davidson, 2003). This thesis has an explicitly stated research objective and description of the data collected and decisions made during the case studies in order to increase the reliability. Further, six papers are appended in the thesis to provide a rich description of the data collected in the case studies and the survey. In case study research, as much data as possible should be presented (Yin, 2009).

While the previous measures mainly increase the reliability with regard to data collection, Säfsten (2002) highlights also the need to look separately at the data analysis and at how the analysis may affect the reliability. As previously described, the data analysis followed the three flows of activities suggested by Miles and Huberman (1994) and the aim was to be as explicit as possible about the analysis process and the steps taken in the process of the interplay between theory and data. Thus it should be possible for other researchers to repeat the analysis of the data. Finally, the research has been carefully planned and the means used for collecting and analysing the data have been tested and utilized in previous case studies. Case study research is not informal or causal, rather it relies on careful planning and realization (McCutcheon and Meredith, 1993). It should, however, be noted that despite all efforts of providing a detailed description and being rigorous in data collection and analysis, individual judgements and backgrounds affected the research process.

In sum, to strengthen the validity and reliability, different methods have been used (see Table 7). It should, however, be pointed out that most of the empirical data collection, data analysis, and conclusion drawing has been carried out individually, implying that the research process is still to some extent a black box. Undoubtedly, the rich data collected during Case B and Case P facilitated understanding but implied also the largest challenge of maintaining sufficient distance to the research subjects. Thus, the need for reflection and discussion with academic supervisors and colleagues cannot be underestimated. Overall, it is believed that the detailed description of the research methodology increased the credibility of the conclusions presented in this thesis.

Table 7. The applied methods for strengthening validity and reliability (based on Olausson, 2009)*

Test	Methods used	Case B	Case P	Case E	Case T
Construct validity	Use of data triangulation	√	√	√	√
	Key constructs relying on previous studies	(√)	(√)	√	√
	Combining real-time with retrospective studies	√	√	√	√
	Review of case study descriptions by insiders	√	√		
Internal validity	Real-time studies	√	√		
	Identification of unique and cross-case patterns	√	√	√	√
	Enfolding literature	√	√	√	√
	Use of data triangulation	√	√	√	√
	Discussion with research colleagues	√	√	√	√
	Clear communication of assumptions made	√	√	√	√
External validity	Retrospective cases			√	√
	Replication logic	(√)	√	√	√
Reliability	Detailed and continuous data documentation	√	√	√	√
	Explicit descriptions	√	√	√	√
	Systematic work procedures	√	√	√	√

* Brackets denote that the method was used to a limited extent.

3.7 CONTRIBUTION TO THE PAPERS

During the process, papers have been written, highlighting different aspects of the managing of design information; they are appended to this thesis. The process of writing up the papers was important to be able to prioritize and select relevant data. Table 8 clarifies the semantics used in the thesis and the attached papers and summarizes the contributions from the different authors of the papers. All papers were initiated and the conference papers presented by the author of this thesis.

Table 8. Case study denotations in the thesis and papers and the authors' contributions to the papers

Paper	Cases, Survey	Denotation in the papers	First-author contribution	Contribution of co-author(s)
I	-	-	Theory review, data collection, data analysis and writing	Review, quality assurance
II	Case B	Company A	Theory review, data collection, data analysis and writing	Theory review, data collection, data analysis, writing
III	Case B, Survey S	Case Study, Survey	Theory review, data collection, data analysis and writing	Review, quality assurance
IV	Case B	Case Study	Theory review, data collection, data analysis and writing	Review, quality assurance
V	Case B, Case P	Case A, Case B	Theory review, data collection, data analysis and writing	Review, quality assurance
VI	Case B, Case P	Case A, Case B	Theory review, data collection, data analysis and writing	Review, quality assurance

CHAPTER 4

EMPIRICAL FINDINGS

CHAPTER INTRODUCTION

In this chapter of the thesis, the empirical findings from the four case studies and the survey are presented in more detail. Separate case descriptions are given to illustrate the specific situation and preconditions when designing the production system, followed by a description of the management of design information.

4.1 CASE B

The case study referred to as Case B relates to the introduction of a new product in the case study company, which had 15 years of product development and production experience. The case study company was a minor player in the studied product segment on a market with rather tough market conditions. The new product development (NPD) project was initiated to strengthen the market position and to lead to a positive cash flow in the product segment. Therefore, this project was deemed as strategically important by the management and received a great deal of management attention.

The NPD project was initiated in 2008 in cooperation with a customer and had a time frame of three years with a specified date for start of production. To support the various work activities, the project was divided into three work packages: (1) product development, (2) industrialization, and (3) improvements after start of production. Case B targeted work package two, which covered the industrialization from concept generation to serial production and thus included the responsibility for the design of the production system and the acquisition of the production equipment. The new product was highly complex, in line with previous products on the same platform. However, the product could not be assembled in the existing production system, which required the development of a new production system. The different stages of product and production development were carried out in the same building.

The NPD project followed a stage-gate process with critical go/no go decision points and included members from different functions. Although production system design issues were considered in the stage-gate model, the model was created from a product perspective. As a result, the focus of gravity in the model was on product issues, while many important issues of the production system design process fell outside of the used stage-gate model. A formal process coordinating the work activities required in the industrialization project separately from the NPD model was not available.

In general, the project was carried out under severe time pressure as the time plan for product design was not adhered to and the resources allocated for work package two were inadequate at the beginning. At the start of the NPD project it was mainly the production engineering manager who gave valuable input to work package one and worked with a production system concept. The production engineer manager had experience from several production system design projects and he had also been responsible for the design of the existing production system for the same product platform. From November 2009, i.e. after one and a half years, extra resources were allocated to work with work package two. One of the resources provided was the appointment of a separate industrialization project manager responsible for the industrialization of the product from concept until serial production. The appointed industrialization project manager came from a neutral function, i.e. he was an expert in project management issues but not in production issues. Due to the high priority of the project, the industrialization project manager reported jointly with the advanced engineering project manager (responsible for work package one) directly to the steering group on a weekly basis. Another person assigned to work full time with the industrialization project was the one responsible for the design of the material supply system. For the first eight months an external consultant was assigned the task of designing the material supply system, while an internal resource was appointed for the remaining time of the industrialization project.

Since there was little room for concept iterations, the case study company commissioned one equipment supplier to also design a concept solution between November and December 2009. In parallel, two internal solutions had been created based on the earlier ideas of the production engineering manager. The three different concepts were evaluated and synthesized into one final solution, which focused on production equipment and material supply aspects. Overall, the generation of the conceptual solution was influenced by the financial and temporal scope of the project.

Although production system design was not a new task to the case study company, the collection and documentation of design information prior to the studied industrialization project mainly concerned production equipment information, i.e. information that focused on functions, properties, and capabilities of the technical subsystem. Since the production equipment was acquired from an external equipment supplier, it was necessary to work with technical information rather than information regarding material supply, human, and control subsystems. These types of information had not been specified in detail in previous projects, while it was a natural step to document information concerning the production equipment acquisition. For example, technical specifications and guidelines from previous projects were accessible. Other design information than the one related to the production equipment acquisition was usually transferred orally or was stored in the mind of the system designer and was thus based on experience rather than documented facts. Thus, the ability to reuse previous experiences that were not related to the acquisition of the production equipment tended to be limited.

As a holistic perspective was emphasized in the studied industrialization project, specific focus was placed on various production system parameters. That means that not only design information necessary for the acquisition of the production equipment from an external equipment supplier was included but also design information for internal use such as information about work organization and material supply. In general, information concerning material supply, human, and control systems played a minor role in the concept generation but became increasingly important in the detailed design phase. However, by having a holistic perspective when designing production systems, the information included in the technical requirement specification was modified. Relevant design information about material supply, human, and control subsystems was included. For example, information regarding workplace design (ergonomic aspects) was included but information about work organization was left out, as this information was deemed irrelevant to the equipment supplier. Further, to ensure a better fit between the equipment ordered and future customer demands, design information about the manufacturing and product strategy, lean production, and production performance was included. Another aspect was the need for environmental awareness. On previous occasions, the only reference was that the environmental impact should be reduced as much as possible, which is open to interpretation and difficult to verify. In the studied industrialization project, the information gathered resulted in 17 environmental requirements with clear verification measures. The specified environmental requirements dealt mainly with energy and material concerns as well as the avoidance of waste by improving the production process itself.

To collect relevant information, the existing production system was analysed and evaluated to identify good solutions to be included in the new production system. In order to gain an understanding of assembly challenges, the new product was analysed through various iterations of assembly and disassembly. In addition, similar products of the main competitors were studied in detail. Further, at the beginning of the production system design process much effort was also placed on acquiring information about market opportunities, objectives, and strategies. Market distinctions were made in order to identify market potential, competitive advantages on different markets, and market characteristics. Potential future customers and markets were cross-functionally analysed and documented. This analysis resulted in a better understanding of future demands from new customers and markets both geographically and in terms of new product areas. The results were used to identify future demands on the production system.

In order to improve the flow of information among the different functions, the industrialization project manager gradually introduced two key initiatives: documentation and a cross-functional industrialization project team. The first initiative involved a detailed documentation of relevant and necessary design information in order to improve accessibility of information within but also beyond the project boundaries. The detailed documentation also led to some standards of how information should be documented. The second initiative related to the composition and start of a cross-functional industrialization team. Relevant functions including production engineering, material supply, and quality management met in separate project meetings to discuss the situation and decide on future actions. Further, the workshop manager and operators were invited if needed and thus much earlier included in the project compared to previous projects. The result was that relevant design information was frequently shared within the industrialization project. One major implication was that it was easier for the industrialization manager to prioritize work activities, clarify expectations, and advance the interests and needs of production against the interests of other functions.

Based on the need to share information with the external equipment supplier and on the tight schedule, attention was placed on minimizing misunderstandings and different interpretations of the specified design information. In order to avoid unnecessary discussion and conflicts, a verification plan was developed. That is, in the studied industrialization project, a great deal of effort was spent on when and how to verify the specified requirements. A comprehensive verification plan was developed, which was adjusted to the request of quotation for the production equipment. In order to control the progress of the production equipment design and development as well as fulfilment of stated requirements, the case study company defined different verification occasions. Figure 12 illustrates the structure of the verification plan.

Types of verification						
ID	Verification	Verification occasion				
		1	2	3	4	5
1	Design for Assembly (DFA)	x	x	x	x	x
....	......					
21	Factory acceptance test			x		
22	Site acceptance test				x	

Verification		
Requirement	Description	Types of verification
3.1	Yearly production volume and controlling cycle time	1, 21, 22
.....	.....	....

Description of the course of verification		
DFA		
Requirement	Description	Level of acceptance
3.1	Annual production volume and controlling cycle time	Controlling cycle time and number of operators has to be specified in the DFA
...	.....	.....

Figure 12. Illustration of the verification plan in Case B.

As illustrated in Figure 12, for each verification occasion, it was clearly stated what verification type should be used, how each requirement should be verified, and the course of verification. A total of 22 different types of verification including both testing and documentation were identified. The identified types were then coupled to the different requirements stated in the technical requirements specification. In addition, the document included a detailed description of under what conditions each requirement would be approved. A number of requirements were verified on more than one occasion to ensure progress as well as provide the possibility to act at the appropriate time.

4.2 CASE P

Case P was carried out at a business unit with a different product segment from that in Case B, 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 NPD. Market share was 30 to 40 per cent depending on product variant and market.

The NPD project was very challenging since it was the most complex product developed by the site so far and thus also had major implications on the production complexity. A standard product had about 15 components, while the new product had around 60 components. Further, the product included a new raw material, which needed to be handled with special equipment, influenced the balancing in the assembly process, and required new competencies from the assembly operators. The product concept presented in 2008 received positive feedback from customers. Therefore, the product was introduced to the market earlier than originally planned resulting in a high time pressure. Despite the challenges, the project was seen as strategically important for the manufacturing company, since a successful product introduction could imply a large market potential. Although the work was not divided into different work packages, the production engineering manager was assigned as responsible for the industrialization of the new product. He was located together with the product engineers in one office.

Although the product design was not completed at the required gate, the deadline for market launch was unchanged. The fixed date for start of production was prescribed by the customer, who did not allow any delays. The customer also imposed tough requirements regarding the installation of the production equipment and the preproduction series, which made the time schedule tight.

Traditionally the Advanced Product Quality Planning (APQP)[7] framework was used to facilitate new product development. However, due to the need to manage more

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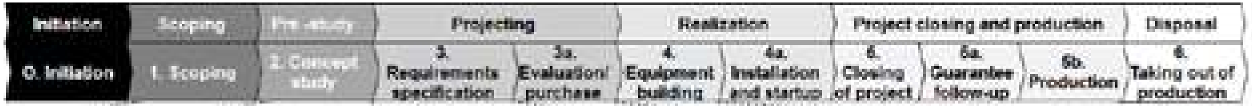
[7] The APQP is a framework of procedures and techniques used to develop products in industry, particularly the automotive industry. The framework aims at ensuring a collaborative product and production system design, i.e. its purpose is to facilitate communication with everyone involved in the project including internal and external suppliers (Thisse, 1998). APQP consists of five concurrent and collaborative phases: (1) program planning and definition, (2) product design and development verification, (3) process design and development verification, (4) product and process validation, and (5) feedback, assessment, and corrective action. The method is supported by a variety of tools that provide a road map to follow.

and larger NPD projects and increased customer expectations, a stage-gate model with a series of mapped-out activities from inspection to launch was introduced. Even though the stage-gate model encompassed APQP elements and was benchmarked with the models used by the other business divisions of the case study company, the list of activities and linked standards and routines was less comprehensive. The case studied was one of the first NPD projects to be managed by using the new 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.

Because the production engineering manager was new in his job, the instructions given in the NPD stage-gate model were not sufficient enough to support his work activities. In order to support him in his work activities and help him become more effective in future production system development projects, the management recognized the need to create a production system development model that could be integrated with the NPD project model. The developed model with a detailed emphasis on the production system design activities is summarized in Figure 13. To ensure a high level of recognition, the production system development model consisted also of stages and gates. For each activity listed below, a detailed discussion of the content of the activity was reported in a separate, more detailed document. The detailed description gave an overview of the required input information for each activity, and each stage incorporated the sharing of new information between multiple functions.



1.1 Appointing of project leader	2.1 Assigning the project team	3.1 Identifying of quality parameters	3.19 Reviewing of quotation surveys	4.1 Detailed planning of activities with the equipment supplier
1.2 Formulating of directives	2.2 Formulating of project plan	3.2 Determining rules regarding workplace design/ ergonomics	3.20 Selecting of equipment supplier	4.2 Reviewing and evaluating robustness of the steady state design
	2.3 Establishing of budget	3.3 Determining of design rules	3.21 Negotiation and drawing up of contract	4.3 Reviewing of material feeding
	2.4 Reviewing of legislations and patents	3.4 Reviewing of packaging requirements	3.22 Presentation of recommended contract	4.4 Reviewing of material storage
	2.5 Identifying of financial parameters	3.5 Determining of how the material supply will integrate	3.23 Decision by steering committee	4.5 Reviewing of material transport
	2.6 Reviewing of manufacturing strategy	3.6 Determining of how the work content will integrate	3.24 Ordering equipment	4.6 Reviewing of material handling
	2.7 Determining of level of automation	3.7 Choice of suitable location		4.7 Updating of facilities layout drawing
	2.8 Reviewing of product portfolio	3.8 Creating of concept solution		4.8 Ordering of tooling, jigs and fixture
	2.9 Reviewing of production volume	3.9 Performing of Process FMEA		4.9 Developing of work instructions
	2.10 Performing of risk analysis	3.10 Identifying of training needs		4.10 Determining of training procedures
	2.11 Determining of performance objectives	3.11 Reviewing of critical characteristics or capabilities		4.11 Inception of training
	2.12 Evaluating production philosophy	3.12 Reviewing of ITIS architecture		4.12 Developing of detailed quality procedures
	2.13 Reviewing of environmental policy	3.13 Reviewing of health and safety regulations		4.13 Preparing of quality plan
	2.14 Preforming of feasibility study	3.14 Determining of environmental requirements		4.14 Establishing of incoming material inspections
	2.15 Creating of preliminary concept	3.15 Compiling of RFQ		4.15 Developing of communication and reaction plan
	2.16 Production scenario costing	3.16 Developing of verification plan		4.16 Performing of relocation meeting
		3.17 Selection of equipment suppliers		4.17 Ordering of trial material
				4.18 Ordering of transport and insurance
				4.19 Preparing of building
				4.20 Performing pre-acceptance test
				4.21 Dealing with issues
				4.22 Checking of CE mark
				4.23 Carrying out of safety inspections

Figure 13. Detailed list of work activities that should be accomplished in the production system design process.

