With increasing competition in the market, new product development (NPD) has gained more importance for many industries. The viability of manufacturing companies is determined by the success or failure of their products; thus, companies try to be more innovative while streamlining their processes in order to remain competitive. New products should demonstrate superiority in design and performance. Moreover, they must be released to the market at the right time, at a reasonable price, and with a high level of quality. Manufacturing has a determining role in achieving delivery, cost, and quality targets. Early manufacturing involvement in NPD plays a significant role in achieving manufacturability and reducing costs.

The point of departure in the performed studies was that the reason for manufacturing involvement in NPD projects is to ensure transfer of manufacturing requirements between manufacturing and design functions. Thus, the objective of this thesis is to investigate practices used for manufacturing involvement in the early stages of the NPD process in order to understand how they support management of manufacturing requirements.

To fulfill the objective of the thesis, two case studies were conducted—a single-case and a multiple-case study. The studies included three NPD projects in two manufacturing companies. The aim of the studies was to investigate how manufacturing requirements were managed and communicated to product design teams in early-stage NPD; moreover, what manufacturing requirements were raised was also investigated. The findings revealed that requirements which were raised comprised three clusters: requirements on the physical properties of the parts, requirements from the assembly process perspective, and requirements from the material handling perspective. Further, mechanisms utilized in managing the requirements were identified as various risk analyses (e.g., SWOT and FMEA), DFA guidelines, ergonomics checklist, simulation and CAD tools, design reviews, digital/physical test assemblies, and discussions during meetings. Further, these mechanisms were analyzed to define how they supported the management of manufacturing requirements. The analysis indicated that the mechanisms could be used to support the management of requirements in three ways: to elicit the requirements, to inform them, or to evaluate and assess their fulfillment. This research suggests that the manufacturing function should first work toward identifying their requirements and then focus on communicating and following up the requirements using appropriate mechanisms. In other words, to improve the manufacturability aspects and outcomes of manufacturing involvement, manufacturing requirements should be incorporated effectively and efficiently in an NPD project.
PRACTICES FOR MANUFACTURING INVOLVEMENT IN NEW PRODUCT DEVELOPMENT

A STUDY WITH ASSEMBLY REQUIREMENTS IN FOCUS

Mariam Nafisi

2018

School of Innovation, Design and Engineering
Abstract

With increasing competition in the market, new product development (NPD) has gained more importance for many industries. The viability of manufacturing companies is determined by the success or failure of their products; thus, companies try to be more innovative while streamlining their processes in order to remain competitive. New products should demonstrate superiority in design and performance. Moreover, they must be released to the market at the right time, at a reasonable price, and with a high level of quality. Manufacturing has a determining role in achieving delivery, cost, and quality targets. Early manufacturing involvement in NPD plays a significant role in achieving manufacturability and reducing costs.

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This research suggests that the manufacturing function should first work toward identifying their requirements and then focus on communicating and following up the requirements using appropriate mechanisms. In other words, to improve the manufacturability aspects and outcomes of manufacturing involvement, manufacturing requirements should be incorporated effectively and efficiently in an NPD project.

**Keywords:** New product development (NPD), design-manufacturing interface, manufacturing involvement
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Mariam Nafisi
Stockholm, May 2018
Preface

This chapter is intended to provide a brief background for why I selected this particular research area for the thesis you will be soon reading.

I began developing an interest in manufacturing involvement in NPD sometime in 2013. I worked at a cab production plant as my first job after graduation. I belonged to an organisation that was responsible for industrialisation of a new cab generation in the assembly shop. One of the new parts that would be assembled in the cab was the roof hatch. Based on customer wishes and safety measures, it was decided earlier that the new roof hatch shall be larger to allow for more light and also serve as an emergency exit in case the cab would roll over. Based on the production target, the new roof hatch was planned to be lighter and take less time to assemble. When I got involved in the project, the product was designed almost completely and we were preparing the assembly system for the start of production. To the surprise of the assembly operators, roof hatch assembly included fastening 16 screws as opposed to the 4 screws for the previous design.

Manufacturing had indeed been involved in the project and had provided their viewpoints, in the form of various risk analyses such as SWOT and FMEA; thus, the design came as a surprise. The problem with the design was that it could negatively impact the assembly time (due to the number of screws) and ergonomics (due to weight). The ergonomics problem could be tackled by investing in some lifting equipment by the assembly line and material handling area. However, this led to prolonged assembly time for handling the part with the lifting equipment. The assembly could not be finished within the takt time in one assembly station and, thus, had to be spread over two stations. This could potentially increase quality risks in case more than one operator would perform the assembly task.

This was one of hundreds of parts that the mentioned industrialisation project had to take care of. Yet, the instances in which the final design is not favoured by manufacturing is not limited to this project or company. The point in describing the event is not to criticise or find fault- especially that the new design was favoured by the final customers- but to reflect the industrial challenges in NPD projects and occurrence of designs that are not optimal for manufacturing despite the efforts made. There are various aspects and requirements to be considered in the development of a new product, thus, a holistic view and coordination are needed in order to improve the project results.
Publications

The conducted research resulted in three publications, which are appended in the thesis and serve as the foundation of this thesis.

Paper A


*Nafisi conducted the study and was the main author and presenter of the paper. Wiktorsson and Rösiö participated in the discussions, writing, review, and quality assurance of the paper.*

Paper B


*Nafisi and Wiktorsson conducted the study. Nafisi was the main author of the paper and presented it. Wiktorsson participated in discussions, writing, review, and quality assurance of the paper.*

Paper C (Accepted)


*Nafisi and Wiktorsson conducted the study. Nafisi was the main author, while Wiktorsson, Rösiö and Granlund participated in discussion, reviewing and quality assurance of the paper.*

Additional publications not included in this thesis:

Abbreviations

CAD  Computer-aided design
CAM  Computer-aided manufacturing
CD   Concept development
CE   Concurrent engineering
DFA  Design for assembly
DFM  Design for manufacturing
DTA  Digital test assembly
FMEA Failure modes and effects analysis
IPD  Integrated product development
MBD  Model-based definition
MBE  Model-based enterprise
MBM  Model-based manufacturing
NPD  New product development
PLM  Product lifecycle management
PTA  Physical test assembly
QFD  Quality function deployment
RE   Requirements engineering
RQ   Research question
SWOT Strength, weakness, opportunity, threat
Term definitions

**Assembly constraint:** A restriction in the order of execution of assembly tasks, resulting from geometric interference, instability, etc. (C.I.R.P., 2012).

**Assembly:** The action of bringing individual parts into a subunit, a unit, or a product. Assembly also includes the subsidiary functions of materials handling, adjusting, and inspection of the parts or final product. The result of carrying out assembly is a part, unit or group of parts which is also commonly called an assembly (C.I.R.P., 2012).

**Design for assembly:** Analysis of products that results in simplified product designs that are easier and less costly to assemble, particularly by attempting to reduce the number of parts (C.I.R.P., 2012).

**Failure modes and effects analysis:** A method of (preventive) reliability analysis intended to identify potential problems, that is, failure modes for components, processes, or systems and to trace their effects on other components, processes, and systems within the application considered (C.I.R.P., 2004).

**Function:** 1) What an element of a product or human does in order to contribute to a certain purpose. 2) A defined entity of an organisation carrying out work with a specific purpose (Adamsson, 2007).

**Functionality:** Suitability of a unit for meeting a required function under given application conditions (C.I.R.P., 2012).

**Integrated product development:** A product development approach where the requirements from the areas constitutive of the product lifecycle such as design, manufacturing, maintenance, disposal etc. are considered, weighed, discussed, and balanced at the conceptual phase of the product development process (Pessôa and Trabasso, 2016).

**Involvement:** Participation in a jointly produced social, civic, or community activity. Involvement requires a person to participate and interact with others (Katz and Rice, 2002).

**Manufacturing:** Includes operations and steps needed to make a product from raw material to the finished product (Groover, 2001). In this thesis, manufacturing includes both processing (e.g., machining) and assembly operations.

**Part assemblability:** Property of a part of subassembly governing the ease with which it can be integrated to the product.

**Product:** Item resulting from an activity, operation, or process, particularly from a manufacturing process.

**Product development process:** Also referred to as new product development process, is “the sequence of steps or activities that an enterprise employs to conceive, design, and commercialise a product” (Ulrich and Eppinger, 2012, p. 12).
Production system: The production system is the collection of people, equipment, and procedures organised to accomplish the manufacturing operations of a company (Groover, 2001).