In order to acquire relevant information, the production engineering manager frequently met and discussed critical issues with key persons such as the global engineering director, the operations director and the business area manager. The business area manager was to be responsible for the production after production ramp-up and provided valuable feedback from the operations perspective early in the industrialization project. The operations director gave input regarding objective and strategy, while the global engineering director was an important source for information about the production equipment. In addition, the production engineering manager was part of the NPD team.

Even though the project was challenging and rather complex according to the team members, it was not the only project for which the production engineer manager was responsible. Concurrently with the studied project, the case study company worked with five other "equally important" projects which all had the same date for the start of production. These projects also required the creation of new production systems but were less complex as similar products are manufactured at the site today. In addition, the production engineering manager was also responsible for operational production engineering issues.

The employees working with the design of the production system were dependent on the product information but also on directives from the management with regard to financial restrictions and strategy. However, the uncertainty concerning final customer design and future markets made the communication of directives difficult. For example, the differences in the product design[8] were so extensive that it was difficult to judge whether the products for two different customers could be assembled on the same production system. As a result, it was difficult to plan for and design an appropriate production system as the decision about one or two production systems had major implications for the solution. Another decision that contained important information for the production system design but that had not yet been finalized was the make-or-buy decision, i.e. what components should be made in-house and what should be acquired from suppliers.

The complexity of the product and its related production challenges as well as the absence of previous knowledge made equipment suppliers and the consultant an important source of information for creating a conceptual solution. The consultant also supported the production engineering manager in his work of creating a conceptual system solution. Further, through the contact with the equipment supplier, there was the possibility to study production systems of other manufacturing companies that had met the challenge of balancing with the particular raw material.

Assembly of prototypes gave valuable product information. Further, product and production system designers were placed in the same office, which facilitated communication between the people involved. One of the major challenges during concept generation was that the product information, i.e. information about the final design of the product that was going to be manufactured, was highly ambiguous. The customer was also a source of information with regard to the

[8] In the studied product segment, there is no generic product design; instead each application is significantly adjusted to fit the demands of the customer's product.

production ramp-up, i.e. the customer determined, for example, when production equipment had to be in place or how the production equipment should be tested.

In order to keep the deadline, much effort was devoted to finding technological solutions to the problem. As no similar product had been manufactured previously by the division, there was no possibility to study the existing production system. Overall, the focus was on the technical subsystem, i.e. the production equipment required. The case study company worked intensively with the request for quotation, i.e. what information should be included and how the information should be structured in order to improve understandability for the equipment suppliers. For example, the content of the request for quotation was benchmarked with the request for quotation of other manufacturing companies in the automotive industry.

Even though it was agreed to take a more holistic approach, information about material supply, human, and control subsystems was not prioritized early in the concept generation phase and had only been documented to a limited extent in earlier industrialization projects. The majority of information related to these three subsystems was transferred during meetings without any links to standards and routines. Further, one major challenge was to get employees involved in the project as things were not going smoothly and numerous problems had to be solved. Nevertheless, there were several factors indicating that the initiatives taken by the employees resulted in a more holistic approach. For example, the early inclusion of the business area manager in the project made it more explicit to also consider information that concerned operational production issues. In addition, focus was also placed on developing support for the production engineering manager that included not only production equipment issues but all aspects affecting the creation of the production system.

4.3 CASE E

Overall, the production equipment acquisition was carried out in a project following a standardized process including a comprehensive technical requirement specification as part of the request for quotations. The case study company did not have a long tradition of major production equipment acquisition projects, but during the previous five years almost the entire production equipment had been replaced. At the beginning, the acquisition of production equipment did not work satisfactorily. For example, the dialogue window of the production equipment had a different appearance although it had the same control system, which implied that the operator had to learn the handling of the dialogue window each time he/she used a new type of equipment. As a result, major adjustments and modifications in the technical requirement specification were made. One of the major problems was not that the content of the technical requirement specification was wrong but that directives were unclear and difficult to understand. The changes made led to clearer directives, which ensured better consistency in the equipment. The requirement specification was deemed as a useful document but it was also highlighted that usually not all requirements stated can be fulfilled in the acquisition projects. In addition to the technical requirement specification, project-specific requirements, company-specific documents and information about the product are usually transferred.

Today, the technical requirement specification is updated every one or two years depending on the available time. The modifications follow a standard process and are often based on feedback received from equipment suppliers or experience gained with the existing equipment. The equipment suppliers' feedback is seen as a valuable input, as it is aligned to changes in the context. Before changes in the technical requirement specification are implemented, revision meetings take place in which suggestions are discussed, and it is mutually agreed whether the suggestions should be included or not. The major benefits of a standardized and detailed technical requirement specification came from the increased consistency in the production equipment, which minimized the need for spare parts and reduced the support required with regard to, for example, the software. The technical requirement specification included eight environmentally sustainable requirements.

There were several obstacles to a more holistic perspective of the specification of the requirements included in the technical requirement specification, i.e. having a more comprehensive technical requirement specification. First, the function responsible for the technical requirement specification was production engineering, which had its competency in issues related to the production equipment, i.e. the technical subsystem. Second, the content of the technical requirement specification was based on experience from operations and previous acquisition projects. However, production engineering had limited insight into problems of the other subsystems. Another factor that affected the specification of other requirements was the absence of clear objectives related to the environment. For example, environmental sustainability has been a buzzword for a long time but it was not implemented in the operational organization. Environmental sustainability tended to be in the periphery and not in the focus of the business. Finally, although the company had a detailed and sophisticated technical requirement specification, the final production equipment depended also on the background and interest of the person responsible for the acquisition of the production equipment. This implied that if the person in charge of the acquisition of the production equipment had a general interest in material supply, there was a much stronger focus on these issues when acquiring the production equipment.

4.4 CASE T

The company in Case T had a long tradition of acquiring production equipment and had worked intensively on a process to be used when acquiring production equipment; the acquisition was carried out in the form of a project. The process had links to standards and routines, of which the technical requirement specification was one critical document. Other information transferred related among other things to the specific project, the products to be manufactured, and policies.

The requirement specification is adjusted on an annual basis. Updates are made by experts in the specific area. For example, the maintenance function is responsible for the specification of the maintenance requirements that should be included in the technical requirement specification. Changes in the technical requirement specification were derived from experiences in operation, but also from the input of the equipment suppliers. The general parts of the requirement specification were written by senior staff, i.e. employees who had detailed knowledge about production equipment and the acquisition of production equipment. The ability to ensure that all requirements were fulfilled and that the process of acquiring production equipment was less dependent on individuals was mentioned as the major advantage of the standardized technical requirement specification. Thus, the company also allocated the responsibility for the acquisition of the production equipment to employees with limited knowledge and yet a high degree of consistency in their production equipment. On the other hand, the detailed level of specifying requirements made it difficult for a less experienced and knowledgeable person to follow up all requirements. In addition, the high level of detail caused extra costs, as the company's standards were not necessarily similar to those of the equipment supplier.

In general, environmentally sustainable requirements were not listed as a separate category but included in the sections, where judged as relevant. It was argued that a category only related to environmentally sustainable requirements would require a change in the work with the equipment suppliers. Equipment suppliers did not have environmentally sustainable experts employed who could work exclusively with these requirements; the equipment supplier rather concentrated on finding technological solutions to the specified demands. In addition, it was emphasized that it was important to consider first how the production process actually worked and then specify how the various production processes influenced the environment.

Although a wide variety of areas were considered, three causes that made the specification of other requirements a challenging task were identified. First, requirements needed to be specified on such a generic level that they were valid to all acquisition projects. Second, the employees working with the requirement specification were no experts in other areas that might affect the production system such as material supply issues, which also made it problematic to understand their impact. Third, not all aspects had the same priority as technological issues. This can be illustrated by the example of environmental requirements. It was concluded that technological problems limited the manufacturing company in its efforts to make more products, to produce according to drawings, etc., while environmentally sustainable requirements were not always seen as an obstacle to achieving higher levels of performance and thus not as detailed as the technical requirements.

4.5 SURVEY S

With regard to the design information required by equipment suppliers it can be said that various categories of design information are applied by equipment suppliers, see Table 9. The equipment suppliers quoted the requirement specification as the most important document for their work activities, while the verification plan played only a minor role for the work of the equipment suppliers.

Furthermore, the design information exchanged between the equipment supplier and the buyer, i.e. the manufacturing company, was classified into hard design information and soft design information. Overall, equipment suppliers tended to rely more on hard design information (median 70 per cent) than soft design information (median 30 per cent), see Figure 14. It should be emphasized, though, that all equipment suppliers stated that they used a combination of hard and soft design information and did not solely rely on one kind of design information. Examples of typical hard design information were cycle time, production volume, price, and capacity requirements, while soft design information related to ergonomics, safety, and maintainability. However, the equipment suppliers also stressed that performance information, such as tact time, production volume, or quality requirements stated by the manufacturing company could be further enhanced.

Table 9. Categories of information used by the equipment suppliers and ranked by relevance to the suppliers

Information categories	*Quoted (%)*
Technical information – information about general technical requirements and project-specific technical requirements	96 %
Product information – information about the products that are going to be manufactured in the new production equipment	80 %
Strategic information – information about needs and wants	64 %
Project information – information about timing, scope, terms of purchase, etc.	56 %
Context information – information about the specific background and context of the actual production equipment acquisition project	48 %
Financial information – information about the investment budget	28 %*
Verification information – information about how and when to verify stated requirements	8 %

*Note: Financial information was not a proposed category of information in the questionnaire but was quoted by seven equipment suppliers as a relevant category of information. Thus, the relevance might have been different if financial information had been included as a proposed alternative.

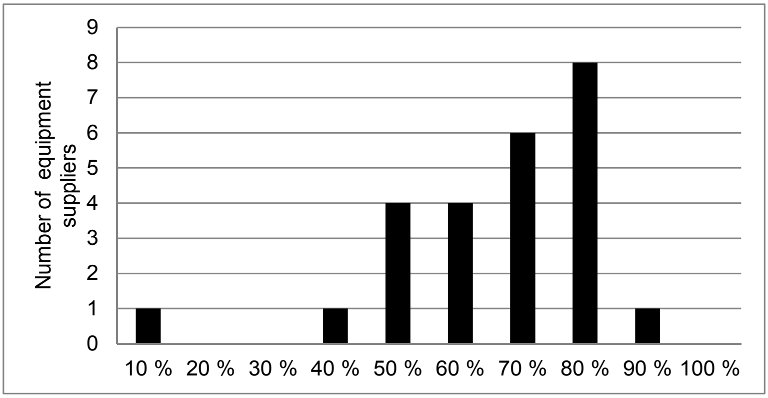


Figure 14. The proportion of hard design information used by equipment suppliers in relation to total information.

In addition, the data from the survey indicated that equipment suppliers obtained the majority of the required design information from their customers. In total 21 out of 25 equipment suppliers stated that 50 per cent or more of the needed design information was provided by the customer. For the whole sample, however, the median was 50 per cent, which indicates that the design information provided by the manufacturing company was incomplete. At the time a lack of design information was identified by the employees of the equipment supplier, they had to act on their own initiative to obtain the required design information. In these cases equipment suppliers got access to design information by getting in contact with the customer, preferably an appointed contact person. Usually telephone or e-mail communication was used to obtain the missing design information, but sometimes the equipment supplier made a study visit. Another aspect of obtaining information is that the preferred communication media depends on the type of information to be shared. The results showed that documents were usually the preferred choice for obtaining information, but information about the objective was preferably obtained by personal interaction.

Further, the differences in the perception of relevant and necessary design information between the manufacturing company and the equipment supplier became clear when the equipment supplier had to explicitly indicate the proportion of relevance of the perceived design information, i.e. the percentage of the transferred design information needed by equipment suppliers in their work activities. Based on the answers of the equipment suppliers it was identified that the majority of the transferred design information was needed by the equipment suppliers (median 80 per cent). However, only four equipment suppliers stated that the provided design information was 100 per cent needed.

The results also highlighted the need to appoint a skilled contact person. The equipment suppliers stated that the manufacturing companies should carefully select a skilled contact person for effective collaboration. The contact person was ranked as the most important factor that contributed to an effective acquisition of production equipment, see Table 10. The possibility to openly discuss alternative options with the customer was considered very important by the equipment suppliers. Table 10 summarizes those factors that were identified by the equipment suppliers as being the most important to achieve an effective production system acquisition process. Overall, it can be concluded that formal coordination mechanisms were more important than informal coordination mechanisms.

Table 10. The four most important factors contributing to an effective production equipment acquisition process as identified by 25 equipment suppliers in the survey

	No. of respondents that ranked factor as			
Factor	*important to a large extent*	*one of the five most important factors**	*of crucial importance*	*most important factor**
Appointed contact person	9	18	13	8
Clear/formal hand-over	9	8	9	3
Continuous communication	16	17	6	5
Common objective	16	15	5	5

* Note: The equipment suppliers were asked to choose and rank the five most important factors out of 19 stated factors. The respondents ranked the most important factor as 1, the second most important factor as 2, etc.

To summarize, in this chapter parts of the material gathered during the case study and the survey have been briefly described. The description provides an overview of the case-specific prerequisites and how design information was managed. The material presented in this chapter will be used in the analysis. Discussing the analysis of the empirical findings is the subject of the next chapter.

CHAPTER 5

CONTENT AND STRUCTURE OF DESIGN INFORMATION

CHAPTER INTRODUCTION

The present chapter analyses the empirical findings starting with a categorizing of the design information followed by an analysis of the management of design information. In order to clarify the relationship between the management of information and the process of designing the production system, testable propositions are formulated.

5.1 CATEGORIZING DESIGN INFORMATION

In the following, the design information applied when designing a production system will be categorized. Based on the empirical findings and the frame of reference, ten categories of design information to be used when designing a production system are identified. The different categories of design information identified are based on differences in the information content.

The first and most common category of information is *production system information*, which regards information about the elements and subsystems of the production system. Based on Groover's (2008) classification of the production system into four subsystems (see Chapter 2), the empirical findings indicated that information regarding the technical subsystem had the highest priority when designing the production system. In addition, the findings from Case B and Case P indicated that information about the other three subsystems was only of minor relevance in the early phases but became increasingly important in the final stages. The production system information was either developed internally from the representatives of the functions[9] that influenced the design of their subsystems or externally from consultants and equipment suppliers.

In Case B and Case P, the design of the production system partly overlapped with that of the product to be manufactured. Previous research has pointed out that concurrent development projects of products presuppose interaction between the design activities. As a consequence, it has been argued that the manufacturing function needs to receive sufficient information about the product design,

[9] As described in Chapter 2 in this thesis the term function is used to denote responsibilities and work areas required to design the production system.

particularly when the design of the product and the production system should be carried out in parallel (Gerwin and Barrowman, 2002; Ha and Porteus, 1995). The empirical findings showed that *product information*, i.e. all information about the products to be manufactured, was also an important category of information required for the design of the production system. A more detailed description of product information is provided in Paper II. The product information was mainly developed by the representatives of the design engineering and verification laboratory functions.

In Case P knowledge of how the new material should be handled in operation was limited. Therefore, opportunities were used to study production systems of other manufacturing companies that had solved similar problems. Studying other production systems is a type of benchmarking, resulting in a reference point (Sandkull and Johansson, 1996) and can be a source of inspiration (Säfsten, 2002). In Case E and Case T it was also pointed out that good relations with the equipment supplier provided insights into how competitors have solved similar problems. As a consequence, *competitor information* is identified as an important category of design information when designing the production system. It is important to note that competitor information in this context refers to the study of suitable production system solutions outside the company rather than to information about competitors' products.

The empirical studies revealed that the design of the production system was also affected by the manufacturing strategy and lean production philosophy. In Case T it has been emphasized that the production system solution has to be based on the production philosophy to facilitate operational excellence. Before the design of the production system started in Case B and Case P, it was agreed on what lean implementation level had to be accomplished. Company I had different levels of implementing lean production, where each level placed different requirements on, for example, key performance indicators, overall equipment effectiveness, operator maintenance, etc. Because of the different possibilities to design a production system, information about the overall objectives has to be clearly defined. As stated by one equipment supplier in the survey, the absence of a common objective at their customers could lead to misunderstandings and miscommunication when designing the production system. Only with information about the objectives is it possible to achieve a fit between the expected production system and the production system solution (Wu, 1994). Therefore, *strategic information* can be identified as an information category required when designing the production system.

Another category identified is *customer information*, which refers to the particular demands placed by a customer. The signing of a customer in Case B and Case P made it necessary to clearly specify the demands of the final customer and to consider them in the design of the production system. When designing the production system, customer information related among other things to total market demand, product packaging, and test specifications and thus did not deal with the functionality of the designed product. Having information about specific customer characteristics has also been expressed as important by Ruffini (1999). This information category might be more uncertain when no customer has been signed to the project.

The design of the production systems was closely aligned to the market requirements in Case B and Case P. During the initial phases there were a number of discussions to develop an understanding of the product market and the customers in order to understand the consequences for the production system solution. This is in line with earlier research in the production system design field which argues that the market strategy should be considered when designing the production system (Bennett and Forrester, 1993; Ruffini, 1999). Because of the different demands of different markets, it is necessary to include *market information* when designing production systems. The information in this category came from the representative of the market function or from outside the company and provided data about current and potential customers and markets.

In all four case studies, the design of the production system was influenced by legislation, which can differ from country to country. Work organization and environmental sustainability issues are typical examples. In Case B, the patent of a competitor also influenced the production system solution and disregarding it would have had severe consequences such as penalties or rework. The information that determines the legal freedom of decisions is categorized as r*egulatory information*. It includes rules, regulations, patents, etc. and is made available by the authorities.

The prerequisites for carrying out the design of the production system differed between Case B and Case P. However, despite the differences it was obvious that the process required some kind of guidance. For instance, in order to make sure that everyone was updated and that the design of the production system was coordinated, project meetings were continuously initiated and a timeline was developed. Meetings were not only used to keep members informed, but they also offered the project leader a possibility to determine whether there was a need for members to support each other and take on other activities. The value of information that contributes to a structured process has also been pointed out by the equipment suppliers in the survey. The need to have information about the management and control of the project is crucial to the management of manufacturing projects (O'Sullivan, 1994). The information that guides the process of designing the production system is categorized as *project management information,* and it was mainly the responsibility of the project manager to provide this information. However, also engineering design is an important sources for project centric information (Paper II).

The design information identified in the empirical studies and categorized as *financial information* defined the budget and costs and was provided by the steering committee. Accordingly, the financial information determined the scope for investments and resource allocation in both Case B and Case P and investments in production equipment in Case E and Case T. Several equipment suppliers in the questionnaire pointed out that it would be generally beneficial to receive financial information from their customers to define the scope of the project. To avoid greater risk of costly rework, equipment suppliers wanted to have information about the budget to be able to present a quote in line with expectations of their customers. The importance of financial considerations is also confirmed by the research presented by Bellgran (1998).

To follow the work progress at the equipment supplier and to have the possibility to check if all requirements specified in the request for quotation were fulfilled was seen as an important aspect in Case B. Therefore, the employees put great emphasis on the development of a verification plan, which involved a process for verifying the specified requirements at different points in time and by different means. To continuously follow up the status of each individual requirement specified is a key issue in a development process as discussed by Andersson (2003). Thus, v*erification information* about how and when to verify specified requirements is therefore a category that needs to be included in the design of the production system. The employees who specified the requirements were responsible for the verification information.

Although the content of the design information will be dependent on the specific context, the ten categories of design information described above (see Figure 15) should be viewed as a guiding principle around which the content of design information should be individually discussed. The identification of the design information categories created a foundation for what design information needed to be handled when designing the production system, which will be discussed in the next section.

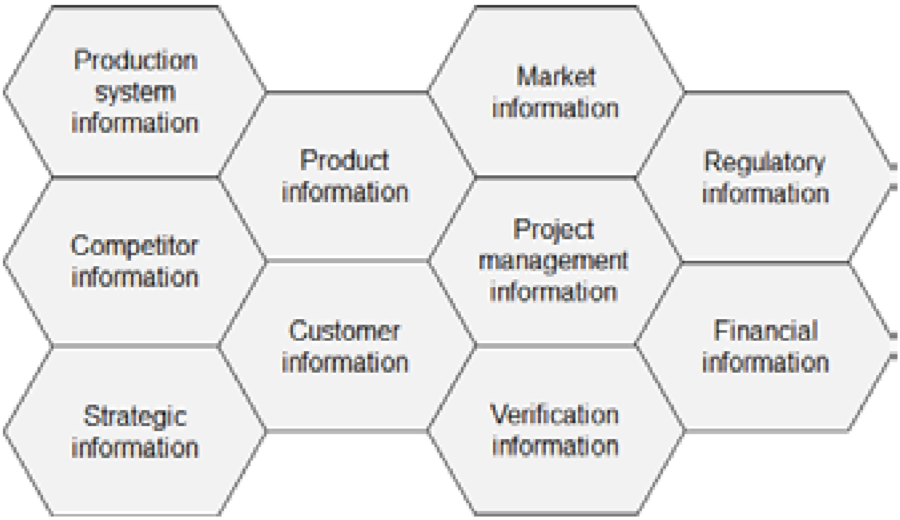


Figure 15 Ten identified categories of design information required for the design of the production system.

5.2 STRUCTURE FOR HANDLING DESIGN INFORMATION

In line with prior research (Frishammar, 2005; Frishammar and Ylinenpää, 2007; Ottum and Moore, 1997) discussed in Chapter 2, the management of design information can be divided into the three dimensions acquiring, sharing, and using design information. Dividing the management of design information into the three dimensions facilitates structuring and analysis of the management of design information (see also Paper V).

5.2.1 Acquiring of design information

Information type

An examination of the ten identified design information categories reveals that the content of the design information had to cover four aspects important for the design of the production system.

- First, it was necessary to acquire design information about all elements and subsystems of the production system in order to minimize the risk of suboptimization, which builds on the idea of applying a holistic perspective (e.g. Bennett, 1986; Groover, 2008).
- Second, it has been argued that the external context needs to be analysed when designing the production system as not everything of importance occurs within the manufacturing company (Bennett and Forrester, 1993; Ruffini, 1999). Thus, there is a need to acquire design information that is developed external to the manufacturing company.
- Third, when designing the production system, it is also necessary to consider internal requirements, i.e. information that was developed internal by the manufacturing company but external to the industrialization project. For example, the design of the production system has to be in line with the manufacturing strategy and the production philosophy (Cochran *et al.*, 2001/2002; Duda, 2000).
- Fourth, information about project organization and progress needed to be acquired in order to provide sufficient constraints and control mechanisms. This is in line with arguing that the success of a project depends on the planning of the process (Bellgran, 1998).

Based on the empirical findings, the following conclusion could be drawn:

Acquiring a broad variety of design information facilitates the process of designing the production system.

According to theory, information can also be divided into hard and soft information and any kind of information is almost always a combination of soft and hard information (Frishammar, 2003; Häckner, 1988). During the design of the production system, both hard and soft information was used to accomplish the task at hand. Nevertheless, the empirical findings highlighted that a greater amount of hard information was acquired when designing the production system. One possible reason for the reliance on hard information is the possibility to easily process greater amounts of information (Häckner, 1988). Another explanation is that the processing of hard information is not tied to an individual person (Shrivastava, 1985). However, one should not underestimate the value of soft information. Soft information was needed to place hard information in a context and to improve the understanding of how to apply the acquired hard information. Based on the empirical findings, the following conclusion could be drawn:

Acquiring a combination of soft and hard design information facilitates the process of designing the production system, but the larger part should be hard information.

Source of information

To acquire information related to each identified design information category made it necessary to acquire design information from both internal and external sources when designing the production system. This is similar to the findings presented by Zahay *et al.* (2004), who point out that information is either developed internally or originates from outside the company. Internally developed design information was acquired from employees of the company ranging from operators to top-level management. Typically, external sources relevant for the production system design project in the cases studied were equipment suppliers, consultants, customers, and regulatory bodies. Table 11 classifies the ten identified categories of design information (see Figure 15) according to where the content of the design information was developed.

Table 11. The ten design information categories classified according to their origin

Internally developed design information	Internally and externally developed design information	Externally developed design information
1. Product	6. Market	8. Regulatory
2. Strategic	7. Production system:	9. Competitor
3. Project management	• Technical	10. Customer
4. Financial	• Material supply	
5. Verification	• Human	
	• Control	

The empirical findings showed a pattern where internal sources of design information seemed to be preferred over external ones, i.e. whenever possible, design information was acquired from an internal source. One explanation for favouring internal sources is the perceived accessibility of sources, which is positively related to the frequency of usage (Sawyerr *et al.*, 2000). The absence of a clear strategy of how to acquire information from external sources was found in Case B and Case P. In general, the design information that was acquired from external sources was used to get a more complete understanding, to solve problems in an appropriate way and to limit the scope of possible actions. For instance, the design of the technical subsystem benefited from acquiring additional design information from equipment suppliers who were experts in this area. Thus, the acquiring of design information from external sources provided a valuable input to the design of the production system. Based on the empirical findings, the following conclusion could be drawn:

Acquiring design information from internal and external sources facilitates the process of designing the production system, but internal sources are the preferred choice.

Recalling the discussion in Chapter 2, sources can also be divided into personal and impersonal sources. From the analysis of Case B and Case P it is clear that personal sources, i.e. "other people", were the preferred source for the acquiring of information. Continual meetings provided an efficient possibility to acquire valuable information from other project members. In addition, the empirical findings on impersonal sources reveal that the process, i.e. the operationalized production system, was hardly applied as a source. Seeing production systems that were in operation as a source was only applied when the production system of the same product platform had been studied and analysed in Case B. Documents, on the other hand, were considered as an important source of information, particularly when designing the technical subsystem of the production system.

The findings about preferring personal sources is in line with the findings of Daft *et al.* (1988), who emphasize that personal sources may be needed to allow for enactment and clarification of ambiguous situations. The process of designing a production system is often associated with a high degree of uncertainty with representatives from different functions differing in training and background. Another explanation for the use of personal rather than impersonal sources may be the limited documents available. Based on the empirical findings, the following conclusion could be drawn:

Acquiring design information from personal and impersonal sources facilitates the process of designing the production system, but personal sources are the preferred choice.

The process of designing the production system evolved over a considerable amount of time and consisted of several distinct phases as discussed in Chapter 2 and highlighted in Chapter 4. Although the phases are partly overlapping, each phase requires the accomplishment of different work activities, see Figure 13, and thus the required information varied between the different phases of the production system design process. Based on the findings in Case B and Case P, Figure 16 summarizes the categories of design information that were required in each phase of the design process. The analysis was based on the phases and activities that were described in Case P in Chapter 4.

In the concept study phase in Figure 16 there was a need to attain almost all categories of design information, while in the scoping phase only two categories of design information were attained according to the empirical findings. In addition, in the first two phases much effort was placed on acquiring information that ensured alignment with the external context. In the later three phases, on the other hand, the acquired design information dealt to a larger extent with accomplishing a suitable design of the four subsystems, i.e. the technical, material supply, human, and control systems of the production system. The findings from Case B and Case P also indicated that soft information was more relevant early in the process of designing the production system, and design information of a hard character became more important in the later phases. Based on the empirical findings, the following conclusion could be drawn:

Acquiring different design information categories at different points in time facilitates the process of designing the production system. In general, soft information should be emphasized in the early design phases, while hard information becomes more relevant in the later design phases.

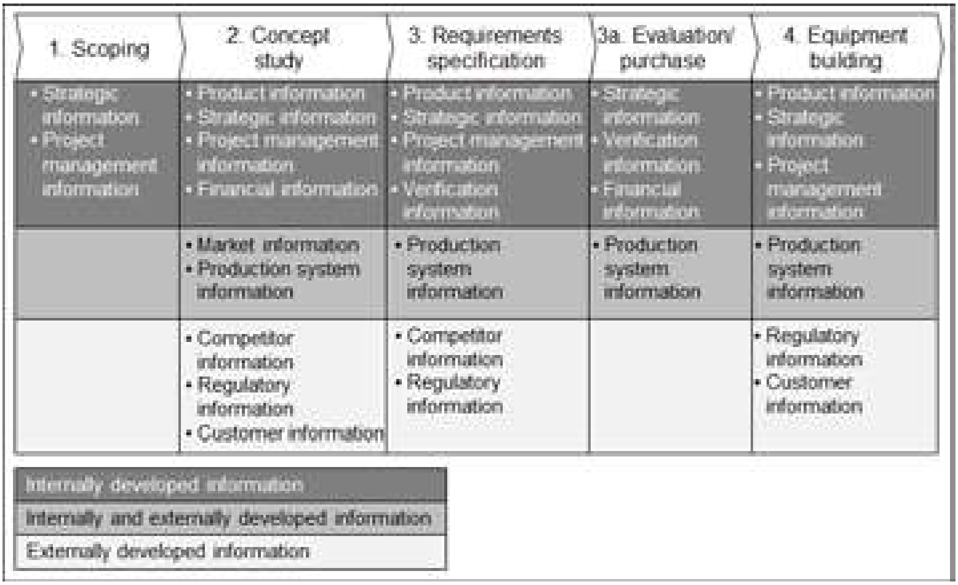


Figure 16 Categories of design information acquired in the different phases of the production system design process. The different grey scales indicate the origin of the information.

5.2.2 Sharing of design information

Communication medium

The results of the empirical studies showed that in order to accomplish the interdependent work activities, design information was shared among the representatives from the various functions involved in the design of the production system. The sharing of design information took place by either a less rich medium such as documents or a rich medium such as face-to-face interaction. During the progress of the industrialization projects in Case B and Case P, continual meetings in different constellations took place. In addition to the weekly meetings with the new product development team, separate meetings concerning the design of the production system took place on a frequent basis. The cross-functional meetings focused on critical issues that needed to be addressed and usually resulted in action lists that were followed up at the next meeting. Among the project members who were involved in the design of the production system, the sharing of information by face-to-face interaction was acknowledged as informative and particularly suitable for solving unclear issues in both Case B and Case P. This is in line with other research advocating that that a rich medium is appropriate for resolving complex issues since it allows for immediate feedback and enactment (e.g. Daft and Lengel, 1986; Frishammar *et al.*, 2011).

Although face-to-face contacts and meetings were the dominant strategy for the sharing of information in the cases studied, documents were also used to share relevant information. The results of the survey revealed that documents were the preferred way of obtaining information from their customers. However, as pointed out in Case E documents are a suitable medium only when information has been carefully documented, i.e. there is a need to devote great care to the structure and content of documents to minimize the risk that information will be misunderstood or interpreted incorrectly.

One thing worth noting is that in Case B and Case P documents were most suitable when a common perspective and terminology had been established. For instance, in order to share the design information with the equipment supplier, it was more important to have devices in place that facilitated the sharing of a sufficient amount of the required design information than to meet frequently to discuss critical issues. Once a common understanding and perspective has been established among the functions involved, documents can be used to coordinate the task at hand (Daft and Lengel, 1984). The people involved in the design of the technical subsystem had the same background and training as the representatives of the equipment suppliers in the cases studied. However, one should remember that there was a general lack of documentation in earlier projects, which makes it difficult to share information by means of documents. Therefore, it would be beneficial to improve the overall documentation in order to base the choice of the communication medium on the information richness and not on the only medium available. Based on the empirical findings, the following conclusion could be drawn:

Sharing design information through documents and meetings facilitates the process of designing the production system but meetings should be emphasized in ambiguous situations, while documents are more suitable for the sharing of well understood messages.

Formalization

Achieving a holistic view required the sharing of information between several functions in the manufacturing company and with external partners in Case B and Case P. Figure 17 summarizes the flow of information between the industrialization project manager and production engineering manager with the internal and external functions involved in the design of the production system in Case B. It is important to note that the figure is schematic and includes only an indication of the information flow on a general level. However, it highlights the information dependency among the functions involved in the production system design project. That is, if design information was not adequately shared among the functions involved, it caused difficulties in carrying out the task at hand without avoiding suboptimization. Challenges and consequences of the sharing of design information between representatives from design engineering and the representatives from production engineering are discussed in detail in Paper II.