Quality function deployment: A structured method employing matrix analysis for linking what the market requires to how it will be accomplished in the development effort. This method involves a multifunctional team agreeing on how customer needs relate to product specifications and the features that meet those needs (Kahn et al., 2005).

SWOT analysis: A formal review of the internal strengths and weakness and the external opportunity and threats. It provides a model to evaluate a strategy (Heizer and Render, 2011).

Requirement: A need or expectation that is stated, generally implied or obligatory (International Organisation for Standardisation, 2015).
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1. Introduction

This chapter presents some background on the research area of new product development and the product design-manufacturing interface. It also clarifies the motivation underlying the current research. Furthermore, it contains the research objective and questions that are addressed. At the end of this chapter, the scope and limitations are explained.

1.1. Background

Manufacturing companies face challenges to be competitive and remain in the market. The intense competition can be contributed to market saturation, increasing demands for a customer-oriented production, economic crisis, etc. (Feldmann et al., 1996; Khan et al., 2013; Surbier et al., 2014). The viability of a manufacturing company is impacted by the success or failure of its products (Cooper, 2001; Whitney, 1995). To be successful in the market, new products should demonstrate superiority in design and performance. Moreover, they must be released to the market at the right time, at a reasonable price, and have a high level of quality (Koren, 2010; Wiesner et al., 2015).

New product development (NPD) is important for manufacturing companies (Tuli and Shankar, 2015) and is a core process for many of them (Johansson et al., 2016). The NPD process includes steps that are necessary from the idea to the complete product ready to be released to the market. It is a process in which technology is incorporated into new product concepts that are designed to fit certain manufacturing systems (Adler, 1995).

The success of a new product is, to a large extent, determined by the success and efficiency of the NPD process (Cooper, 1988), which reflects in the fact that the NPD process has received a lot of attention in the industry as well as in research. Even so, many new products fail in the marketplace due to various reasons. Based on earlier research investigations, Cooper (1988) elucidates that success factors which distinguish winners from losers in the market include deep understanding of customer needs, a unique superior product, an attractive market, top management support, good internal and external communications, and a well-planned and well-coordinated NPD process. Furthermore, Cooper (1988) argues that a majority of these success factors are determined early in the NPD process; hence, the early stages in NPD are vital in the outcome of the process. In his definition, early stages include idea generation activities, product definition and a project evaluation to decide whether or not the company should continue with NPD efforts.

The automotive industry, similar to many other industries, faces fierce competition. New product generations are designed and introduced continually, while smaller
NPD projects run in parallel to improve, for example, the quality of existing products. Automotive products are often complex, and production volumes are often high. In large companies and large introductions, NPD projects continue for several years and involve hundreds of personnel from different functions in the company. Design teams are responsible for designing the new product, which influences efficiency of manufacturing and sales strategies as well as product maintenance and serviceability among others (Clark and Wheelwright, 1995). They have to balance numerous, occasionally conflicting, requirements set by law, sales/marketing, customers, or the manufacturing system.

Since the ultimate goal of NPD is satisfying customers, criteria such as product quality, functionality, price, and delivery become important. To safeguard that these criteria are fulfilled, several paradigms have been introduced. For example, concurrent engineering (CE) was introduced as an alternative to the sequential NPD and was an effective tool to shorten the development time (Loch and Terwiesch, 1998; Shahin and Rostamian, 2013; Stahl et al., 1997). Other disciplines such as design for assembly (DFA) were introduced to make products a better fit for assembly (Boothroyd et al., 2010), leading to products with higher quality and lower costs.

1.2. Research motivation

In the automotive industry, many times, new product generations are introduced to an existing manufacturing system, since acquiring a completely new system for the new product requires large investments. In such scenarios, a two-way communication between product design and manufacturing functions is critical to ensure that new products meet the needs of the manufacturing system. The manufacturing function possesses what Langowitz (1989) calls a “repertoire of skills,” which is in fact its experience with previous products. Manufacturing should provide input to design teams in terms of what historically works well in the manufacturing system and what manufacturing constraints and capabilities exist. Moreover, it should provide feedback on the design and throughout the entire NPD process. In theory, working in this manner, companies overcome the infamous wall between design and manufacturing. However, in practice, it might not be so straightforward since involvement in the NPD has various dimensions and challenges connected to the inherent complexity of the NPD project.

The NPD process is knowledge-intensive, influenced by many factors, and affects many actors in the organisation (Eriksson, 2009). It is a complex process (Sommer et al., 2015) and requires extensive collaboration and integration within the organisation to secure success. In order to communicate requirements, project teams for the development of new products comprise individuals from different departments to ensure that relevant stakeholders are involved in the NPD process.
The importance of involving stakeholders has been mentioned in several studies (Ettlie, 1995; Koufteros et al., 2001). Early stakeholder involvement has been particularly emphasised, since it enables decision-makers to take a wide range of inputs and requirement into account before irreversible commitments are made (Bunduchi, 2008; Vandevelde and Van Dierdonck, 2003). It is believed that a high proportion of final product cost, in fact over 70%, is determined during the design (Boothroyd et al., 2010; Swink, 1999). Hence, consideration of manufacturing early in the NPD process can provide substantial cost-saving opportunities to companies. Companies realise that no single individual can possess knowledge about all processes involved for manufacturing; hence, they seek ways to enrich product design decisions to include manufacturing aspects (Whitney, 2004). Working in cross-functional teams is a means to involve various stakeholders and enable them to express their concerns and provide their inputs (Koufteros et al., 2001). Manufacturability is said be improved through cross-functional involvement, thereby leading to shorter manufacturing lead times, premium pricing, and better quality (Fleischer and Liker, 1992; Whitney, 1995).

Some researchers such as Gerwin and Susman (1996) raise the question regarding which stakeholders should be involved and what role they should play. Early involvement of a company’s internal and external stakeholders has proved to lead to shorter development times, better product innovation capabilities, lower coordination costs, and improved quality (Fleischer and Liker, 1992; Koufteros et al., 2001). Manufacturing involvement in early stages of NPD appears to have been less researched, particularly “how” involvement should be realised. Empirically-based studies reporting on implemented practices are scarce, revealing the underlying challenges with manufacturing involvement during NPD and what requirements are raised during such involvement. Thus, there is a need to increase the understanding of how manufacturing is involved in the early stages of NPD and collaborates with the design teams.

The studies in this thesis have focused on the manual assembly context. Assembly is an important part of the overall manufacturing process and constitutes a large proportion of production time (Andreasen et al., 1988) and cost (Booker et al., 2005). In vehicle manufacturing, a major proportion of assembly processes are done manually. Manual assembly is important as it involves human beings. The product design, and the respective assembly system design impacts individuals who perform the assembly.

1.3. Research objective and questions

The overall objective of this licentiate thesis is to investigate practices for manufacturing involvement in early stages of the NPD process. It also aims to understand how these practices can help ensure that product design is suitable for manufacturing requirements.
The point of departure in this thesis is that manufacturing involvement serves the purpose of communicating manufacturing requirements and important aspects to design teams. Therefore, it is of interest to explore manufacturing involvement from a requirements perspective. Hence, this thesis takes an explorative perspective on the subject, investigating the “how’s” and “what’s” of manufacturing involvement in NPD, focusing on assembly.

The following research questions can be formulated to achieve the research objective:

**RQ1: How are assembly requirements managed and communicated to the product design teams in the early stages of the NPD process?**

This question deals with interactions and collaboration between assembly function and product design teams in the early stages of NPD, focusing on practices that are used for this purpose.

**RQ2: What assembly requirements are raised in the early stages of the NPD process?**

This question aims to investigate the assembly requirements that are considered in the early stages of the NPD process.

### 1.4. Scope and limitations

The context of this research is the NPD process in manufacturing industry, with a focus on manual assembly. The emphasis is on early stages of the NPD process, which translates to “concept design” and “system-level design” stages in the Ulrich and Eppinger (2012) model.

The empirical base in this thesis is from two vehicle manufacturing companies with a long tradition of research and development as well as manufacturing.

### 1.5. Thesis outline

This thesis consists of six chapters. The first chapter lays the background to the research area and clarifies the research gap, objective, and questions. The remainder of the thesis is arranged in the following order:

- “Research methodology” presents how the studies have been designed and conducted.
- “Frame of reference” presents the state of the art in the research area.
- “Summary of the papers” presents highlights from the three appended papers.
- “Discussions” addresses the empirical findings of the studies in relation to the frame of reference and the research questions.
- Finally, the closing chapter, “Conclusions and future research” draws some conclusions from the research, provides insights on the contributions of this thesis, and lays grounds for the future work.

The three contributing publications are appended at the end of the thesis.
2. Research methodology

This chapter details the research method utilised to conduct the research. It includes the description of the research process, research design, and tools and techniques for collection of data. In conclusion, quality aspects of the research are addressed in this chapter.

2.1. Research process

The context of this research is the automotive manufacturing industry with a particular focus on the heavy automotive industry. Since early 2015, the author of this thesis is employed as an industrial PhD student at a manufacturer of heavy vehicles with a long and successful history. Before assuming this role, the author worked as a production engineer in production development stage for introduction of a new product generation. The very first idea of this research topic originated from the practical problems that were witnessed during the production development activities in the project. This project, although not included in this thesis as a case, was prominent in understanding the industrial challenges and in defining the focus of this research. Subsequently, after assuming the role of an industrial PhD student, the author met various key individuals (14 persons) at several production units of the company with substantial technical or managerial experience in order to investigate strategic challenges within the area of manufacturing involvement in NPD and specify the research areas. Throughout the course of research the author participated (as an observant) in various workshops related to the subject of this thesis. Apart from that, two studies were conducted which constitute the empirical basis of this thesis. Searching the literature was an underlying activity throughout the entire research process. Figure 2.1 below presents the timeline of the studies and the research process.

![Figure 2.1. The timeline of the research process.](image)

The beginning of the research process was a mix of literature reviews and interviews at the company’s production units, mostly with personnel who were, in one way or another, involved in the NPD process. The empirical findings together with the
reviewed literature served as a means to clear the scope and define the focus of the research through an increased understanding of the academic gap as well as the industrial challenges. Following this step, two empirical studies were conducted, which are described in detail in the following subchapter.

2.2. Research design and strategy

Considering the objective of this thesis and the research questions indicates that the research is descriptive. It attempts to explore and explain the phenomenon of “manufacturing involvement in NPD” for a better integration of requirements in the product design. Thus, an abductive research approach has been used. The abductive approach involves systematically combining theoretical and empirical findings to generate new theory (Dubois and Gadde, 1999). In this approach, the researcher “collects data to explore a phenomenon, identify themes and explain patterns, to generate a new or modify an existing theory, which is subsequently tested” (Saunders et al., 2012, p. 145). The choice of research approach influences the research design. Qualitative research design works well with the abductive approach and allows the researcher to examine the relationships among various entities. Consequently, qualitative research design was selected to be able to examine the relationship among the entities involved in NPD projects.

The research method selected to answer the research questions is case study. Case study is a powerful research method when deep understanding about a phenomenon is sought. Yin (2014) defined it is an empirical enquiry that investigates a contemporary phenomenon within its real-life context, particularly when the boundaries between phenomenon and context are not evident. Yin (2014) states that there are three conditions which should be considered when choosing the research method: the type of research question, the extent of control the researcher has over events, and the degree of focus on contemporary versus historical events, as seen below in Table 2.1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Form of research question</th>
<th>Requires control of events?</th>
<th>Focuses on contemporary events?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case study</td>
<td>How, Why</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2.1. Case study as a research method and its corresponding conditions (Yin, 2014).

Case study is suitable for “how” and “why” type of research questions, where the focus is on contemporary events with no requirement to control events. The context and research questions are in agreement with these criteria; hence, case study was considered to be appropriate.
2.3. Case description: Study I

The first empirical study, a single-case study, was the study of an NPD project at company A, which is a leading global manufacturer of heavy vehicles. Two reasons contributed to the choice of this specific project:

The criteria for choosing the project at the company was that the project group and assembly team had to be accessible, so the geographic distance to the researcher was a factor to be considered. Second, the project had to be preferably in the system-design or detail design stage to be able to collect fresh data pertaining to the previous stages of the project. After screening projects according to these criteria, one NPD project was chosen for study. The project was significant as the product was new for the company and did not exist in the product portfolio earlier. At the time of the study, the project was in the detail design stage, which made it possible to study the project in its contemporary context and have access to the archival documents as well as to individuals who had previously been involved in the earlier stages of the project. At the time of the study, the design of the components and parts were almost finalised and the assembly system was being modified to be ready for the initiation of production.

The study was conducted over a four-month period. The unit of analysis was the interactions between manufacturing and design functions, as seen in Figure 2.2. Data collection was done through semi-structured interviews and observations during meetings and work sessions. Company documents pertinent to the project were also utilised as a third source of data.

The study led to identification of functions and methods that the company used in the project to include the assembly department in the NPD process. Based on the result of the study, some challenges in manufacturing involvement were identified as well.

![Figure 2.2. Unit of analysis in study I.](image)

The result is presented in appended paper A. Table 2.2 provides a summary of this study.
2.4. Case description: Study II

The second empirical study was a multiple-case embedded study, which was conducted over a period of nine months. In addition to company A, company B was also part of the study. Company B is a global manufacturer of automobiles. Two NPD projects, one at each company, were selected and studied. The selection of the cases was based on purposive sampling in which the cases were selected on the basis of the expectation to show homogeneity. The focus of the study was on the concept development stage of the NPD projects.

Case description at company A

At the time of the study, an NPD project was in the concept design stage. This project aimed at developing an exhaust component that would be introduced to the final chassis assembly in a later stage. The project was significant for the company because the component did not have any previous equivalent in the product or production range. The project team was cross-functional and comprised design engineers, project managers and production engineers as well as service and maintenance representatives. Project members met once a week cross-functionally to discuss the product concept and the progress made in the design work. Thereafter,
the concept was presented to the project steering group for a Go/No-go decision. The specific focus of this study was to determine how the manufacturing personnel were involved in the early stages of the project and what kind of input and feedback they provided to the project team.

**Case description at company B**

In case study B, the concept development (CD) stage of an NPD project was studied. The project involved the development and introduction of an engine component previously purchased from a supplier. The production of the component entailed two sets of processes: (1) machining of the parts constituting the component and (2) assembly of the parts to achieve the final component. Therefore, machining and assembly workshops had to be in close contact with design teams in this NPD project. Various functions were involved in the project, such as design, manufacturing, sales and marketing, purchasing, and quality assurance.

The focus of study II was twofold. Firstly, it set out to highlight the assembly system requirements that were important to be communicated in the concept development stage. Secondly, it focused on the communication and collaboration aspect of the requirement between assembly and product design functions. The study was intended to answer both RQ1 and RQ2.

Figure 2.3 depicts the units of analysis in the study.

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**Figure 2.3. Units of analysis in study II.**
A brief summary of study II is presented in Table 2.3.

Table 2.3. An overview of study II.

<table>
<thead>
<tr>
<th>Study II</th>
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<tr>
<td><strong>Reported in</strong></td>
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<td><strong>RQ addressed</strong></td>
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<tr>
<td><strong>Design</strong></td>
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<tr>
<td><strong>Units of analysis</strong></td>
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<tr>
<td><strong>Means for data collection</strong></td>
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<tr>
<td><strong>Data collection period</strong></td>
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<tr>
<td><strong>No of interviews</strong></td>
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<td><strong>Roles of interviewees</strong></td>
</tr>
<tr>
<td><strong>Company</strong></td>
</tr>
<tr>
<td><strong>Operations</strong></td>
</tr>
<tr>
<td><strong>Products</strong></td>
</tr>
</tbody>
</table>

2.5. Data collection tools

The choice of data collection tools is determined by the research method employed (Blessing and Chakrabarti, 2009). In case study research, interviews are, in many cases, the primary data collection tool. Triangulation is an underlying principle in data collection in case research (Karlsson, 2010), which entails using different methods to study the same phenomenon and helps increase the validity of the research. Therefore, during the studies conducted in this thesis, interviews, observation and documentations were used to collect data to study and understand the phenomenon. In the following subchapters, these tools are explained in more detail.

2.5.1. Interviews

To understand the topic of communication and cooperation during the NPD project, it was considered most effective to utilise individuals who were involved in the
project as the main source of data. Merriam (1994) recommends that in order to choose interview as the main data collection tool, the researcher must consider the type of information that is needed and check if interviews are the best way to collect that information. Similarly, Dexter (2006) proposes the following as the criteria for choosing interviews: “Interviewing is the preferred tactic for data collection when it appears likely that it will get bette r data or more data or data at less cost than other tactics” (Dexter, 2006, p. 23). Since NPD is a complex activity, includes collaborations, and has various dimensions, it is critical to have rich data to study and understand it. Interviews were considered to provide rich and multifaceted data; hence, it was chosen as the main data collection tool.