Comparing the industrialization project in Case B with that in Case P indicates that the sharing of design information between specialized functions was facilitated by organizing the design of the production system in a separate industrialization project including a project team and a designated project manager. This is in line with the reasoning presented by Love (1996) arguing that a process of designing a production system is organizationally complex requiring a project team with members from different specialized functions. Project teams facilitate the sharing of information across functional boundaries (Lawrence and Lorsch, 1967). In addition, it has been argued that a successful project requires a knowledgeable project manager who can devote sufficient time to plan, manage, and monitor the project (Mabert *et al.*, 1992). In Case B the project manager worked full time with the studied industrialization project focusing on structuring the work and keeping deadlines. This included among other things to ensure that the required information was shared. Based on the empirical findings, the following conclusion could be drawn:

Sharing design information in a dedicated, cross-functional production system design team facilitates the process of designing the production system.

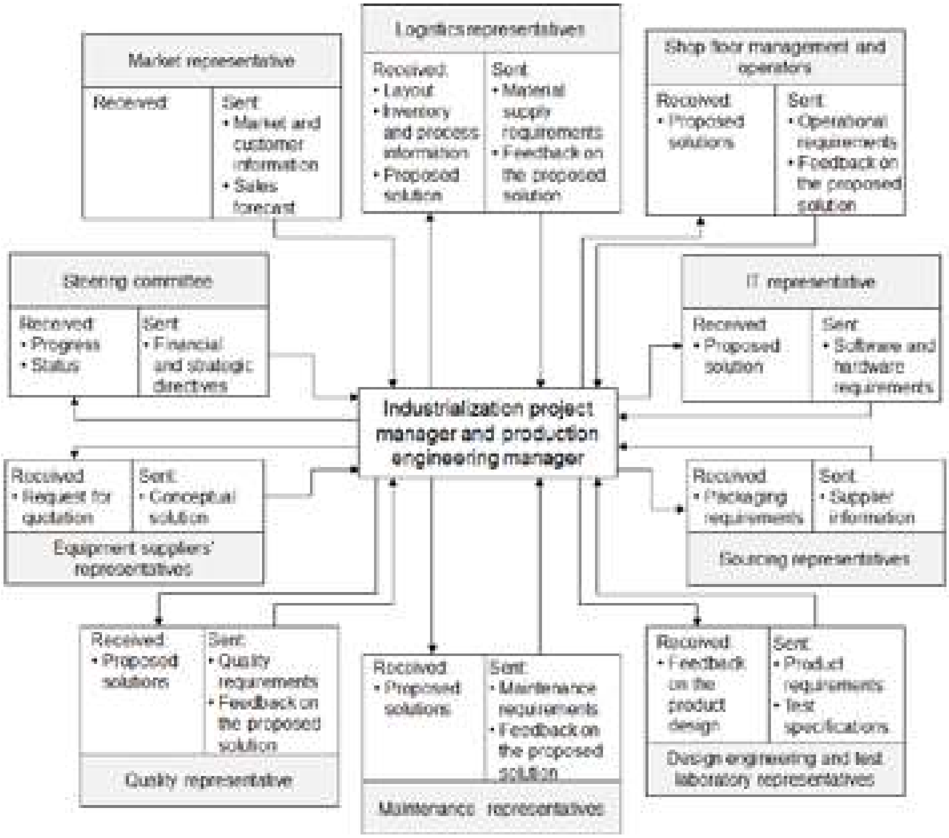


Figure 17. Design information received from and sent to the industrialization project manager and production engineering manager when designing the preproduction system in Case B.

As indicated in Chapter 2, to effectively integrate cross-functional activities requires the sharing of information. The findings in Case B and Case P displayed, however, differences in how design information was shared with the external equipment supplier compared to the sharing of design information among the internal functions of the manufacturing company, (see also Paper IV).

Sharing of design information with the external equipment supplier. Based on the empirical findings from the four case studies, a process for acquiring production equipment could be identified (see Figure 18). In each phase sharing information between the equipment supplier and their customers was required. First, the request for quotation was sent to a number of potential equipment suppliers. The selection of potential suppliers was based on previous experience, timeline of the project, complexity, etc. In the second phase the equipment suppliers were invited to present their quotes at the manufacturing company. Thereafter, a technical and commercial evaluation of the quotes was made at the manufacturing company before one equipment supplier was selected for final negotiation. Finally a contract was created based on the technical solution and the financial details. Overall, it can be concluded that the equipment supplier selection follows a formalized process.

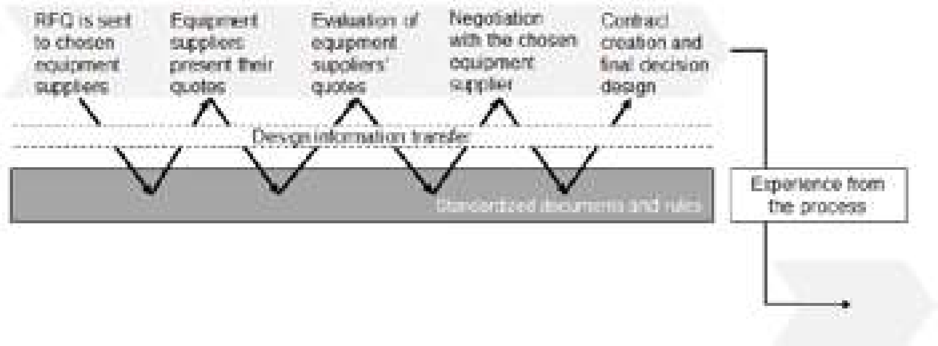


Figure 18. Process for selecting a production equipment supplier based on the four case studies.

To be able to integrate the activities carried out by the equipment supplier, plans and schedules were established including a time plan from sending the request of quotation to the installation of the equipment and start-up of production. The time plan provided a guideline regarding the distribution of design information that needed to be shared in the different phases. Further, the use of standardized documents ensured that previous experiences were reused and that the information was easy to understand for the equipment supplier. In Case E and Case T, the technical requirements specification was updated on a frequent basis to reflect changes in the external context or lessons learned in completed acquisition projects.

Sharing of design information among specialized functions. The standard that guided the design of the production system in Case B and Case P was the stage-gate model used in new product development. However, the applied stage-gate model was created from a product perspective and thus did not include detailed strategies for the design of the production system. For instance, the available schedule lacked some crucial dates relevant when designing the production system such as when to order the production equipment. In addition, the production system design activities that were included in the product development stage-gate model were assigned to individual functions. As a result, each function handled the activities separately as far as possible even if it would have been useful to share information with other functions working with the design of the production system. Based on the findings in Case B and Case P, it can be concluded that the sharing of design information among specialized functions within the manufacturing company was less formalized than the sharing of design information with the equipment suppliers. As a result, the empirical findings suggest that formalization facilitates the sharing of information among functions. The findings are in accordance with previous studies, which emphasize that an intangible and non-standardized content of the design process hampers the sharing of information (Moenaert and Souder, 1990), while a stage-gate process with critical go/no-go decisions at various points provides procedures for improved information sharing (Cooper and Kleinschmidt, 1991; Griffin and Hauser, 1996). Based on the empirical findings, the following conclusion could be drawn:

Sharing design information in a formalized process with different stages and gates facilitates the process of designing the production system.

The sharing of design information in Case B and Case P was also affected by more informal coordination mechanisms that promoted the transfer of design information among specialized functions. When the specialized functions were located close to each other, information was directly shared when unanticipated problems and challenges arose during the design of the production system. This reduced the risk that design information was delayed, lost, or altered. Furthermore, more spontaneous sharing of design information took place when employees met each other in the halls or around the lunch and coffee breaks. On the other hand, longer distances between the functions involved reduced the frequency of spontaneous information sharing and made face-to-face communication inconvenient. This observation is in line with that of Allen (1977), who concluded that the probability of interaction between people is rapidly reduced with the physical distance between their work locations. Project members of the production system design project need to find ways to reduce the physical distance between the specialized functions to facilitate understanding each other (Allen, 1970; Vandevelde and Van Dierdonck, 2003).

In addition, informal personal contacts with other employees not directly involved in the design of the production system were established in Case B. The industrialization project leader contacted other employees who he thought could contribute to the problem solving. These formless relations supported the sharing of additional information. The importance of formless relations has been discussed by, among others, Griffin and Hauser (1996), who emphasize that a formless relation increases coordination in the process and decreases project uncertainties. Based on the empirical findings, the following conclusion could be drawn:

Sharing design information through informal coordination mechanisms including co-location of specialized functions and the building of formless relations facilitates the process of designing the production system.

5.2.3 Using design information

In Paper I it is argued that the use of design information was influenced by the information quality and whether information was pragmatic or not.

Information quality

Four information quality levels are distinguished: relevant information, sound information, optimized process, and reliable infrastructure, where each level is determined by four criteria (see Chapter 2 for a further description). In the following, imperfections in the four information quality levels will be analysed and discussed in detail.

Relevant information refers to whether information is comprehensive, accurate, clear, and easily applicable (Eppler, 2006). In Case B and Case P there were few documents available supporting the design of the production system at the beginning of the industrialization projects. When the members in the industrialization projects studied realized that additional information was needed, they were not always sure of the detail of information required. Similar results were found in Case E, where the absence of documentation in the technical requirements specification resulted in unwanted different solutions between production systems when they started to replace the existing production system five years ago. In the projects studied in Case B and Case P, efforts were made to improve the documentation for the current project, but also for general documentation, which can be reused in future projects. For instance, in Case B, the process of making product design changes was standardized and formalized by the industrialization project manager in order to ensure that the information could be applied and understood by the various functions.

However, also documented information sometimes caused problems regarding its relevance. The findings from the survey revealed that the technical requirements specification often contained too detailed information, while at the same time project-specific information dealing with the context, background, and scope was missing. It was argued by the suppliers that too detailed requirements specifications were unnecessary at an early stage. Overall, the empirical findings suggest that there were difficulties in judging the relevancy of the information.

Sound information refers to whether information is concise, consistent, correct, and current (Eppler, 2006). During Case B and Case P, information was presented differently depending on the competence and experience of the author of the information. It could be found that some information was extensively presented, such as the information concerning the technical subsystem, while information about the human subsystem was hardly even labelled. Further, as most of the information came from one personal source, there was often no possibility to validate the received information and thus there was a risk that the information was biased and contained errors.

One of the major challenges identified in Case B and Case P was the need to overlap the design of the production system with the product design. The product design project did not follow the mandatory timeline, and information about the final design of the product that was supposed to be manufactured was delayed considerably. Consequently, much of the work of designing the actual production system was based on preliminary information that changed during the progress of the new product development project. The use of preliminary information had two consequences. First, the work with the design of the production system was also delayed as the employees waited for more complete information. Second, some rework was required when product design changes were made. This is also discussed by Terwiesch *et al.* (2002). The empirical findings suggest that there were deficiencies regarding the sound information quality level.

Optimized process refers to whether the process by which the information is created and distributed is convenient and whether it is provided in a timely, traceable, and interactive manner (Eppler, 2006). The actual way of handling design information in the industrialization projects studied did not facilitate obtaining the required design information. The search for additional design information was time-consuming as it was not always clear where to find the required information. Often, there was a need to contact several persons who were assumed to have the required design information. Further, it was difficult after some time had passed to trace the information, as information was often transferred orally. Another aspect that clearly influenced the optimized process level was the late release of product information in the industrialization projects studied. As the product information became available late, the ability of influencing the product design was reduced, which limited the available options for the design of the production system.

Reliable infrastructure refers to the process through which information is actually provided and considers accessibility, security, maintainability, and speed (Eppler, 2006). The empirical findings from Case B and Case P and the survey revealed issues with the accessibility of the required design information when designing the production system. Although information was available on the intranet, it was not always easy to know where to find it, or information was kept in a local database that was not accessible to other functions. Another factor that hindered the accessibility was the fact that not all design information was available when needed, such as late decisions on the product design.

As the design information concerning the production system was not handled in any kind of formalized information system, personal contacts were often used to retrieve the required information. However, there was no guarantee that the contacted person possessed the information and even if he/she had relevant design information, the information was often incomplete, which required involving additional people in the cases studied. Thus, retrieving design information was sometimes found frustrating and time-consuming by the project team members when designing the production system. In addition, the limited documentation reduced the ability to maintain the information over time and the content of design information was not restricted, which increased the risk for unwanted changes in the information content. According to the empirical findings, it can be assumed that there were deficiencies regarding the reliable infrastructure level.

A summary of the analysis of the empirical findings indicates that the acquiring and sharing of design information often caused severe problems with the quality of the information, and this affected the utilization of design information when designing the production system. Thereby, the empirical results support prior research stating that information with few deficiencies in quality is likely to be used to a higher extent than information with major imperfections in information quality (O'Reilly, 1982). Further it has been pointed out that complementing approaches have to be applied to deal with shortcomings in information quality (Eppler, 2006; Johansson, 2009). Based on the empirical findings, the following conclusion could be drawn:

Using design information with high information quality facilitates the process of designing the production system, but different complementing approaches are required to achieve high information quality.

Pragmatic Information

Another aspect that clearly influenced the use of information was the degree of newness of its content. Information needs to be a combination of confirmation and novelty, i.e. pragmatic in order to be useful to the receiver (Fjällström, 2007; Von Weizsäcker, 1974). Comparing the industrialization project in Case P with that in Case B suggests that the degree of novelty has to be carefully balanced to ensure that the information is usable. In Case P, the employees were forced to take advice from experts (both consultants and equipment suppliers) to understand the content and implications of the provided information as the amount of novelty of the information was overwhelming. On the other hand, in Case B, the design of the production system was less troublesome as the employees could relate information to experiences gained from the assembling of the previous product generation. Another example showing the importance of combining confirmation with novelty is the efforts of specifying environmentally sustainable requirements in Case E and Case T. Although the importance of considering environmentally sustainable requirements in the technical requirements specification was not disputed, it was difficult to actually specify this kind of requirements. Specifying environmental requirements was not emphasized earlier, which made it difficult to understand the provided information and transfer it into concrete requirements. Based on the empirical findings, the following conclusion could be drawn:

Using pragmatic design information facilitates the process of designing the production system.

To summarize, the analysis of the empirical findings shows that the management of design information is influenced by a number of circumstances and it may be difficult to understand how the circumstances affect the management of design information. Therefore, in Chapter 6 the analysis is taken one step further and the findings are synthesized. As discussed in Chapter 3 the research has been carried out within the field of applied research and thus should also have industrial usefulness. This implies, to some extent, that Chapter 6 is more prescriptive than the thesis has been so far, suggesting a framework that should contribute to an effective management of design information.

CHAPTER 6

TOWARDS EFFECTIVE MANAGEMENT OF DESIGN INFORMATION

CHAPTER INTRODUCTION

This chapter answers the two research questions and synthesizes them into a design information management framework. The framework is a suggestion for how an effective management of design information can be achieved when designing the production system.

6.1 REQUIRED DESIGN INFORMATION WHEN DESIGNING PRODUCTION SYSTEMS

Research question 1 addresses the design information required when designing production systems. The research in this thesis identifies and describes ten categories of such information (see Section 5.1). The identified design information categories cover a broad variety of aspects concerning the production system in itself but also the way the design activities should be carried out. The design information can be further divided into information that avoids suboptimization of individual elements and subsystems of the production system, and design information that ensures that the production system is consistent with the demands from the internal and external context. This is similar to what Miller (1992) and Ruffini (1999) call an internal and external fit. Although the research does not dispute the reasoning that there is not one production system design representing the best fit (Bozarth and McDermott, 1998; Van de Ven and Drazin, 1985), the findings show that the design information needs to support a conceptual solution that is consistent with internal and external demands. Thus, the design information categories can be classified into four main groups:

1. Design information that minimizes the risk of suboptimization of individual elements and subsystems of the production system.
2. Design information that contributes to the alignment of the production system solution with the requirements placed by the external context.
3. Design information that contributes to the alignment of the production system solution with the requirements placed by the internal context.

4. Design information that facilitates advancements in the design work.

The first group, i.e. design information that ensures that suboptimization of individual elements and subsystems of the production system is avoided, minimizes the risk of slack both in terms of waste and in terms of resources. In a production system where design information about all four subsystems, technical, material supply, human, and control systems, is not integrated, the interdependence among the subsystems is disregarded, which increases the risk that the subsystems do not support each other in operation. In the worst case, the created production system could imply that the four subsystems are irreconcilable. The need to include design information about all four subsystems can be traced back to the need to have a holistic perspective when designing the production systems (Bennett, 1986; Groover, 2008). Taking design information about all four subsystems into account should ensure a grounding of design decisions in the context of the demands of the other subsystems.

The second group is design information that ensures that the production system solution is aligned with the requirements placed by the external context. Not all design information required is developed within the manufacturing company. Factors external to the manufacturing company should have an impact on the scope of decisions when designing the production but can also provide opportunities. Models emphasizing the external context such as, for example, that presented by Bennett and Forrester (1993), acknowledge the value of analysing the external context when designing the production system. Taking design information about the context of the manufacturing company into account should contribute to a production system that is consistent with demands placed by customers, competitors, regulatory bodies, etc.

The third group is design information that ensures that the production system solution is aligned with the requirements placed by the internal context. This information facilitates that the production system solution provides the capacities and capabilities required to be successful in the markets. For example, by including design information about the manufacturing strategy in the production system design process, the performance of the production system should also be co-aligned with the corporate strategy (e.g. Hayes and Wheelwright, 1984; Skinner, 1969). Taking design information about the internal context of the industrialization project into account should facilitate that the production system solution satisfies the objectives of the manufacturing company.

The fourth group, i.e. the design information that facilitates advancements in the design work is based on the need for transparency and guidance for the task at hand. This is in congruence with what Petersson and Petersson (1992) call operational information. The people involved in the design of the production system need to be supported in their work activities by information that ensures a smooth progress of the design work. It is important to plan the design process and to have a structured and systematic working process (Bellgran, 1998). Taking design information about the production system design process into account should promote an effective and efficient design process.

6.2 THE CHARACTERISTICS OF DESIGN INFORMATION MANAGEMENT WHEN DESIGNING PRODUCTION SYSTEMS

The second research question addresses the characteristics of the management of design information when designing production systems. A characteristic can be referred to as a distinguishing trait[10] meaning that the management of design information will be dependent on the particular situation. Thus, the management of design information has certain characteristics.

As discussed in Chapter 2, design information is not incorporated in the design process, because the information is not acquired, shared or used. Therefore, in the product development literature it has been suggested that the management of information has to be considered as a multidimensional concept consisting of the three dimensions acquiring, sharing, and using of design information (Frishammar, 2005; Frishammar and Ylinenpää, 2007; Ottum and Moore, 1997). The present research shows that this concept is also valid when designing the production system. In addition, the findings of the current research suggest that acquiring, sharing, and using of design information are highly interrelated with each dimension affecting the other two, i.e. the management of design information is an iterative process which should be viewed as a looping of acquiring, sharing, and using of design information, see Figure 19.

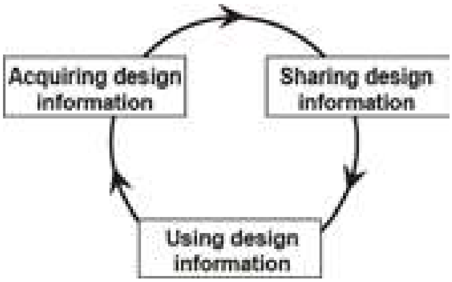


Figure 19. The management of design information should be viewed as a looping of acquiring, sharing, and using of design information with a high dependency between the three dimensions.

As a result, the acquiring, sharing, and using of design information has to be performed continuously throughout the production system design process and should not be considered as a singular event. Figure 20 below illustrates that the management of design information consists of numerous loops of acquiring, sharing, and using design information in each phase of the production system design process.

[10] www.m-w.com, "characteristic", accessed 12 January 2012.

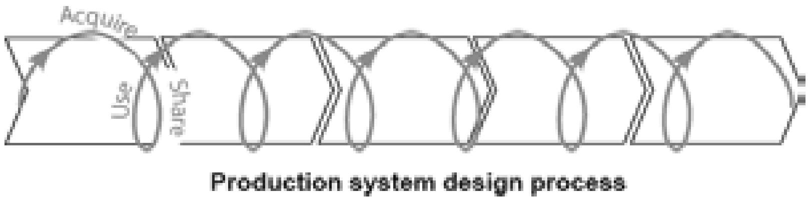


Figure 20. The management of design information is a continuous looping of acquiring, sharing, and using of design information through all phases of the production system design process.

Further, the analysis conducted in Chapter 5 revealed that the management of design information was influenced by several characteristics (see also Paper V). Based on the empirical findings six characteristics could be identified namely: information type, source of information, communication medium, formalization, information quality and pragmatic information. In Chapter 5, each characteristic is discussed under the information management dimension it influences. Figure 21 illustrates a summary of these characteristics.

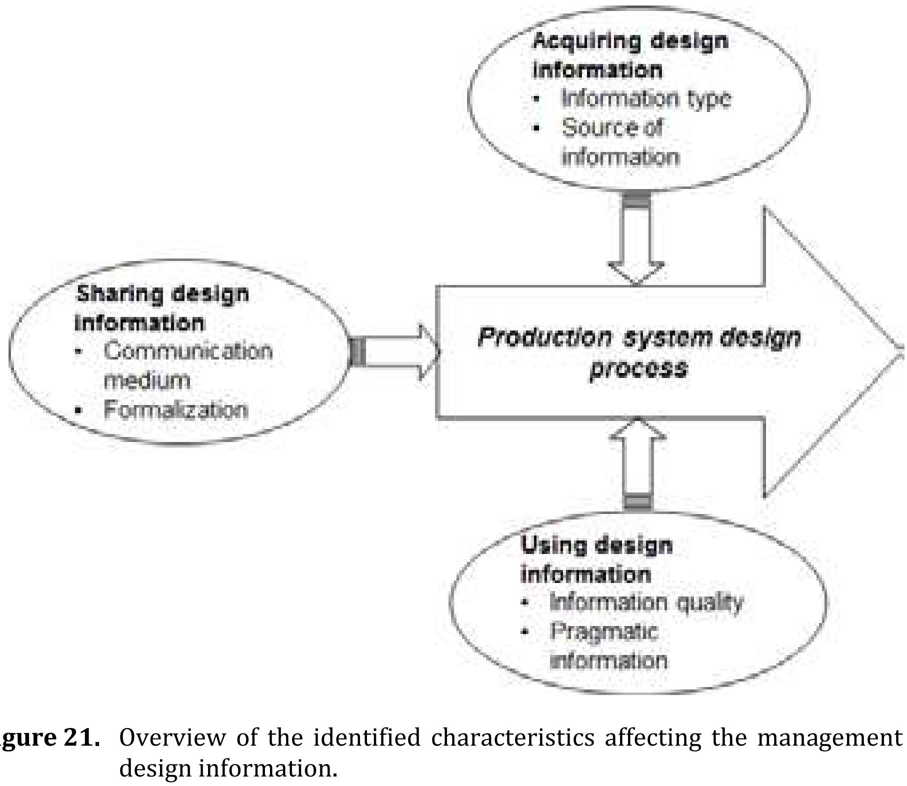


Figure 21. Overview of the identified characteristics affecting the management of design information.

In the following text a more detailed description of the meaning of each characteristic is provided.

The first characteristic is the *information type* that needs to be acquired when designing the production system. 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. The importance of having a holistic perspective and ensuring a fit to the internal and external context has been discussed previously (e.g. Bennett and Forrester, 1993; Ruffini, 1999). Further, it is important to acquire also design information about the project organization, which gives guidance on advancing the project within a predefined scope. However, one should be aware that having a comprehensive view of the design of the production system 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.

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. Design information should be acquired from both internal and external sources. Although a combination of information sources were applied in the empirical studies, internal and personal sources were by far the preferred choice for acquiring design information, as they were easily accessible. However, external sources may help to handle the trade-off between limited resources and the need to minimize uncertainty (Frishammar, 2003). Thus, there is a need for a clear strategy that supports the acquiring of design information also from external sources.

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). There are, however, 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. Another risk is that information is not comprehensively documented, which reduces the ability to reuse experiences in future projects. Based on the reasoning above, it is argued that there is a need to ensure that all relevant functions can acquaint themselves with the relevant design information. One strategy would be to support the development of standard documents. 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 (Paper IV). The more formalized the process was, the more structured was the sharing of design information. Therefore, it is suggested that it would be beneficial to create a production system design process similar to the stage-gate model used in new product development with dedicated resources and a clear process ownership structure. Performing the work activities in each phase requires the sharing of design information both inside and outside the project team. This is supported by Cooper and Kleinschmidt (1991), who found that a stage-gate process led to more information exchange and multifunctional discussions. Further, by dedicating resources to the process, the employees could commit themselves to the work of designing the production system. Process ownership was crucial for coordinating the sharing of design information among the functions involved. However, it is important to also acknowledge the value of informal coordination mechanisms such as co-location and formless relations. 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. p*ragmatic information*. Studies in this research (Case B and Case P) 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.

6.3 DESIGN INFORMATION MANAGEMENT FRAMEWORK

The objective of the research presented in this thesis is to develop knowledge to contribute to an effective management of design information when designing production systems. The analysis of the empirical findings reveal that the management of design information is complex and requires different initiatives in different phases of the production system design process. As a result, it may be difficult for practitioners to assimilate and utilize the developed knowledge. Therefore, this subsections outlines a design information management framework to summarize and visualize the knowledge gained. The developed framework provides a structure that should contribute to long-term knowledge on the issue.

The framework is an elaboration of the result from Research Question 2. It is built on the three dimensions of managing design information, i.e. the acquiring, sharing, and using of design information (Frishammar, 2005; Frishammar and Ylinenpää, 2007) and the six characteristics briefly described above. Thus, the framework comprises three parts:

- The first part – acquiring of design information – comprises the type of design information required and the source of the design information.
- The second part – sharing of design information – comprises the communication medium applied and the degree of formalization in the design process.
- The third part – using of design information – comprises information quality and pragmatic information.

In Chapter 5 and in Section 6.2, a set of critical factors were described under each characteristic, such as design information categories required or whether design information should be acquired from internal or external sources. In Figure 22, an overview of the identified critical factors relevant to consider for an effective management of design information is presented. There is always a need to deal with these factors when designing the production system. However, each factor needs to be adjusted to the specific setting. For example, whether design information should be shared by means of documents or direct interaction depends amongst other on the background and training of the team members. The overview should be considered as a structure around which the factors of the management of design information can be discussed when designing production systems.

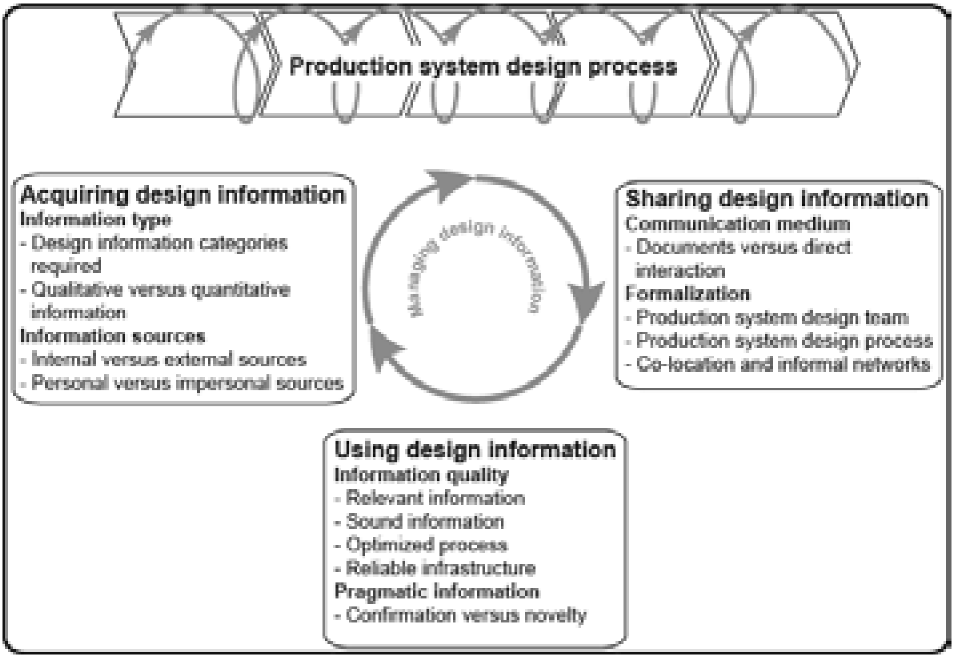


Figure 22. Overview of the key factors influencing the management of design information when designing production systems.

The purpose of developing the design information management framework is to create a valuable tool that can be applied to effectively manage design information when designing the production system. The challenge for manufacturing companies is to acknowledge that the design of production systems has a number of phases, each with different activities that need to be performed. The various activities that need to be carried out make it impossible to manage design information in the same way throughout the entire design process. By separating the various activities into different phases, as presented in Figure 13, it was possible to point out approaches to be used for an effective management of design information. The structure for the design information management framework evolved, see Figure 23. The framework incorporates the factors relevant to reflect upon for an effective management of design information and provide guidelines of how these factors should be considered. The design information management framework should be used by project managers and project members involved in the design of the production system.

Based on the findings of the present study the framework highlights that the demands on the management of design information at the beginning of the production system design process were different from those in the later phases of the process. At the beginning it is important to reduce any equivocality surrounding the process of designing the production system, which points towards the need for personal commitment, as the emphasis should be on personal interaction as often as possible facilitating extensive discussions. As equivocality is reduced, it is possible to rely increasingly on alternatives that are independent of personal interaction. The framework also illustrates that some factors are of relevance in several or all phases of the production system design process. One should also note that each work activity identified in Figure 13 offers more detailed guidance on the required design information in each phase.

			1. Scoping	2. Concept study	3. Requirements specification	3a. Evaluation/ purchase	4. Equipment building
Acquiring design information	Design information type	Required design information category	• Strategic information • Project management information	• Product information • Strategic information • Project management information • Financial information • Market information • Production system information • Competitor information • Regulatory information • Customer information	• Product information • Strategic information • Project management information • Verification information • Production system information • Competitor information • Regulatory information	• Strategic information • Verification information • Financial information • Production system information	• Product information • Strategic information • Project management information • Production system information • Regulatory information • Customer information
		Soft versus hard information	Soft				Hard
	Source of design information	Personal versus impersonal source	Personal				Impersonal
		Internal versus external source	Internal source	Internal and external sources	Internal (and external) sources	Internal and external sources	Internal and (external) sources
Sharing design information	Communication medium	Human interaction versus documents	Human interaction				Documents
	Formalization	Formal process	√	√	√	√	√
		Dedicated resources	√	√	√	√	√
		Co-location		(√)	√		√
Using design information	Information quality		√	√	√	√	√
	Pragmatic information		√	√	√	√	√

Figure 23 The design information management framework to be used when designing production systems.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

CHAPTER INTRODUCTION

In the final chapter of the present thesis the focus is on discussing the results and the research methodology and also to outline the scientific and industrial contributions as well as to suggest directions for further research. The discussion of the results promotes ideas and should be seen as a starting point to advance the findings of the present research. The chapter ends with concluding remarks.

7.1 GENERAL DISCUSSION

The analysis identified ten categories of information that should be applied when designing the production system. Overall, the identified categories should be of general value for the design of production systems as their importance has also been discussed in previous literature. However, it is important to note that the design information categories that need to be handled by the manufacturing company should be a matter of the approach taken to the design of the production system. As described in Chapter 2, it is possible to differentiate between a concept-generating approach, a concept-driven approach, and a supplier-driven approach (Säfsten, 2002). Case B and Case P can be categorized by a concept-generating approach, which implies that the industrialization project was responsible for all design steps. As a result, all design information categories should be handled by the manufacturing company. This might be different in, for example, a supplier-driven approach, where the equipment supplier is responsible for creating a detailed design solution.

In general, the management of design information when designing production systems was challenging. One explanation for difficulties is related to the need to apply a holistic perspective in the concept generation of the production system. The empirical findings indicate that much effort was placed on acquiring information about the technical subsystem, while acquisition of design information regarding the human, material supply, and control subsystems was limited. The employees involved in the production system design process did not dispute the significance of acquiring design information about all subsystems of the production system but found it difficult to gather concrete facts that go beyond laws and provisions.

Several reasons may lie behind the discrepancy concerning the amount of information acquired. First, the technical information is the underlying information used for the creation of production equipment, which is often acquired from an external equipment supplier. External equipment suppliers need information to undertake their work activities of designing and building the production equipment at a given point in time. Without information, equipment suppliers cannot fulfil the objective, and their access to additional information can only be satisfied by getting in contact with people employed at the manufacturing company. Second, the production equipment represents a large part of the production system development project costs, and the cost of failing is evident, while the cost for the other subsystems might not be as apparent. Another argument is that the production system is often implemented in an already existing plant with available structures regarding the material supply, human, and control subsystems. Therefore, the design information that needs to be acquired concerning these three subsystems relates to operations, which may conceal the benefits of acquiring information about the subsystems as they were already predefined from the beginning.