As suggested by Yin (2014), a protocol was developed to increase the reliability and validity of the research. Interviews were designed as semi-structured and allowed interaction during the course of the interview. The interviews were recorded (upon permission from the interviewees) and transcribed.

In case study I, a total of eight interviews were conducted with persons that have been involved in the project. The interviewees had the following roles: Project leader in manufacturing, project leader in the product design team, and manufacturing engineers. An interview guide was developed and used. Questioned covered a wide range of areas and were grouped into five categories: 1) Project management, composition of the project team and meetings, 2) newness of the product and its impact on manufacturing process, 3) requirements from manufacturing function, and how they were formulated and collected, 4) communication and evaluation of the developed product concept, and 5) miscellaneous experiences during the project. The interviews lasted between 30 and 62 minutes.

In the case study II, nine semi-structured interviews were conducted in company A and another global company referred to as company B here. The interviewees had the following roles: Design engineer, project leader in the product design team, product layout engineer, product introduction engineer, technology project manager, and product preparator. The previous interview guide was complemented with further questions focusing on the requirements which were raised in the concept development stage. Moreover, an additional category of questions was directed towards product design function, focusing on their way of working, communication with manufacturing and handling of their requirements. The length of the interviews varied between 40 and 120 minutes.

2.5.2. Observations
Observations together with documents (explained later on) provided further data. Being employed at company A, the author of this thesis had the possibility of following the course of the project closely by observing ongoing activities. These activities included meetings, workshops, risk assessment activities, and digital and physical test assemblies. Observations enabled the author to understand the dynamic
of interactions between different persons and functions. The observations can be classified as passive, since the author was not a project member and did not have any role or responsibilities in the NPD project and, hence, could maintain some detachment and remain objective. In contrast, at company B, there was no possibility to be observing work meetings, etc.; therefore project and company documents were utilised as supplementary data.

2.5.3. Documents
Company documents have been an important part the data for the case studies. At company A, various types of documents were utilised, including company guidelines and checklists, assignment directives, project goal documents, results of performed FMEA and SWOT analyses, minutes of meetings, notes from design review sessions, email correspondence, etc. At company B, the documents provided by the company and utilised included guidelines, processes, and standards.

2.6. Data analysis
The data analysis was conducted in two steps. The first one was preparing and initial processing of the empirical data and material obtained in the studies. Next, the data was further explored to identify patterns and concepts and draw conclusions to answer research questions.

The data analysis was an ongoing process of each study and began at the same time as the data collection was being conducted. As the first step in analysis, recorded interviews were transcribed verbatim by the author as soon as possible after each interview. Furthermore, field notes that were collected throughout miscellaneous meetings, workshops, and observations were rewritten and compiled.

The starting point of the second step of analysis was what Yin (2014) calls “playing” with the data to find patterns or concepts that were promising. To do this, matrices were developed on the basis of interview questions, where the responses and evidence were placed. Responses were summarised and key points were derived. This was followed by identifying themes that were explored to finally draw conclusions.

2.7. Quality of research
Validity and reliability are important aspects in determining the quality of research. To ensure that validity and reliability are achieved and research quality is satisfactory, several tactics in different research phases have been suggested. In the following subchapters, these aspects and tactics are explained.

2.7.1. Validity
Validity has three dimensions: internal validity, external validity, and construct validity.
Internal validity is applicable to explanatory or causal studies and not to descriptive or exploratory studies, as it is concerned with the extent to which a causal relationship can be established (Yin, 2014). External validity is concerned with the extent to which the findings of the study can be generalised. Construct validity is concerned with the extent to which the research measures actually measure what they are intended to assess (Saunders et al., 2012).

To increase internal validity, triangulation was the selected strategy. Data was acquired through various sources such as interviews, observation, and documents. External validity can be rather difficult to achieve as only two companies have been included in the studies. However, it can be argued that at this point in the PhD research journey, the purpose of the studies has been to deepen the understanding of the phenomenon rather than generalising the findings. External validity was supported by using theory in the single-case study and replication logic in the multiple-case study.

2.7.2. Reliability

Saunders et al. (2012) state that reliability refers to whether your data collection and analytical procedures would produce consistent findings if they were repeated in another occasion or by another researcher. In other words, another researcher who follows the same procedure as described by an earlier researcher and conducts the same case study, will get to the same findings (Yin, 2014).

One key to achieving reliability is documenting all procedures. Yin (2014) suggests two tactics during data collection to increase reliability, namely using a case study protocol and developing a case study database. In both studies, databases were developed in order to document the procedure and evidence. The databases included the collected data, various documents on the cases, the author’s notes from observations, meetings, and workshops.

It is noteworthy that achieving reliability in qualitative studies is difficult, since each case has its own particularities; thus, completely recreating a case is not feasible. Yet, the tactics mentioned above lead to transparency, and can support reliability.
3. Frame of reference

*Previous research and theories on the realisation of manufacturing involvement in NPD are presented here using three dimensions: NPD process models, roles and organisation in NPD, and design-manufacturing integration practices.*

3.1. NPD process models

Process models are project management tools that are utilised in order to organise project tasks (Nicholas and Steyn, 2012). The NPD process is approached and described in different ways by various authors (Elfving, 2007) who have proposed process models to define and represent the way of thinking and working within NPD. In this subchapter generic and Stage-Gate models, integrated models and lean product development model are reviewed.

3.1.1. Generic and Stage-Gate models

The NPD process is defined as “the sequence of steps or activities that an enterprise employs to conceive, design, and commercialise a product” (Ulrich and Eppinger, 2012, p. 12). Since the product development process follows a structured flow of activity and information, Ulrich and Eppinger (2012) use the process flow diagram to represent the process. They propose three types of development processes depending on the product being developed: (1) Generic Product Development Process, (2) Spiral Product Development Process, and (3) Complex System Development Process.

The generic product development process consists of six stages, as seen in Figure 3.1 below.

![Figure 3.1. Generic new product development model (Ulrich and Eppinger, 2012).](image)

Being “new” in the NPD context can have different meanings. Product newness is usually defined in relation to being new to the company or being new to the market. Based on this classification, Cooper (2001) makes six distinct classes of new products: (1) New-to-the-world products, (2) new product lines, (3) additions to existing product lines, (4) improvement and revisions to existing products, (5) repositioning, and (6) cost reductions. Even though most companies offer a mixed portfolio of new products, “addition to existing product line” and “product improvement” are the two most frequent classes (Cooper, 2001, p. 15).
Planning is the first stage in the process and results in a mission statement that must be approved so that the concept development stage can begin. The NPD process ends with production ramp-up, making the product available in the market.

Ulrich and Eppinger (2012) made a classification of various types of products, suggesting that the NPD process model should be modified to fit each particular product. As such, the generic process model fits “market-pull” products. Market-pull products are products for which there is a market opportunity that leads the company to develop the product. Other types of products with different degrees of complexity and market uncertainties require adaptations of the generic process model. Spiral product development process fits products such as software and electronics, which need rapid iterative design-build-test cycles. Complex products such as planes and automobiles are classified as complex systems since they consist of various sub-systems. Therefore, they require a complex system development process that reflects the complexities of the development process. Figure 3.2 illustrates the development process of a complex system (i.e., complex product). The detail design stage for such products is characterised by parallel work done by different design teams.

The generic model in Figure 3.1 resembles Cooper’s (2001) Stage-Gate process model, which is often used in the industry. It comprises five stages: scoping, building the business case, development, testing and validation, and finally launch and post-launch review. Each of the stages are followed by a gate, which is basically a decision point. The criteria for passing each gate are defined in advance. Upon completion, the stage is evaluated usually in a steering group meeting based on the predefined criteria. If the criteria are met, the project goes to the next stage. If the faults or risk appear to be too great, the steering group might decide to terminate the project. The Stage-Gate model proposed by Cooper (2001) is presented in Figure 3.3 below.
The Stage-Gate process has been used by many companies to better organise their NPD process, but has been criticised for some practical weaknesses as well. For example, projects must wait at a gate until all activities for a certain stage are completed, which is time inefficient. Moreover, in many projects, there is no clear-cut division between stages, that is, the distinction among stages is hazy (Wynn and Clarkson, 2005). As a solution, it is suggested to incorporate fuzzy gates, which are situational and conditional, to make the model more flexible (Wynn and Clarkson, 2005). Other researchers such as Cagan and Vogel (2005) criticise the Stage-Gate model for focusing on going through gates and not providing any guide about how to get through the stages. In addition, Cagan and Vogel (2005) indicate that the Stage-Gate process model falls short in addressing the early stages of NPD. Both the Stage-Gate and generic NPD process models encourage early involvement of all stakeholders in the process and using cross-functional project teams.