The management of design information is also affected if an external equipment supplier is responsible for the design and subsequent building of the production equipment. Equipment suppliers are sources of major innovations in manufacturing technology, for which the incentives are greater and adopted by the larger user firms (Hutcheson *et al.*, 1996; Reichstein and Salter, 2006). Furthermore, Utterback (1994) argues that major innovations have a tendency to come from unexpected directions. However, if major process innovations originate from outside the company, there is a need to monitor the external environment of the company. The role of a gatekeeper, i.e. a person that helps to overcome barriers raised by organizational boundaries, has received a fair share of attention in new product development (NPD) theory. Gatekeepers can overcome barriers based on differences such as terminology, norms, and values (Allen, 1977; Tushman and Scanlan, 1981) and can be described as key communicators (Davis and Wilkof, 1988) who are strongly linked to the internal and external organization (Tushman and Scanlan, 1981). Consequently, gatekeepers at the manufacturing company can provide a link between the organization and its environment by collecting and translating relevant information (see Paper III). Therefore, engaging gatekeepers also in the production system design process could be of value for increasing the information flow between the manufacturing company and the external environment.

Further, over a long time the focus in the production system area has not been on the design process; rather a considerable amount of work has been devoted to production flexibility, i.e. the creation of “the” system that has “the ability to change or react with little penalty in time, effort, cost, or performance” (De Toni and Tonchia, 1998, p. 1591). Since flexibility costs money, it is necessary to define a dynamic set of requirements to which the production system will react with no or minimal structural intervention (Slack, 1987). However, concerns have been raised that the high level of uncertainty of today’s competitive environment makes it impossible to specify the production flexibility required. Further, it has been pointed out that manufacturing companies find the concept of flexibility difficult to deal with despite its being recognized as central to design efforts (Slack, 2000).

In Case B and Case P, the need to prepare the production system for future product variants was emphasized. With regard to design production systems that could handle future product requirements, information about the life length of the product and potential future markets and customers had been collected and analysed. This information was used to determine the required flexibility and length of life of the production system. However, the case studies demonstrate that having a long-term perspective of the design of the production system was not easily achieved. An important conclusion drawn in Paper VI was that in order to accomplish a more long-term design of a production system it was not sufficient to include only design information about the current product generation, but also design information that was related to the introduction of future generations of product and product variants was needed. However, the findings also revealed that it was difficult to identify, structure, and document the information in an appropriate way that would allow for conscious planning of a production system that is prepared for both today's and tomorrow's challenges.

As a result, there is a need to limit the demand for flexibility by using strategies that can contribute to a more systematic and structured way of planning for changes in the product design, which may lead to changes in the production system design. Production systems need to be designed in a way that they can handle a wide range of product variants and updates without requiring an excessive level of flexibility, as this would be not economically justifiable. Thus, from a more general perspective, to synchronize only the design of the production system with the actual products to be manufactured is insufficient. Rather, the introduction of future generations of products and product variants must be taken into account when designing production systems. One possibility would be to create a product portfolio of future products and a co-portfolio of production systems. This proactive way of thinking leads to a portfolio of a number of tentative products and a portfolio of tentative production systems that match each other (see also Paper VI). Therefore, it is argued that manufacturing companies could accelerate their design process by using a portfolio approach in which the product and the production system portfolio are planned simultaneously.

An effective portfolio management is about making strategic choices (Cooper *et al.*, 1999), which necessitates systematic and careful planning to make sure that the products will fit well with the company's overall objective. However, applying a production system portfolio approach places different demands on the management of design information. To be able to include even future demands and also influence future product design calls for design information. The creation of a production system portfolio alongside the product portfolio requires applying preliminary information in the design of the production system to a larger extent than required when only considering the actual product generation. The empirical findings of the current research and prior research (Hauptman and Hirji, 1996; Johansson, 2009) has, however, shown that the use of preliminary information may have a negative impact on whether or not design information is acquired, shared, and used.

7.2 CONCLUSIONS

Today's manufacturing industry is more global than ever facing new challenges of long-term viability. Designing production systems in an efficient and effective manner was initially pointed out as critical to creating competitive advantages. In the research presented in this thesis, it is argued that the capability to effectively manage the required design information is one way to facilitate the design process.

The objective of the research has been to develop knowledge to contribute to an effective management of design information when designing production systems. In order to fulfil the research objective, two research questions have been formulated and answered.

The answer to the first research question reveals the wide variety of design information that needs to be considered in the production system design process. Based on the results of the investigation, it can be concluded that design information required when designing the production system is a combination of information that minimizes the risk of suboptimization, ensures an alignment with external and internal demands, and supports advancements in the research process. The answer to the first research question contributes to achieving the objective by increasing the understanding of what design information is required during the process of designing the production system and thus identifies what design information needs to be managed.

The answer to the second research question confirms prior research from the NPD field seeing the management of design information as a multidimensional construct consisting of the three dimensions acquiring, sharing, and using design information also when designing the production system. Further, it is argued that the management of design information is affected by six characteristics that can be attributed to the three dimensions. These characteristics are type of information, source of information, communication medium, formalization, information quality, and pragmatic information. The answer to the second research question contributes to achieving the objective by increasing the understanding of what characterizes the management of design information and thus identifies how the process can be shaped to best fit the context of the particular production system design project.

The answers to the two research questions were synthesized into a design information management framework, see Figures 22 and 23. The findings are an important first step in an area that has received only limited attention from academics and practitioners alike. The framework visualizes the complexity of managing design information and presents a structured approach of how design information can be managed when designing the production system. In the long term the framework may even facilitate handling production system design activities more proactively. A proactive way of working implies that events are dealt with before or when they occur in order to create favourable outcomes. As has been illustrated in Figure 5, proactive handling of work activities depends on whether an event is planned and/or whether the handling of the event is known. Therefore, an effective management of design information should lead to improved possibilities to re-use previous experiences and to plan for different activities that need to be carried out in the production system design process.

7.3 METHODOLOGICAL DISCUSSION

Although it is believed that the current research contributes to knowledge about a more effective management of design information when designing the production system, it is important to acknowledge that the selected research method and the research design influence the conclusions that can be drawn in the research.

The choice of the case study method for answering the research questions resulted in very detailed and rich data about the management of design information when designing the production system. Therefore, a challenge perceived in the use of the case study method was handling the overwhelming amount of data. As Pettigrew (1990, p. 281) concludes, the volume of data brings about the danger of "death by data asphyxiation". While in statistical analyses the researcher is guided by rules and formulas, support in the analysis of case study data has been insufficiently developed (Yin, 2009). To minimize the risk that the amount of data was overwhelming, the collected data were continuously analysed and each data collection occasion was prepared in order to avoid what Voss *et al.* (2002) call "industrial tourism", i.e. visiting numerous organizations without being certain about the objective of the research. Further, the analysis was based on a model that contributed to a structured and systematic analysis of the data. It is necessary to consider analytic approaches in the research design to avoid ending up in a situation of not knowing what to do with the collected data (Yin, 2009).

The research design rests on two real-time and two retrospective case studies and a descriptive survey. The case studies were performed in the automotive industry because of the dynamic conditions of handling shrinking product life cycles combined with an increasing number of product models and variants. The survey was answered by representatives of equipment suppliers, since equipment suppliers are of great importance for the design of production systems. The research design was perceived as suitable as it revealed similarities but also highlighted individual differences.

An industrialization project is often carried out over several months or years and includes different functions, which made it difficult to coordinate the data collection. However, a considerable amount of time was spent at the case study company in Case B and Case P and thus events could be observed at first hand instead of relying on retrospective narratives. In Case B, the industrialization project was studied for one and a half years, which made it impossible to spend every day at the company. Therefore, tight coordination between the researcher and the project members was used to make sure that that no critical issues were missed. In addition, to minimize the risk of relying on the retelling of individual employees, various kinds of data triangulation were applied.

It is evident that the outcome of the research was influenced by the selected research method. The question is whether an explanatory survey method could have been an alternative method for studying the management of design information. One possibility would have been to take the propositions made in prior NPD research and test their validation in the production system design process. It is likely that such an approach would have led to more analytical generalizability of the findings. Nevertheless, as noted by Meredith (1998), the increased reliability and validity associated with a more rationalist approach could only be obtained at the expense of the contextual and temporal richness that case studies offer. As a result, the findings would not have been as detailed as the ones presented in this thesis and there would have been the risk that critical issues particular to the production system design process would have been lost.

7.4 DISCUSSION OF THE CONTRIBUTIONS OF THE RESEARCH

7.4.1 Scientific contributions

The production system design process refers to the process of creating a detailed description of the proposed production system. What this thesis has added to the field of the design of production systems is new knowledge about the design information required in the design process by identifying ten categories of design information (see Figure 15) that can be divided into four main groups. Further, the research presented in the thesis outlines what categories of design information are required in the different phases of the production system design process and where the design information is developed, as illustrated in Figure 16.

Another contribution of this thesis is the identification of the six characteristics that affect the management of design information. The characteristics can be assigned to the three dimensions acquiring, sharing, and using design information. While prior research developed tools that supported the overall production system design, the current research outlines a design information management framework that provides important insights regarding the actual management of design information when designing production systems. Further, the empirical findings presented in this thesis increase the overall awareness of the importance of an effective management of design information as a critical factor for successful industrialization projects.

7.4.2 Industrial contributions

In the production system design process a wide variety of design information is required, which has to be acquired and used to create a production system. Even though the studied companies had a routine of designing production systems, the management of design information was challenging. By using the outlined design information management framework, challenges related to the managing of design information can be reduced. For instance, it is indicated where the relevant design information is generated, which should make it easier to access the required design information.

Further, a common way of working in NPD projects is to regard the production system design process as one of several sub-activities. However, on the basis of the present results, it is possible to argue that the key to success lies in the ability of a manufacturing company and its managers to understand that it may not be enough to consider the production system design process as just one of many activities required to introduce a product to the market. The production system design process requires structure and transparency for the people involved in the process. Based on the analysis in Chapter 5, it is possible to see the potential benefits of formal and informal coordination mechanisms. A high degree of formalization in the production system design process should improve the sharing of information between specialized functions and also increase the understanding of the different needs of the various functions involved in the design process. In addition, a higher degree of formalization contributes to more documentation. Documentation is crucial to learning from previous mistakes and to transferring knowledge between different production system design projects.

The findings of the current thesis show that the management of design information is heavily dependent on the persons involved in the design process. This means that information is preferably acquired from personal sources and shared through human interaction. This increases the risk that information gets lost when people change their working places or are not involved in future projects. Further, although the current research does not outline any kind of formalized information system to be used when designing a production system, it highlights that manufacturing companies should pay attention to developing an information system to be used in design processes. Special attention should be given to measures that facilitate the transfer of rich information, i.e. information that helps to reduce equivocality. This kind of information is often difficult to capture and manage but of high value when designing the production system. One possibility would be to explore the potential of video- and audiotapes. As more and more projects are carried out in international environments where functions are located at different geographical places, companies are in urgent need of information systems that support them in managing disparate kinds of design information and in making design information available across functions and locations.

7.5 SUGGESTIONS FOR FURTHER RESEARCH

Subsequent and future research in the area of management of design information when designing the production system can take a number of directions.

While a case study design generally allows for retaining the holistic and meaningful view of the phenomenon studied, the generalization of the findings has to be done with caution. The case studies have been carried out in the automotive industry. Hence, more research is clearly needed to evaluate and test the value of the proposed framework. One possibility would be to replicate the empirical data collection in different types of industries. Another possibility would be to turn to a fixed research approach such as the survey method to investigate the possibility of statistical generalization. As Karlsson (2009) has remarked, in order to develop knowledge in a field, there is a need to go through different phases starting with exploring before being able to describe a field of knowledge, to know the components before understanding the relations, and to know the relations before predicting the effects.

Further research is also required concerning the identified characteristics (see Figure 21) and the design information management framework. Although the six characteristics seem plausible since the significance of the identified characteristics has been identified in prior research, it is likely that the current research has not identified the complete range of characteristics that affect the management of design information. Further, the identified six characteristics are probably interrelated. For example, the source of information has probably consequences for the communication medium applied. Accordingly, further research should focus on how these characteristics are connected and their consequences for the management of design information. Another limitation of the research was that the suggestions made in Figure 23 are only phase-specific to a limited extent. However, it would be of interest to study if the management of design information has to be more adjusted to each phase due to the different work activities conducted in each phase of the design process and if some characteristics are more or less relevant in the different phases.

Finally, also the settings of the current research influenced the conclusions drawn. In the cases studied, the internal functions involved in the production system design process were located at the same site. Today, there is no guarantee that all functions are located at the same site, and one general conclusion on studies of dispersed settings is that geographical distance influences the flow of information. Thus, it would be of interest to see if and how the management of design information will change when key functions are located at different places. Another important aspect that turns into a suggestion for further research is the fact that the framework presented in the current research is to a large extent limited to the present product generation, i.e. the design of the production system was aligned to the actual product developed. However, in an ever-changing environment with reduced product life cycles, the issue of design information concerning future product generations is of high relevance. To be able to design production systems that are easily adjustable to future product generations requires having an efficient flow of information between product design and manufacturing functions indicating future product demands but also manufacturing capabilities. As suggested, one possibility would be to base future research on the idea of using a production system design portfolio approach when designing production systems.

Research in the field of production system design and particularly on the management of design information is valuable in the effort to create the best possible production system. Since an effective and efficient production system design process can play a critical role in gaining an edge, the motivation for further research in the area should be high.

REFERENCES

Abernathy, W.J. and Wayne, K. (1974), "Limits of the Learning Curve", *Harvard Business Review*, Vol. 52, No. 5, pp. 109-119.

Adler, P.S. (1995), "Interdepartmental Interdependence and Coordination: The Case of the Design/Manufacturing interface", *Organization Science*, Vol. 6, No. 2, pp. 147-167.

Aguilar, F.J. (1967), *Scanning the Business Environment*, New York, NY: Macmillan.

Aitken, J., Childerhouse, P. and Towill, D. (2003), "The impact of product life cycle on supply chain strategy", *International Journal of Production Economics*, Vol. 85, No. 2, pp. 127-140.

Allen, T.J. (1970), "Communication networks in R & D Laboratories", *R&D Management*, Vol. 1, No. 1, pp. 14-21.

Allen, T.J. (1977), *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information Within the R&D Organization*, Cambridge, MA: MIT Press.

Alm, I. and Fjällström, S., (2003), "Dealing with Production Disturbances: The Significance of Change and Pragmatic Information", in *Automated Systems Based on Human Skill and Knowledge, Proceedings of the 8th International Federation of Automatic Control Symposium*, Gothenburg, Sweden, 22-24 September, 2003.

Andersson, F. (2003), *The Dynamics of Requirements and Product Concept Management: A Product Modelling Approach,* PhD Thesis, Chalmers University of Technology, Gothenburg, Sweden.

Andreasen, M.M. and Hein, L. (1987), *Integrated product development*, Berlin, Germany: Springer-Verlag.

Arbnor, I. and Bjerke, B. (2009), *Methodology for Creating Business Knowledge*, 3rd ed., London, UK: SAGE.

Asnafi, N., Hjelm, S., Holmgren, B., Malmsköld, L., Granström, M., Svenningstorp, J. and Mellgren, H. (2008), *2015 Sustainable Manufacturing Systems Capable of Producing Innovative Environmentally Friendly and Safe Products*, R&D program proposal to secure competitive vehicle and powertrain production in Sweden,

Barney, J. (1991), "Firm Resources and Sustained Competitive Advantage", *Journal of Management*, Vol. 17, No. 1, pp. 99-120.

Barney, J., Wright, M. and Ketchen Jr., D.J. (2001), "The resource-based view of the firm: Ten years after 1991", *Journal of Management*, Vol. 27, No. 6, pp. 625-641.

Barton, J.A., Love, D.M. and Taylor, G.D. (2001), "Design determines 70% of cost? A review of implications for design evaluation", *Journal of Engineering Design*, Vol. 12, No. 1, pp. 47-58.

Baxter, M. (1995), *Product Design: Practical methods for the systematic development of new products*, London, UK: Chapman & Hall.

Bellgran, M. (1998), *Systematic Design of Assembly Systems: Preconditions and Design Process Planning,* PhD Thesis, Linköping University, Linköping, Sweden.

Bellgran, M. and Säfsten, K. (2010), *Production Development: Design and Operation of Production Systems*, London, UK: Springer-Verlag.

Bennett, D. (1986), *Production Systems Design*, London, UK: Butterworth-Heinemann.

Bennett, D.J. and Forrester, P.L. (1993), *Market-Focused Production Systems: Design and Implementation*, New York, NY and London, UK: Prentice Hall.

Berglund, M., Skog, E. and Öjmertz, B. (2001), *Driftsättning av monteringssystem - Erfarenheter och synpunkter från svenska industriföretag*, IVF-rapport 01009 [in Swedish], IVF, Mölndal, Sweden.

Bergman, B. and Klefsjö, B. (2010), *Quality from customer needs to customer satisfaction*, 3rd ed., Lund: Studentlitteratur.

Bozarth, C. and McDermott, C. (1998), "Configurations in manufacturing strategy: a review and directions for future research", *Journal of Operations Management*, Vol. 16, No. 4, pp. 427-439.

Bruch, J. (2009), *Information Requirements in a Proactive Assembly Work Setting,* Licentiate Thesis, Chalmers University of Technology, Gothenburg, Sweden.

Bruch, J. and Karltun, J., (2009), "Information Requirements in a Proactive Assembly Work Setting", *Proceedings of the 3rd International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2009)*, Munich, Germany, 5-7 October, 2009.

Bruzelius, L.H. and Skärvad, P.-H. (1989), *Integrerad organisationslära* [in Swedish], 6th ed., Lund: Studentlitteratur.

Butcher, H. (1998), *Meeting Managers' Information Needs*, London, UK: Aslib.

Byström, K. (1999), *Task Complexity, Information Types and Information Sources: Examination of Relationships,* Doctoral Thesis, University of Tampere, Tampere, Finnland.

Chapanis, A. (1996), *Human Factors in Systems Engineering*, New York, NY: John Wiley & Sons.

Checkland, P. (1999), *Systems Thinking, Systems Practice: Includes a 30-year retrospective*, 8th ed., Chichester, UK: John Wiley & Sons.

Chisholm, A.W.J. (1990), "Nomenclature and definitions for manufacturing systems", *CIRP Annals*, Vol. 39, No. 2, pp. 735-742.

Choudhari, S.C., Adil, G.K. and Ananthakumar, U. (2010), "Congruence of manufacturing decision areas in a production system: a research framework", *International Journal of Production Research*, Vol. 48, No. 20, pp. 5963-5989.

Christensen, C.M. (2006), "The Ongoing Process of Building a Theory of Disruption", *Journal of Product Innovation Management*, Vol. 23, No. 1, pp. 39-55.

Chryssolouris, G. (2006), *Manufacturing Systems: Theory and Practice*, 2nd ed., New York, NY: Springer.

Churchman, C.W. (1978), *Systemanalys* [in Swedish] *(Original title: The Systems Approach, translated by Björk, L.)*, Stockholm: Rabén & Sjögren.

Clark, K.B. and Fujimoto, T. (1991), *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry*, Boston, MA: Harvard Business School Press.

Cochran, D.S., Arinez, J.F., Duda, J.W. and Linck, J. (2001/2002), "A decomposition approach for manufacturing system design", *Journal of Manufacturing Systems*, Vol. 20, No. 6, pp. 371-389.

Cooper, R.G. (1975), "Why new industrial products fail", *Industrial Marketing Management*, Vol. 4, No. 6, pp. 315-326.

Cooper, R.G. (1999), "From Experience: The Invisible Success Factors in Product Innovation", *Journal of Product Innovation Management*, Vol. 16, No. 2, pp. 115-133.

Cooper, R.G. (2008), "Perspective: The Stage Gate® Idea-to-Launch Process—Update, What's New, and NexGen Systems", *Journal of Product Innovation Management*, Vol. 25, No. 3, pp. 213-232.

Cooper, R.G. and Kleinschmidt, E.J. (1991), "New product processes at leading industrial firms", *Industrial Marketing Management*, Vol. 20, No. 2, pp. 137-147.

Cooper, R.G., Edgett, S.J. and Kleinschmidt, E.J. (1999), "New Product Portfolio Management: Practices and Performance", *Journal of Product Innovation Management*, Vol. 16, No. 4, pp. 333-351.

Cross, N. (2000), *Engineering Design Methods: Strategies for Product Design*, 3rd ed., Chichester, UK: John Wiley & Sons.

Daft, R.L. and Lengel, R.H. (1984), "Information Richness: A New Approach to Managerial Information Processing and Organization Design", *Research in Organizational Behavior*, Vol. 6, pp. 191-233.

Daft, R.L. and Weick, K.E. (1984), "Toward a Model of Organizations as Interpretation Systems", *Academy of Management Review*, Vol. 9, No. 2, pp. 284-295.

Daft, R.L. and Lengel, R.H. (1986), "Organizational Information Requirements, Media Richness and Structural Design", *Management Science*, Vol. 32, No. 5, pp. 554-571.

Daft, R.L., Sormunen, J. and Parks, D. (1988), "Chief executive scanning, environmental characteristics, and company performance: An empirical study", *Strategic Management Journal*, Vol. 9, No. 2, pp. 123-139.

Dankbaar, B. (2007), "Global Sourcing and Innovation: The Consequences of Losing both Organizational and Geographical Proximity", *European Planning Studies*, Vol. 15, No. 2, pp. 271-288.

Davenport, T.H. (1997), *Information Ecology: Mastering the Information and Knowledge Environment*, New York, NY: Oxford University Press.

Davenport, T.H. and Prusak, L. (1998), *Working knowledge: How organizations manage what they know*, Boston, MA: Harvard Business School Press.

Davis, P. and Wilkof, M. (1988), "Scientific and technical information transfer for high technology: keeping the figure in its ground", *R&D Management*, Vol. 18, No. 1, pp. 45-58.

De Toni, A. and Tonchia, S. (1998), "Manufacturing flexibility: A literature review", *International Journal of Production Research*, Vol. 36, No. 6, pp. 1587-1617.

Deshpande, R. and Zaltman, G. (1982), "Factors Affecting the Use of Market Research Information: A Path Analysis", *Journal of Marketing Research*, Vol. 19, No. 1, pp. 14-31.

Draaijer, D. and Boer, H. (1995), "Designing market-oriented production systems: theory and practice", *Integrated Manufacturing Systems*, Vol. 6, No. 4, pp. 4-15.

Duda, J.W. (2000), *A Decomposition-Based Approach to Linking Strategy, Performance Measurement, and Manufacturing System Design,* PhD Thesis, Massachusetts Institute of Technology, Cambridge, MA.

Edmunds, A. and Morris, A. (2000), "The problem of information overload in business organisations: a review of the literature", *International Journal of Information Management*, Vol. 20, No. 1, pp. 17-28.

Eisenhardt, K.M. (1989), "Building Theories from Case Study Research", *Academy of Management Review*, Vol. 14, No. 4, pp. 532-550.

ElMaraghy, H.A. (2009), "Changing and Evolving Products and Systems - Models and Enablers", in ElMaraghy, H.A. (Ed.), *Changeable and Reconfigurable Manufacturing Systems*, London: Springer-Verlag, pp. 25-45.

ElMaraghy, H. and Wiendahl, H.-P. (2009), "Changeability - An Introduction", in ElMaraghy, H.A. (Ed.), *Changeable and Reconfigurable Manufacturing Systems*, London, UK: Springer-Verlag, pp. 3-24.

Engström, T., Jonsson, D. and Medbo, L. (1998), "The Volvo Uddevalla plant and interpretations of industrial design processes", *Integrated Manufacturing Systems*, Vol. 9, No. 5, pp. 279-295.

Eppler, M.J. (2006), *Managing Information Quality: Increasing the Value of Information in Knowledge-intensive Products and Processes*, 2nd ed., Berlin, Germany: Springer-Verlag.

Fjällström, S. (2007), *The Role of Information in Production Ramp-up Situations,* PhD Thesis, Chalmers University of Technology, Gothenburg, Sweden.

Fjällström, S., Säfsten, K., Harlin, U. and Stahre, J. (2009), "Information enabling production ramp-up", *Journal of Manufacturing Technology Management*, Vol. 20, No. 2, pp. 178-196.

Forza, C. (2009), "Surveys", in Karlsson, C. (Ed.), *Researching Operations Management*, New York, NY: Routledge, pp. 84-161.

Frishammar, J. (2003), "Information use in strategic decision making", *Management Decision*, Vol. 41, No. 4, pp. 318-326.

Frishammar, J. (2005), *Towards a Theory of Managing Information in New Product Development,* PhD Thesis, Luleå University of Technology, Luleå.

Frishammar, J. and Hörte, S.Å. (2005), "Managing External Information in Manufacturing Firms: The Impact on Innovation Performance", *Journal of Product Innovation Management*, Vol. 22, No. 3, pp. 251-266.

Frishammar, J. and Ylinenpää, H. (2007), "Managing Information in New Product Development: A Conceptual Review, Research Propositions and Tentative Model", *International Journal of Innovation Management*, Vol. 11, No. 4, pp. 441-467.

Frishammar, J., Florén, H. and Wincent, J. (2011), "Beyond managing uncertainty: insights from studying equivocality in the fuzzy front end of product and process innovation projects", *IEEE Transactions on Engineering Management*, Vol. 58, No. 3, pp. 551-563.

Galbraith, J.R. (1973), *Designing Complex Organizations*, Reading, MA: Addison-Wesley.

Galliers, R. (1987), "On the Nature of Information: Introduction", in Galliers, R. (Ed.), *Information Analysis: Selected Readings*, Wokingham, UK: Addison-Wesley, pp. 3-6.

Gerwin, D. and Barrowman, N.J. (2002), "An Evaluation of Research on Integrated Product Development", *Management Science*, Vol. 48, No. 7, pp. 938-953.

Girotra, K., Terwiesch, C. and Ulrich, K.T. (2007), "Valuing R&D Projects in a Portfolio: Evidence from the Pharmaceutical Industry", *Management Science*, Vol. 53, No. 9, pp. 1452-1466.

Griffin, A. (1997), "PDMA Research on New Product Development Practices: Updating Trends and Benchmarking Best Practices", *Journal of Product Innovation Management*, Vol. 14, No. 6, pp. 429-458.

Griffin, A. and Hauser, J.R. (1996), "Integrating R&D and Marketing: A Review and Analysis of the Literature", *Journal of Product Innovation Management*, Vol. 13, No. 3, pp. 191-215.

Groover, M.P. (2008), *Automation, Production Systems, and Computer-Integrated Manufacturing*, 3rd ed., Upper Saddle River, NJ: Prentice-Hall.

Gupta, A.K., Raj, S.P. and Wilemon, D. (1987), "Managing the R&D-marketing interface", *Research Management*, Vol. 30, No. 2, pp. 38-43.

Ha, A.Y. and Porteus, E.L. (1995), "Optimal Timing of Reviews in Concurrent Design for Manufacturability", *Management Science*, Vol. 41, No. 9, pp. 1431-1447.

Harlin, U. (2000), *Towards Strategic Disturbance Management in Advanced Manufacturing Systems,* Licentiate Thesis, Chalmers University of Technology, Gothenburg, Sweden.

Hauptman, O. and Hirji, K.K. (1996), "The influence of process concurrency on project outcomes in product development: an empirical study of cross-functional teams", *IEEE Transactions on Engineering Management*, Vol. 43, No. 2, pp. 153-164.

Hayes, R.H. and Wheelwright, S.C. (1984), *Restoring our Competitive Edge: Competing Through Manufacturing*, New York, NY: John Wiley & Sons.

Hayes, R., Pisano, G., Upton, D. and Wheelwright, S. (2005), *Operations, Strategy, and Technology: Pursuing the Competitive Edge*, Hoboken, NJ: John Wiley & Sons.

Hendricks, K.B. and Singhal, V.R. (2008), "The Effect of Product Introduction Delays on Operating Performance", *Management Science*, Vol. 54, No. 5, pp. 878-892.

Hertzum, M. and Pejtersen, A.M. (2000), "The information-seeking practices of engineers: searching for documents as well as for people", *Information Processing & Management*, Vol. 36, No. 5, pp. 761-778.

Hobday, M. (1998), "Product complexity, innovation and industrial organisation", *Research Policy*, Vol. 26, No. 6, pp. 689-710.

Hobday, M. (2000), "The project-based organisation: an ideal form for managing complex products and systems?", *Research Policy*, Vol. 29, No. 7-8, pp. 871-893.

Hobday, M., Prencipe, A. and Davies, A. (2005), "Introduction", in Prencipe, A., Davies, A. and Hobday, M. (Eds.), *The Business of Systems Integration*, New York, NY: Oxford University Press, pp. 1-14.

Hoopes, D.G., Madsen, T.L. and Walker, G. (2003), "Guest editors' introduction to the special issue: why is there a resource-based view? Toward a theory of competitive heterogeneity", *Strategic Management Journal*, Vol. 24, No. 10, pp. 889-902.

Hubka, V. and Eder, W.E. (1988), *Theory of Technical Systems: A Total Concept Theory for Engineering Design*, Berlin, Germany: Springer-Verlag.

Hutcheson, P., Pearson, A.W. and Ball, D.F. (1995), "Innovation in Process Plant: A Case Study of Ethylene", *Journal of Product Innovation Management*, Vol. 12, No. 5, pp. 415-430.

Hutcheson, P., Pearson, A.W. and Ball, D.F. (1996), "Sources of technical innovation in the network of companies providing chemical process plant and equipment", *Research Policy*, Vol. 25, No. 1, pp. 25-41.

Häckner, E. (1988), "Strategic development and information use", *Scandinavian Journal of Management*, Vol. 4, No. 1-2, pp. 45-61.

Jacobs, P.F. (1996), *Stereolithography and Other RP&M Technologies: From Rapid Prototyping to Rapid Tooling*, New York, NY: ASME Press.

Johansson, A. (1999), *On Optimizing Manufacturing Systems: A User Perspective,* PhD Thesis, Chalmers University of Technology, Gothenburg, Sweden.

Johansson, B. and Nord, C. (1999), *Nyanskaffning av produktionssystem – mer än bara inköp* [in Swedish], Mölndal, Sweden: Institutet för verkstadsteknisk forskning (IVF).

Johansson, E. (2009), "Information management for materials supply systems design", *International Journal of Production Research*, Vol. 47, No. 8, pp. 2217-2229.

Kahn, K.B. (1996), "Interdepartmental Integration: A Definition with Implications for Product Development Performance", *Journal of Product Innovation Management*, Vol. 13, No. 2, pp. 137-151.

Kahn, B.K., Strong, D.M. and Wang, R.Y. (2002), "Information Quality Benchmarks: Product and Service Performance", *Communications of the ACM*, Vol. 45, No. 4, pp. 184-192.

Karlsson, C. (2009), "Researching Operations Management", in Karlsson, C. (Ed.), *Researching Operations Management*, New York, NY: Routledge, pp. 6-41.

Keen, P.G.W. and Knapp, E.M. (1996), *Every Manager's Guide to Business Processes: A Glossary of Key Terms & Concepts for Today's Business Leader*, Boston, MA: Harvard Business School Press.

Kehoe, D.F., Little, D. and Lyons, A.C., (1992), "Measuring a company IQ", *Proceedings of the Third International Conference on Factory 2000 – Competitive Performance Through Advanced Technology*, London, England, 27-29 July 1992, pp. 173-178.

Keller, K.L. and Staelin, R. (1987), "Effects of Quality and Quantity of Information on Decision Effectiveness", *Journal of Consumer Research*, Vol. 14, No. 2, pp. 200-213.

Krishnan, V. and Ulrich, K.T. (2001), "Product Development Decisions: A Review of the Literature", *Management Science*, Vol. 47, No. 1, pp. 1-21.

Lager, T. and Frishammar, J. (2010), "Equipment supplier/user collaboration in the process industries: in search of enhanced operating performance", *Journal of Manufacturing Technology Management*, Vol. 21, No. 6, pp. 698-720.

Larsson, A.C. (2006), "Interactive Research – Methods and conditions för joint analysis", in Nielsen, K.A. and Svensson, L. (Eds.), *Action and Interactive Research. Beyond Practice and Theory*, Maastricht, Netherlands: Shaker Publishing, pp. 241-258.

Lawrence, P.R. and Lorsch, J.W. (1967), "Differentiation and Integration in Complex Organizations", *Administrative Science Quarterly*, Vol. 12, No. 1, pp. 1-47.

Lawrence, P.R. and Lorsch, J.W. (1986), *Organization and Environment: Managing Differentiation and Integration*, Boston, MA: Harvard Business School Press.