In various studies, it is shown that companies consider having a well-defined NPD process with clearly defined activities in each stage and decision points to be a critical best practice (e.g., Cooper and Edgett, 2012; Cooper et al., 2004). Nevertheless, it can be claimed that not all firms follow a well-defined process to manage their NPD activities or may not even be able to describe their NPD process (Ulrich and Eppinger, 2012, p. 12).

Design and manufacturing are two fundamental functions in NPD. Throughout NPD stages, these two functions perform various tasks, as shown in Figure 3.4 below.
Due to the significance of their roles, the design-manufacturing interface has been a topic of interest in NPD research. Vandeveld and Van Dierdonk (2003) have studied integration barriers between design and manufacturing functions. Personal and cultural differences between design and manufacturing play a significant role, even though both functions belong to the same company. Additionally it can be claimed that each of these two functions create a technical language of their own (Weick, 1969) which is not beneficial to cross-functional information transfer (Wolff, 1985). Organisational and physical barriers are other types of barriers that exist between design and manufacturing.

Figure 3.4. The generic product development process. Six stages are shown, including some of the typical tasks and responsibilities of the design and manufacturing functions (Ulrich and Eppinger, 2012).
**Front-end in new product development**

Front-end and back-end are two terms often found in the literature to refer to various stages of NPD. Front-end, also referred to as fuzzy front-end, begins with the idea for a new product and ends with a formal decision to begin a product development project (Kurkkio et al., 2011). Back-end is the execution-oriented part that includes production through product launch.

Ulrich and Eppinger (2012) argue that the front-end stage is characterised by activity overlap and iterations. Iterations are almost unavoidable due to the fact that new information might become available as the project progresses and necessitate that previous steps should be repeated (Ulrich and Eppinger 2012). Therefore, the front-end stage requires more coordination among functions. Several activities take place in the front-end stage: identifying customer needs, establishing target specifications, concept generation, concept selection, concept testing, setting final specifications, project planning, economic analysis, benchmarking of competitive products and modelling and prototyping.

Front-end activities have a considerable impact on the success of product development (Kurkkio et al., 2011). Moreover, decisions made during the front-end influence downstream activities, thereby playing an important role in the success or failure of an NPD project (Wagner, 2012). Quality, cost, and timing are mainly determined during the front-end (Verworn et al., 2008). It is vital to have an early and well-defined product definition, which will be used to make the decision to go to the next stage or terminate the project (Kahn et al., 2012). A product definition includes a product concept which considers production targets, market, customer needs, and product requirements. Hence, manufacturing, sales and marketing, and service functions are involved in the activities leading to product definition.

### 3.1.2. Integrated models

With the growing competition in industry and product life cycles becoming shorter, companies aim at shortening product realisation times, achieving more efficient developments, and making superior products (Valle and Vázquez-Bustelo, 2009). This has led to the emergence of certain practices to improve the NPD process, such as Concurrent Engineering (CE) and Integrated Product Development (IPD).

**Integrated product development**

Traditionally, activities performed during an NPD project were functionally divided into distinct stages, and the project went sequentially from one stage to the next (Haque, 2003). In the literature, this approach is occasionally referred to as relay race (Clark and Wheelwright, 1995). In this approach, the interaction and communication between functions are minimum, which leads to quality problems as well as increased development cost and times. To tackle this issue, alternative
approaches to management of the NPD process were introduced, such as IPD and CE.

IPD is an approach to the management of NPD to improve its performance, for example, by reducing development time (Pessôa and Trabasso, 2016) and make the process quicker and more flexible. Two pillars of IPD are activity overlap (partial or complete parallel execution of activities) and the interaction between activities (Gerwin and Barrowman, 2002). For a successful implementation of IPD, overlap and interaction must be well-coordinated.

Andreasen and Hein (1987) present a model for IPD that highlights the integration of various stakeholders and the parallelism of activities. The process is initiated with an identified need and continues in five stages: (1) investigation of need, (2) product principle, (3) product design, (4) production preparation, and (5) execution. Marketing, design, and manufacturing functions are the main stakeholders that are responsible for various activities during different stages of the process. Figure 3.5 demonstrates the IPD model proposed by Andreasen and Hein (1987).

The model highlights the parallelism in the set activities that are undertaken by various departments for the development of products, as well as the production system and sales strategies.

**Concurrent Engineering**

Over recent decades, CE has become a key trend in product development. It is an organisational mechanism that was introduced in the 1980s as a response to the inadequacies of the traditional management of NPD activities. The Institute of Defense Analysis provided one of the early definitions of CE:

“A systematic approach to the integrated concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life.
from conception through disposal including quality, cost, schedule and user requirements” (Winner et al., 1988, p. 11).

In the product development context, CE can be defined as “integrating the new product development process to allow participants making upstream decisions to consider downstream and external requirements” (Loch and Terwiesch, 2000, p. 263). To achieve this, CE emphasises the development of new products in a cross-functionally integrated manner. The use of cross-functional teams, early involvement of all functions, and overlapping of activities are three of the cornerstones of CE (Haque, 2003). For example, CE encourages having manufacturing experts on the design team to ensure that the product can be produced and can meet cost requirements (Ullman, 1992). Activity overlapping and information transfer in small batches are also mentioned as central characteristics of CE (Gerwin and Susman, 1996).

There are tools known as common CE tools that enable successful implementation of CE by facilitating collaboration between stakeholders. QFD, FMEA, DFA/DFM and CAD tools are some of the tools used by companies to facilitate communication (Haque, 2003; Peng et al., 2014; Prasad, 1997). The main benefit reported from CE is the reduction in the product development time, which shortens time-to-market. Due to the activity overlap, the total product development time is reduced in CE compared to the sequential PD. The disadvantage with overlapping, in case of interdependent activities, is that it increases uncertainty for downstream activities and can potentially increase the risk of rework (Loch and Terwiesch, 2000). This risk can be reduced through standardisation of work methods, specifications, and material; clear and well-communicated goals and strategies; and close collaboration and frequent communication (Paashuis and Boer, 1997). It also results in quality and engineering process improvements (Clark and Fujimoto, 1991; Koufteros et al., 2001; Stahl et al., 1997).

For successful implementation of CE, a two-way communication between design and manufacturing functions is critical (Sosa et al., 2007).

3.1.3. Lean product development

Lean product development (LPD) refers to the application of lean manufacturing to product development. Lean manufacturing was initially used in a manufacturing context; however, its success led researchers and practitioners to extend its application to other areas of enterprises including product development (Khan et al., 2013). LPD is value-focused where value is defined in terms of stakeholder needs and desires. All activities should result in stakeholder requirements being met. Set-based concurrent engineering and a knowledge-based environment are stated as enablers to focus on value (Khan et al., 2013). A culture of continuous improvement serves as an enabler for LPD and is also a result of it. Morgan and Liker (2006)
identify 13 principles for LPD based on studies of the Toyota lean product development system. These principles which correspond to three dimensions (process, skilled people, and tools and technology) are presented in Figure 3.6. Process refers to the process of bringing product from concept to production. In LPD, when the process is defined and improved, the focus is on skilled people. Tools and technology deal with the tools that help individuals in the organisation add more value to the customer.

1. Establish **customer-defined value** to separate value added from waste
2. Front-load the **product development process** to alternative solutions while there is maximum design space
3. Create a **levelled** product development process flow
4. Utilize **rigorous standardization** to reduce variation, and create flexibility and predictable outcomes

5. **Develop a chief engineer system** to integrate development from start to finish
6. **Organize** to balance functional expertise and cross-functional integration
7. **Develop towering** technical competence in all engineers
8. **Fully integrate suppliers** into the product development system
9. **Build in** learning and continuous improvement
10. **Build a culture** to support excellence and relentless improvement
11. Adapt technology to fit your people and process
12. Align your organization through simple, visual communication
13. Use powerful tools for standardization and organizational learning

![Figure 3.6. The principles of lean product development (Morgan and Liker, 2006).](image-url)

The process dimension is focused on the elimination of waste. Here, the first principle is definition of value and what stakeholders want. The stakeholder values should be clear and all the activities should be aimed at creating value. Front-loading the product development process implies an emphasis on early design stages with the aim of not diverging to a single solution too early. A practice used by Toyota to achieve front-loading is set-based CE. It is a design practice that begins with sets of possible solutions which are gradually narrowed down to obtain the final solution (Sobek II et al., 1999). Cross-functional communication and team working are essential parts of this practice. The fourth principle indicates the role and significance of standardisation for processes. LPD advocated use of design techniques and practices, such as design for X, design for cost, robust design, Poke Yoke, risk analysis (FMEA), lifecycle analysis and QFD, value stream mapping (among others) early in the design process (Khan et al., 2013).
3.2. Organisation, roles, and requirements in NPD

Many companies, particularly larger and more mature ones, have a functional structure where people are grouped based on their area of specialisation (Clark and Wheelwright, 1992). The group is supervised by a functional manager with expertise in the same field. This type of organisation is characterised by highly skilled employees, fixed roles and responsibilities, and a clear hierarchy. A disadvantage with this type of organisation, relevant to this research, is poor communication among departments (Clark and Wheelwright, 1992). Another type of organisation is the project organisation that comprises groups of people from several different functions who work together on a full-time basis toward the development of a specific product (Larson and Gobeli, 1988; Ulrich and Eppinger, 2012). In this type of organisation, proximity is favourable; therefore, members of the team would be collocated as much as possible, for example, in the same office or part of a building.

A matrix organisation is a hybrid of the two aforementioned types of organisation. In the matrix organisation, individuals are linked to others according to both the project they are working on and their function. Typically, each individual has two supervisors, a project manager and a functional manager (Ulrich and Eppinger, 2012).

Functional organisations give rise to specialisation and deep expertise in functional areas. Project organisations tend to enable rapid and effective coordination among diverse functions. Matrix organisations, being hybrids, have the potential to exhibit some of each of these characteristics (Ulrich and Eppinger, 2012, p. 28).

Different functions of a firm are normally involved in NPD projects with specific responsibilities and perform various activities. Marketing, design, and manufacturing are three functions that are continuously involved in NPD (Koren, 2010; Ulrich and Eppinger, 2012). Other support functions such as purchasing, sale, and marketing, service and maintenance, and finance are also involved and influenced by NPD activities. These functions together with end user of the product are called the stakeholders.

Stakeholder involvement in NPD is one of the dimensions of CE. In fact, the CE tools mentioned before are devised to enable and facilitate early involvement and better communication. Previous research indicates that involvement of relevant stakeholders early in the NPD process can increase the chances of success when commercialising new products (Bunduchi, 2008). Further, it prevents wasting resources and improves product concept quality since it allows stakeholders to give feedback early in the process. However, a hindrance in early involvement is that it increases the time spent in the early stages of the process. Therefore, it is important to clarify the optimal type and time of involvement.
Requirements engineering

Requirements engineering (RE) is a field of research that originates from software engineering but has evolved to include a broader perspective and applications. It has become critical in developing informal, fuzzy individual statements of requirements to a formal specification that is understood and accepted by all stakeholders (Loucopoulos, 2005). RE is important in NPD activities because NPD projects are based on requirements that define what results stakeholders expect (Wiesner et al., 2015). Wiesner et al. (2015) assert that RE is the key to the success or failure of NPD projects, because the project outcomes are the results of the requirements that were initially set.

As defined in ISO 9000:2015, a requirement is a need or expectation that is stated, generally implied, or obligatory (International Organisation for Standardisation, 2015). Thus, the term “manufacturing requirements” includes needs, expectations, wishes, and demands that originate from the manufacturing function during NPD projects.

NPD projects have various stakeholders, each of which have requirements that should be discussed and considered in the project. Striking a balance between the requirements is often a challenge, particularly when there are contradicting requirements. One difficulty in RE is that requirements can be unclear, which can lead to misunderstandings (Almefelt et al., 2003). Thus, development of requirement is an essential element in product development (Kar and Bailey, 1996). According to Loucopoulos (2005), RE consists of four stages:

- Requirements elicitation: understanding the current situation and need for change
- Requirements negotiation: establishing an agreement on the requirement among the various stakeholders
- Requirements specification: describing functional and non-functional goals
- Requirements validation: validating against stakeholders’ goals.

In the planning and CD stages, stakeholders and downstream departments must be sufficiently involved in order to communicate and understand requirements and to come to an agreement. The decisions made at these stages will influence stakeholders and downstream processes; therefore, it is important that the stakeholders are involved in decision making in the front-end of NPD projects and their requirements are considered.

Requirements standards and textbooks typically classify requirements into functional requirements (required operations and/or data) and non-functional requirements (quality requirements). In contrast, Glinz (2005) argues that this classic categorisation is inconsistent and ambiguous, and proposes a new
classification of requirements based on four facets: kind (e.g., function, performance or constraint), representation (e.g., operational, quantitative or qualitative), satisfaction (hard or soft), and role (e.g., prescriptive or assumptive). Another dimension is that many researchers have implicitly or explicitly described specifications as being separable in terms of criteria that must be fulfilled and criteria that is desired to be fulfilled (e.g., Paul and Beitz, 1996). For application in assembly system development, Wiktorsson et al. (2000) show industrial cases with requirements categorised into four groups: functional requirements (musts in terms of performance), internal design constraints (musts in terms of design solutions due to internal reasons), external design constraints (musts in terms of design solutions due to external reasons), and winning criteria (wants in terms of assembly system capabilities).

With regard to the explicit content of assembly systems requirements, previous studies on assembly systems shed light on the components of assembly systems and increased the understanding of the dynamics among the components. Asadi et al. (2014) studied assembly requirements in the context of NPD and identified seven categories of assembly requirements:

- Assembly operations
- Logistics
- Quality
- Cost
- Safety and ergonomics
- Environment, and
- Product design

However, their research did not investigate which of these requirements were handled and communicated at the beginning of NPD projects and what mechanisms were used for this purpose.

3.3. Design-manufacturing interface and integration

The total cost of a product is determined to a large extent during its design. Similarly, final quality of a product is influenced by the design of its constituent parts, which reflects the significance of the decisions made by designers while designing the parts. Design work involves making various decisions by the designer to come up with an optimum balance between the various requirements that a part/product shall satisfy. Traditionally, it has been difficult for designers to evaluate the consequences of their design decisions on downstream processes such as manufacturing, which could potentially lead to increase in the cost of production as well as quality issues. To tackle this problem, concepts such as design for assembly (DFA) were introduced.
Meerkamm and Koch (2005) make a distinction between the DFX (a term which includes DFA and DFM among others) approach, criteria and method. They state that DFX, as an approach, is a holistic approach that offers strategies for supporting fundamental decisions at the planning stage of the product development process and helps in distributing resources during the development process to obtain the desired effect. To achieve this, there are DFX methods that are in fact procedures through which a product designer makes the decision to optimise the desired criterion (X). In this sense, DFA refers to procedures through which the product designer makes decisions to optimise the desired criterion, that is, assemblability.

Other researchers—for example, Prasad (1996)—define DFA as an analysis technique that focuses on the relationship between joining parts. The aim of DFA is to enable designers to quantitively evaluate their design with regard to the ease/difficulty of assembly and reduce assembly costs (Booker et al., 2005; Prasad, 1996) by simplifying product structure. Therefore, it could be argued that using DFA methods can even help create a better working environment for the workforce in manual assembly (Andreasen et al., 1988).

Several DFA methods have been developed by various companies or scholars. For example, Hitachi and Sony developed their own DFA methods that fitted their products and operations (Boothroyd and Alting, 1992). The Boothroyd-Dewhurst DFA method developed and presented in the 1980s is a widely-applied DFA method. The core of all DFA methods is similar: assembly operation is broken down to smaller tasks and analysed. The criteria for evaluation include shape, orientation, alignment, insertion direction, fastening processes, etc. (Mašín, 2014).

DFA guidelines are another type of support tool available to designers. Some of the widely used DFA guidelines are presented in Table 3.1.
Table 3.1. Product-level and component-level DFA guidelines (based on Booker et al., 2005).