Leonard-Barton, D. (1990), "A Dual Methodology for Case Studies: Synergistic Use of a Longitudinal Single Site with Replicated Multiple Sites", *Organization Science*, Vol. 1, No. 3, pp. 248-266.

Lesca, H. and Lesca, E. (1995), *Gestion de l'information: Qualité de l'information et performances de l'entreprise* [in French], Paris: Litec.

Lewis, M., Brandon-Jones, A., Slack, N. and Howard, M. (2010), "Competing through operations and supply: The role of classic and extended resource-based advantage", *International Journal of Operations & Production Management*, Vol. 30, No. 10, pp. 1032-1058.

Liker, J.K. (2004), *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, New York, NY: McGraw-Hill.

Love, D. (1996), "The Design of Manufacturing Systems", in Warner, M. (Ed.), *International Encyclopaedia of Business and Management*, Vol. 4, London, UK: Routledge, pp. 3154-3174.

Mabert, V.A., Muth, J.F. and Schmenner, R.W. (1992), "Collapsing New Product Development Times: Six Case Studies", *Journal of Product Innovation Management*, Vol. 9, No. 3, pp. 200-212.

MacGregor, S.P., Thomson, A.I. and Juster, N.P., (2001), "Information Sharing Within a Distributed, Collaborative Design Process: A Case Study", *Proceedings of ASME 2001 Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Pittsburgh, PA, USA 9-12 September, 2001.

Magrab, E.B., Gupta, S.K., McCluskey, F.P. and Sandborn, P. (2010), *Integrated Product and Process Design and Development: The Product Realization Process*, 2nd ed., Boca Raton, FL.: CRC Press.

Makadok, R. (2001), "Toward a synthesis of the resource-based and dynamic-capability views of rent creation", *Strategic Management Journal*, Vol. 22, No. 5, pp. 387-401.

Martinez, J.I. and Jarillo, J.C. (1989), "The Evolution of Research on Coordination Mechanisms in Multinational Corporations", *Journal of International Business Studies*, Vol. 20, No. 3, pp. 489-514.

Mata, F.J., Fuerst, W.L. and Barney, J.B. (1995), "Information Technology and Sustained Competitive Advantage: A Resource-Based Analysis", *MIS Quarterly*, Vol. 19, No. 4, pp. 487-505.

McCutcheon, D.M. and Meredith, J.R. (1993), "Conducting case study research in operations management", *Journal of Operations Management*, Vol. 11, No. 3, pp. 239-256.

Meredith, J. (1998), "Building operations management theory through case and field research", *Journal of Operations Management*, Vol. 16, No. 4, pp. 441-454.

Merriam, S.B. (1994), *Fallstudien som forskningsmetod* [in Swedish], Lund: Studentlitteratur.

Miles, M.B. and Huberman, A.M. (1994), *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd ed., London, UK: SAGE.

Miller, D. (1992), "Environmental Fit versus Internal Fit", *Organization Science*, Vol. 3, No. 2, pp. 159-178.

Miller, D. and Friesen, P.H. (1982), "Innovation in conservative and entrepreneurial firms: Two models of strategic momentum", *Strategic Management Journal*, Vol. 3, No. 1, pp. 1-25.

Miltenburg, J. (2005), *Manufacturing Strategy: How to Formulate and Implement a Winning Plan*, 2nd ed., New York, NY: Productivity Press.

Moenaert, R.K. and Souder, W.E. (1990), "An Information Transfer Model for Integrating Marketing and R&D Personnel in New Product Development Projects", *Journal of Product Innovation Management*, Vol. 7, No. 2, pp. 91-107.

Moenaert, R.K., De Meyer, A., Souder, W.E. and Deschoolmeester, D. (1995), "R&D/marketing communication during the fuzzy front-end", *IEEE Transactions on Engineering Management*, Vol. 42, No. 3, pp. 243-258.

Mortensen, M. and Hinds, P. (2002), "Fuzzy Teams: Boundary Disagreement in Distributed and Collocated Teams", in Hinds, P.J. and Kiesler, S. (Eds.), *Distributed work*, Cambridge, MA: MIT Press, pp. 283–308.

Olausson, D. (2009), *Facing interface challenges in complex product development,* PhD Thesis, Linköping University, Linköping, Sweden.

Olausson, D. and Magnusson, T. (2011), "Manufacturing competencies in high-tech NPD: on the impact of vertical integration and coordination", *International Journal of Manufacturing Technology and Management*, Vol. 22, No. 3, pp. 287-300.

Omar, A.R., Harding, J.A. and Popplewell, K. (1999), "Design for customer satisfaction: an information modelling approach", *Integrated Manufacturing Systems*, Vol. 10, No. 4, pp. 199-209.

O'Reilly, C.A. (1982), "Variations in Decision Makers' Use of Information Sources: The Impact of Quality and Accessibility of Information", *Academy of Management Journal*, Vol. 25, No. 4, pp. 756-771.

O'Sullivan, D. (1994), *Manufacturing Systems Redesign: Creating the Integrated Manufacturing Environment*, Englewood Cliffs, NJ: Prentice Hall PTR.

Ottum, B.D. and Moore, W.L. (1997), "The Role of Market Information in New Product Success/Failure", *Journal of Product Innovation Management*, Vol. 14, No. 4, pp. 258-273.

Pahl, G. and Beitz, W. (1996), *Engineering Design: A Systematic Approach*, 2nd ed., London: Springer Verlag.

Patel, R. and Davidson, B. (2003), *Forskningsmetodikens grunder: Att planera, genomföra och rapportera en undersökning* [in Swedish], 3rd ed., Lund: Studentlitteratur.

Peteraf, M.A. (1993), "The Cornerstones of Competitive Advantage: A Resource-Based View", *Strategic Management Journal*, Vol. 14, No. 3, pp. 179-191.

Petersson, S. and Petersson, K. (1992), *Internt: om information och kommunikation i arbetslivet* [in Swedish], Bromma, Sweden: Sakprosa.

Pettigrew, A.M. (1990), "Longitudinal Field Research on Change: Theory and Practice", *Organization Science*, Vol. 1, No. 3, pp. 267-292.

Pisano, G.P. (1997), *The Development Factory: Unlocking the Potential of Process Innovation*, Boston, MA: Harvard Business School Press.

Powell, T.C. and Dent-Micallef, A. (1997), "Information technology as competitive advantage: The role of human, business, and technology resources", *Strategic Management Journal*, Vol. 18, No. 5, pp. 375-405.

Rauterberg, M. and Ulich, E., (1996), "Information processing for learning systems: an action theoretical approach", in *Information, Intelligence and Systems, Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics*, Beijing, China, 14-17 October 1996, pp. 2276-2281.

Reichstein, T. and Salter, A. (2006), "Investigating the sources of process innovation among UK manufacturing firms", *Industrial and Corporate Change*, Vol. 15, No. 4, pp. 653-682.

Richtnér, A. (2004), *Balancing Knowledge Creation: Examining Organizational Slack and Knowledge Creation in Product Development,* PhD Thesis, Stockholm School of Economics, Stockholm, Sweden.

Robson, C. (2002), *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*, 2nd ed., Oxford, UK: Blackwell Publishers.

Roozenburg, N.F.M. and Eekels, J. (1995), *Product Design: Fundamentals and Methods*, Chichester, UK: John Wiley & Sons.

Ruekert, R.W. and Walker, O.C. (1987), "Marketing's Interaction with Other Functional Units: A Conceptual Framework and Empirical Evidence", *The Journal of Marketing*, Vol. 51, No. 1, pp. 1-19.

Ruffini, F.A.J. (1999), *Production system design. From practice to theory,* PhD Thesis, University of Twente, Enschede, Netherlands.

Ruffini, F.A.J., Boer, H. and van Riemsdijk, M.J. (2000), "Organisation design in operations management", *International Journal of Operations & Production Management*, Vol. 20, No. 7, pp. 860-879.

Rönnberg Sjödin, D. and Eriksson, P.E. (2010), "Procurement Procedures for Supplier Integration and Open Innovation in Mature Industries", *International Journal of Innovation Management*, Vol. 14, No. 4, pp. 655-682.

Säfsten, K. (2002), *Evaluation of assembly systems: An exploratory study of evaluation situations,* PhD Thesis, Linköping University, Linköping, Sweden.

Säfsten, K., Harlin, U., Fjällström, S. and Berglund, M., (2008), "Proactive and Reactive Ways of Managing Product Introduction", *Proceedings of the 2nd Swedish Production Symposium*, Stockholm, 18-20 November 2008.

Sandkull, B. and Johansson, J. (1996), *Från Taylor till Toyota* [in Swedish], Lund: Studentlitteratur.

Sawyerr, O.O., Ebrahimi, B.P. and Thibodeaux, M.S. (2000), "Executive Environmental Scanning, Information Source Utilisation, and Firm Performance: The case of Nigeria", *Journal of Applied Management Studies*, Vol. 9, No. 1, pp. 95-115.

Schuh, G., Lenders, M., Nussbaum, C. and Kupke, D. (2009), "Design for Changeability", in ElMaraghy, H.A. (Ed.), *Changeable and Reconfigurable Manufacturing Systems*, London, UK: Springer-Verlag, pp. 251-266.

Shrivastava, P. (1985), "Knowledge Systems for Strategic Decision Making", *Journal of Applied Behavioral Science*, Vol. 21, No. 1, pp. 95-107.

Sivadas, E. and Dwyer, F.R. (2000), "An Examination of Organizational Factors Influencing New Product Success in Internal and Alliance-Based Processes", *The Journal of Marketing*, Vol. 64, No. 1, pp. 31-49.

Skinner, W. (1969), "Manufacturing – Missing Link in Corporate Strategy", *Harvard Business Review*, Vol. 47, No. 3, pp. 136-145.

Skinner, W. (1992), "The shareholder's delight: companies that achieve competitive advantage from process innovation", *International Journal of Technology Management*, Vol. 7, No. 1/2/3, pp. 41-48.
Slack, N. (1987), "The Flexibility of Manufacturing Systems", *International Journal of Operations & Production Management*, Vol. 7, No. 4, pp. 35-45.
Slack, N. (2000), "Flexibility, trade-offs and learning in manufacturing system design", *International Journal of Manufacturing Technology and Management*, Vol. 1, No. 4/5, pp. 331-348.
Slack, N. and Lewis, M. (2008), *Operations strategy*, 2nd ed., Harlow, UK: FT Prentice Hall.
Slack, N., Chambers, S., Harland, C.M., Harrison, A. and Johnston, R. (1998), *Operations Management*, 2nd ed., London, UK: Pitman.
Smith, P.G. and Reinertsen, D.G. (1998), *Developing Products in Half the Time: New Rules, New Tools*, New York, NY: Van Nostrand Reinhold.
Souder, W.E. (1988), "Managing Relations between R&D and Marketing in New Product Development Projects", *Journal of Product Innovation Management*, Vol. 5, No. 1, pp. 6-19.
Stalk Jr., G. and Hout, T.M. (2003), *Competing Against Time: How Time-based Competition is Reshaping Global Markets*, New York, NY: Free Press.
Strong, D.M., Lee, Y.W. and Wang, R.Y. (1997), "10 Potholes in the Road to Information Quality", *Computer*, Vol. 30, No. 8, pp. 38-46.
Svensson, L. and Nielsen, K.A. (2006), "Introduction and Background", in Nielsen, K.A. and Svensson, L. (Eds.), *Action and Interactive Research: Beyond Practice and Theory*, Maastricht, Netherlands: Shaker Publishing, pp. 1-12.
Tanner, K. (2002), "Survey research", in Williamson, K. (Ed.), *Research methods for students, academics and professionals: Information management and systems*, 2nd ed, Wagga Wagga, NSW, Australia: Centre for Information Studies, pp. 89-109.
Teece, D.J., Pisano, G. and Shuen, A. (1997), "Dynamic capabilities and strategic management", *Strategic Management Journal*, Vol. 18, No. 7, pp. 509-533.
Terwiesch, C., Loch, C.H. and De Meyer, A. (2002), "Exchanging Preliminary Information in Concurrent Engineering: Alternative Coordination Strategies", *Organization Science*, Vol. 13, No. 4, pp. 402-419.
Thisse, L.C. (1998), "Advanced Quality Planning: A Guide for Any Organization", *Quality Progress*, Vol. 31, No. 2, pp. 73-77.
Thomke, S. and Fujimoto, T. (2000), "The Effect of 'Front-Loading' Problem-Solving on Product Development Performance", *Journal of Product Innovation Management*, Vol. 17, No. 2, pp. 128-142.
Thompson, J.D. (1967), *Organizations in Action: Social Science Bases of Administrative Theory*, New York, NY: McGraw-Hill.
Trott, P. (2008), *Innovation Management and New Product Development*, 4th ed., Harlow, UK: FT Prentice Hall.
Turkulainen, V. (2008), *Managing Cross-Functional Interdependencies – The Contingent Value of Integration,* PhD Thesis, Helsinki University of Technology, Helsinki, Finnland.
Tushman, M.L. and Scanlan, T.J. (1981), "Boundary Spanning Individuals: Their Role in Information Transfer and Their Antecedents", *Academy of Management Journal*, Vol. 24, No. 2, pp. 289-305.

Twigg, D. (2002), "Managing the design/manufacturing interface across firms", *Integrated Manufacturing Systems*, Vol. 13, No. 4, pp. 212-221.

Ulrich, K.T. and Eppinger, S.D. (2007), *Product Design and Development*, 4th ed., New York, NY: McGraw-Hill.

Utterback, J.M. (1994), *Mastering the Dynamics of Innovation*, Boston, MA: Harvard Business School Press.

Van de Ven, A.H. and Drazin, R. (1985), "The concept of fit in contingency theory", *Research in Organizational Behavior*, Vol. 7, No. 3, pp. 333-365.

Vandevelde, A. and Van Dierdonck, R. (2003), "Managing the design-manufacturing interface", *International Journal of Operations & Production Management*, Vol. 23, No. 11, pp. 1326-1348.

Vincent, A. and Ross, D. (2001), "Personalize training: determine learning styles, personality types and multiple intelligences online", *The Learning Organization*, Vol. 8, No. 1, pp. 36-43.

Von Haartman, R. and Bengtsson, L. (2009), "Manufacturing competence: a key to successful supplier integration", *International Journal of Manufacturing Technology and Management*, Vol. 16, No. 3, pp. 283-299.

Von Weizsäcker, E.U. (1974), "Erstmaligkeit und Bestätigung als Komponenten der pragmatischen Information", in von Weizsäcker, E.U. (Ed.), *Offene Systeme I: Beiträge zur Zeitstruktur von Information, Entropie und Evolution* [in German], Stuttgart, Germany: Ernst Klett Verlag, pp. 82-113.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002), "Case research in operations management", *International Journal of Operations & Production Management*, Vol. 22, No. 2, pp. 195-219.

Weick, K.E. (1969), *The Social Psychology of Organizing*, Reading, MA: Addison-Wesley.

Weick, K.E. (1995), *Sensemaking in Organizations*, Thousand Oaks, CA: SAGE.

Wheelwright, S.C. and Clark, K.B. (1992), *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality*, New York, NY: Free Press.

Wiendahl, H.P., ElMaraghy, H.A., Nyhuis, P., Zäh, M.F., Duffie, N. and Brieke, M. (2007), "Changeable Manufacturing – Classification, Design and Operation", *CIRP Annals – Manufacturing Technology*, Vol. 56, No. 2, pp. 783-809.

Wigren, C. and Brundin, E. (2008), "Interaktiv fältforskning – möjligheter och omöjligheter", in Johannisson, B., Gunnarsson, E. and Stjernberg, T. (Eds.), *Gemensamt kunskapande – den interaktiva forskningens praktik* [in Swedish], Växjö: Växjö University Press, pp. 95-114.

Wu, B. (1994), *Manufacturing Systems Design and Analysis: Context and techniques*, 2nd ed., London, UK: Chapman & Hall.

Yin, R.K. (2009), *Case Study Research: Design and Methods*, 4th ed., Thousand Oaks, CA: SAGE.

Zahay, D., Griffin, A. and Fredericks, E. (2004), "Sources, uses, and forms of data in the new product development process", *Industrial Marketing Management*, Vol. 33, No. 7, pp. 657-666.

Zahay, D., Griffin, A. and Fredericks, E. (2011), "Information Use in New Product Development: An Initial Exploratory Empirical Investigation in the Chemical Industry", *Journal of Product Innovation Management*, Vol. 28, No. 4, pp. 485-502.