<table>
<thead>
<tr>
<th>Product-level guidelines</th>
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<tbody>
<tr>
<td>• Optimise part count (and types) by consolidation and integration of feature/parts</td>
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<tr>
<td>• Reduce variants and modularise the design</td>
</tr>
<tr>
<td>• Design for an optimum assembly sequence</td>
</tr>
<tr>
<td>• Provide a base for assembly to act as a fixture or work carrier</td>
</tr>
<tr>
<td>• Design the assembly process in a layered fashion (from above)</td>
</tr>
<tr>
<td>• Keep centre of gravity low</td>
</tr>
<tr>
<td>• Use gravity to aid assembly operations</td>
</tr>
<tr>
<td>• Minimise overall product weight</td>
</tr>
<tr>
<td>• Design parts for multi-functional uses where possible</td>
</tr>
<tr>
<td>• Strive to eliminate adjustments (especially blind adjustments/shimming)</td>
</tr>
<tr>
<td>• Ensure adequate access and unrestricted vision</td>
</tr>
<tr>
<td>• Eliminate unnecessary joining processes</td>
</tr>
<tr>
<td>• Reduce number of fasteners to a minimum</td>
</tr>
<tr>
<td>• Use common, efficient fastening system (when they must be used)</td>
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</table>

<table>
<thead>
<tr>
<th>Component-level guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Use standard components where possible</td>
</tr>
<tr>
<td>• Maximise part symmetry</td>
</tr>
<tr>
<td>• Design parts that cannot be installed incorrectly</td>
</tr>
<tr>
<td>• Minimise handling and re-orientation of parts</td>
</tr>
<tr>
<td>• Design parts for ease of handling from bulk (avoid nesting, tangling)</td>
</tr>
<tr>
<td>• Design parts to be stiff and rigid, not brittle or fragile</td>
</tr>
<tr>
<td>• Design parts to be self-aligning and self-locating</td>
</tr>
<tr>
<td>• Use good detail design for assembly</td>
</tr>
<tr>
<td>• Avoid burr and flash on component parts</td>
</tr>
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</table>

These guidelines are intended to help designers to design the components that fulfil specific requirements (e.g., performance, function, or tolerance requirements) as well as being sufficiently easy to assemble or manufacture (Fleischer and Liker, 1992). These requirements could be contradicting or difficult to fulfil simultaneously. DFA may assist designers in designing more assembly-friendly components or parts. Vandevelde and Van Dierdonck (2003) classify DFA/DFM as a means of structuring the product development process to facilitate design-manufacturing integration and bring issues of assemblability and manufacturability into the design process as early as possible.

Various benefits are reported to arise from applying DFA methods. For example, Branan (1991) reports that Motorola could reach a 80% reduction in assembly
defects after applying Boothroyd-Dewhurst Design for Manufacturing and Assembly technique. This was attributed to higher assembly efficiency, which resulted in fewer defects.

DFA aims at reducing the number of parts and increasing efficient assembly, which subsequently means less expensive products with higher quality. Boothroyd and Alting (1992) maintain that DFA encourages dialogue between design and manufacturing functions during the early stages of design and is a powerful tool for concurrent engineering.

DFA techniques have been criticised to have shortcomings as well. Molloy et al. (1991) mention that DFA techniques do not reflect all the manufacturing concerns. They also believe that DFA techniques provide quantitative results without making any recommendations. In the over-the-wall design philosophy, design engineers occasionally consider manufacturing issues, but since they are not experts, they sometimes do not make good decisions.

Various types of supporting tools are available to designers who use DFA/DFM in their design work. CAD tools enable designers to check the assembly interfaces using 3-D models. Various software programs make it possible to simulate assembly stations and use mannequins to check how easily an assembly task can be performed. Design guidelines and checklists provide instructions for the appropriate design of technical products (Meerkamm and Koch, 2005). They are company-specific and are devised with consideration to the company’s products and its structure. Nevertheless, since they are generic, designers need to make their own interpretation of the general rules to make them useful for specific cases (Meerkamm and Koch, 2005). Using manufacturing knowledge to support design decisions can be a means to address the aforementioned disadvantage. Recent research has indicated that model-based manufacturing (MBM) can be a means of integrating manufacturing knowledge earlier in the product lifecycle. MBM, which is part of the larger model-based enterprise (MBE) concept, utilises model-based definitions (MBDs) in manufacturing products. The MBM uses digital communication between the design and manufacturing functions, thereby enabling a more collaborative product development environment (Hedberg Jr. et al., 2017).

Failure modes and effect analysis (FMEA) is another tool used during NPD projects. By performing FMEA during the project, possible failures in a design can be identified. The consequences of the risks are classified according to severity (Zandin, 2001). FMEA requires a cross-functional team of experts to ensure that all risks are identified in the analysis.

The challenges facing NPD originate from different sources and require special treatment. Lakemond et al. (Lakemond et al., 2013) suggest that these challenges stem from three interfaces, namely contextual, organisational, and technical system.
interfaces. Contextual interfaces deal with interactions between the market and the technology. Organisational interfaces include the challenges of interaction between NPD project team and the surrounding organisation. The technical system interface deals with interactions between the product and the production system. Due to its significance, the technical system interface (referred to design-manufacturing interface in this thesis) has been studied from a coordination perspective over the past 50 years with the aim of proposing coordination mechanisms.

**Design-manufacturing coordination mechanisms**

According to Adler (1995), design-manufacturing coordination mechanisms are meant to ensure the fit between product and process parameters. Adler (1995) suggested four types of design-manufacturing coordination mechanisms in each of the three temporal phases of NPD, which results in 12 distinct mechanism for design-manufacturing coordination. The four types of design-manufacturing coordination mechanisms are (1) standards, (2) schedules and plans, (3) mutual adjustments, and (4) teams. In a comparable study, Nihtilä (1999) identified four mechanisms as key design-manufacturing integrators: (1) Standards, procedures and plans, (2) milestone and design review practice, (3) individual integrator, and (4) cross-functional team. In a similar study on the design-manufacturing interface, Lakemond et al., (2007) present factors that influence the design-manufacturing management into six clusters:

- Analysing manufacturability
- Production involved early
- Specific resources
- Active involvement
- Common vision

Job rotation, informal contacts, formal meetings, liaison personnel, independent integrators, interdepartmental committees, and information technology are some of the mechanisms mentioned by various researchers (Trygg, 1991).

Dekkers et al. (2013) argue that regardless of what mechanisms a company employs to manage product design-manufacturing interface, it needs to focus on the success factors. Top management commitment, skills and capabilities of staff involved, willingness and ability to internally collaborate in a team, and knowledge management practices are the success factors. This implies that an underlying theme for the success in design-manufacturing integration is the company culture and willingness and commitment at various organisational levels to achieve integration. Table 3.2 presents an overview of the mentioned literature.
Table 3.2. An overview of some of the mechanisms for design-manufacturing coordination.

<table>
<thead>
<tr>
<th>Researcher(s)</th>
<th>Term</th>
<th>Content of the term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nihtilä (1999)</td>
<td>Key design-manufacturing integrator</td>
<td>Standards, procedures, and plans, Milestone and design review practice, Individual integrator, Cross-functional team</td>
</tr>
<tr>
<td>Lakemond et. al (2007)</td>
<td>Factors influencing design-manufacturing management</td>
<td>Analysing manufacturability, Production involved early, Specific resources, Active involvement, Common vision</td>
</tr>
<tr>
<td>Gerwin and Susman (1996)</td>
<td>Integrative mechanisms</td>
<td>Team boundaries, Collocation, Assign downstream personnel upstream, Goal-setting and formal reviews, Performance evaluation, Team-based rewards</td>
</tr>
</tbody>
</table>
4. Results

This chapter presents a summary of the papers appended to this thesis. The main points of the papers and their contribution to the research objective and questions are discussed.

4.1. Paper A


Summary

This paper was based on the empirical findings from study I, which was a single-case study in heavy vehicle component assembly. The aim of the paper was to examine manufacturing involvement in NPD, and it addressed the following research question: “How and when are manufacturing personnel involved in early stages of new product development, to safeguard that manufacturing system requirements are communicated to product development teams?” The unit of analysis was the interactions between manufacturing and product development teams.

The point of departure in the study was that individuals who work in manufacturing operations have the deepest knowledge about how a new product fits the manufacturing system. Therefore, their involvement and knowledge provide valuable input to the design teams early in the design work. Similarly, their continuous feedback to the design teams is critical in the outcome of the design work during the NPD project.

In the available theory, initial stages of the NPD are highlighted as being significant in the outcomes of the project; thus, the timespan of the NPD project was divided into “initial stage,” “concept development stage,” and “the running of the project,” which covered the later stages of the NPD project. Accordingly, manufacturing involvement was evaluated and discussed in three corresponding categories: (1) involvement in setting requirements, (2) involvement in first concept development, and (3) involvement during the running of project (which basically is equivalent to the detail design stage).

The findings in this paper indicated that manufacturing involvement in the NPD project and communication between design and manufacturing functions were regarded crucial in the company. The company employed various NPD practices, some of which could enable and improve manufacturing involvement. These practices included cross-functional project meetings, digital/physical test assemblies, and design review sessions through which manufacturing had the
possibility to express their requirements on the product. Various risk analysis techniques (e.g. FEMA and SWOT) were performed to acquire manufacturing requirements and inform them to the product design teams. It was noted that in most of the activities only manufacturing engineers were present. Some operators were involved later in the NPD process, for example, during the detail design stage, particularly when physical test assemblies were performed.

This study resulted in some findings about the project organisation, type of intersections between design and manufacturing, as well as cultural difference between the product design team and the manufacturing personnel in the project work. For example, the findings indicated that high personnel turnover in manufacturing had resulted in poor communication between manufacturing and design functions as some information had been lost due to personnel turnover. Further, it was argued by some interviewees that manufacturing operators could not contribute in the early stages of NPD with their knowledge and competence due to the fact that design was so incomplete; thus, their presence and involvement was not regarded as necessary or value-adding.

To conclude, paper A contributed to this thesis by investigating the way of working between the product design teams and manufacturing personnel, thereby providing an indication of which roles from manufacturing personnel tend to be involved in NPD projects and what tools are used to realise the involvement.

4.2. Paper B


Summary

This paper was written based on study II, which was a multiple-case embedded study. The empirical data was collected from two NPD projects in two automotive manufacturing companies that are successful and leading in their respective sectors. Manufacturing involvement and design-manufacturing integration mechanisms during concept development and early detail design stages were the focal points of the paper.

The objective of the paper was to elaborate on how early manufacturing involvement in NPD was realised to ensure manufacturability. The following research question was addressed: “What forms of manufacturing involvement are especially important during early phases of concept and product development when the new product design has a considerable impact on the production system?”
The empirical findings were categorised into three topics: Organisation, process, and mechanisms. The companies were functionally organised, with highly specialised departments; however, in order to bring design and manufacturing closer, they created cross-functional project teams in which manufacturing was represented by the product introduction unit. During the concept development (CD) stage, the working group was kept small and meetings were held frequently in order to remain focused during this stage. A cross-functional steering group made the Go/Kill decision at the end of the CD stage. To manage projects, companies used an NPD project model that was an adaptation of the generic serial NPD model.

The results of this paper indicated that manufacturing sites were not directly included in project teams. Instead, an intervening function called “product introduction” represented manufacturing in project meetings. From the organisational structure viewpoint, this function was part of the manufacturing organisation, yet it did not have any direct connection to daily operations. This included several implications. In one case, several manufacturing sites were going to be affected by the new part/product, yet one engineer from the product introduction function represented all of them in the project team. This meant that the engineer had to have tight contact with them to acquire knowledge about what prerequisites and conditions these manufacturing sites had. This added to the challenges in their role, given that some of the manufacturing sites were in other countries. As the product introduction function had a key role in safeguarding manufacturing interests in the NPD projects, engineers working in function had to be experts in their respective manufacturing areas.

Another result discussed in the paper was that companies did not appear to have different approaches to manufacturing involvement in the CD and detail design stages, even though in literature concept development is highlighted to be the most critical stage in the NPD process when changes to design are not as costly. The companies utilised similar NPD practices to integrate manufacturing and their concerns in NPD. Most dominantly, the following NPD practices were used: risk analyses (e.g., SWOT and FMEA), DFA and ergonomics checklists, digital test assemblies, project meetings, and design review sessions. It was noted that companies did not utilise practices that help designers better understand manufacturing aspects. Examples of these practices are job-rotation for designers in manufacturing and locating designers in manufacturing sites to reduce physical distance and involve them in production start-up.

The used practices could be categorised into formal and informal practices where formal mechanisms such as FMEA and SWOT were easier to document, archive, and follow up throughout the course of the project. What happened at project meetings and design reviews sessions were prone to not being well documented,
which resulted in low traceability of design decisions or changes and could potentially lead to sub-optimisation.

The results indicated that design-manufacturing collaboration could be individual-dependent and not robust. In other words, integration of manufacturing requirements depended to a certain extent on the personal contact between assembly representatives and the design team. This could partially be due to a shortage of formal and established way of working in the design-manufacturing interface, which could result in some degree of variation and inconsistency among various NPD projects.

This paper contributes to the thesis with a more detailed investigation of manufacturing involvement in CD stage, including organisation, process and mechanisms that are used to enable manufacturing involvement.

4.3. Paper C


Summary

Paper C was written based on the results from study II. The aim of the paper was to explore handling of manufacturing requirements in NPD projects with two foci: 1) exploring what manufacturing requirements existed in the studied projects and 2) how these requirements were integrated into the fuzzy front-end of NPD projects when an existing manufacturing system was to produce the new product. To achieve this a multiple-case embedded study was carried out.

A list of manufacturing requirements was compiled from the empirical data and complemented with the requirements listed in literature. A model was developed to visually relate these manufacturing requirements to manufacturing functions (such as production planning, assembly, maintenance, quality, safety, health and environment, etc.) and to the source and effects of those requirements. Further, the forms of requirements were discussed and divided into qualitative vs. quantitative, soft vs. hard and musts vs. wants. The results of the paper could also shed light on the handling of requirements in the early stages of NPD projects and indicated that some requirements (e.g., those related to material handling aspects) were not sufficiently discussed.

In addition, the paper also investigated the mechanisms (NPD practices) used for the communication and integration of these requirements. QFD, SWOT, FMEA, CAD tools, DFA, and ergonomics checklists were among the NPD practices identified and investigated. Inspired by the steps carried out in requirements
engineering (RE), the paper mapped these practices to the following three steps: Eliciting the requirements, informing them, and evaluating/assessing their fulfilment. It was evident that DFA/DFM and ergonomics checklists could convey general requirements. Various risk analysis techniques were the main tool for eliciting manufacturing requirements in specific projects and/or regarding a specific part/product.

Further, some reflections were made on the suitability/efficiency of these mechanisms for their intended purpose in managing the requirements. Therefore, appropriate presentation of the requirements to the design teams and a follow-up routine must be in place, since merely performing the FMEA and SWOT does not guarantee that the requirements elicited are going to be treated as desired. This highlights the role of project leaders and higher managers to have a mindset that supports the integration of manufacturing requirements into product design.

This paper contributes to the thesis with a clearer picture of manufacturing requirements which are handled during the CD stages and the investigation of the use of NPD practices to communicate requirements to design teams.
5. Discussion

The objective of this licentiate thesis has been to investigate practices for manufacturing involvement in early stages of the NPD process in order to understand how they can lead to the creation of a product design that is suitable for the manufacturing system. Accordingly, this chapter discusses the findings in relation to the frame of reference in two subchapters based on the research questions. First, the practices for handling of assembly requirements are discussed. This is followed by a discussion on what assembly requirements are handled in the early stages of NPD. The third and final subchapter presents the reflections on the challenges of managing assembly involvement in NPD projects.

5.1. Communication of assembly requirements to the product design teams in the early stages of the NPD process

The first research question was formulated as “How are assembly requirements managed and communicated to the product design teams in the early stages of NPD process?”. To safeguard that assembly requirements were managed and communicated to design teams, a cross-functional project organisation was created that included representatives from assembly function in addition to other functions. As mentioned in papers A and B, there was no direct contact between design teams and assembly personnel (e.g., assembly operators, or production supervisor/production engineer). The contacts between these two functions in the early stages of the project was through an intermediate function called “product introduction.” In addition, the studied companies incorporated milestones in their NPD process models, during which manufacturing and design should jointly make various decisions.

Established NPD practices, guidelines, and standards as well as company-specific tools were used in the cases to manage the design-manufacturing interface and assembly requirements. These practices included DFA/DFM, FMEA, SWOT analysis, digital and physical test assemblies, ergonomics checklist, and CAD tools and simulation software programs. In addition to these, project meetings and design review sessions were the arenas available to manufacturing to participate in discussions regarding the design.

An initial assumption in the thesis was that manufacturing involvement is intended for the management of its requirements. Hence, NPD practices to involve manufacturing were studied and discussed in the light of assembly requirements in study II and presented in paper C. Inspired by the stages in the Requirements Engineering (RE) process (Loucopoulos, 2005), the tasks that assembly function performs for the management of their requirements were divided into three stages: (1) elicit the requirements, (2) inform the requirement (to the design teams), and (3) evaluate and assess the fulfilment of requirements.
The first research question was concerned with “how” the assembly requirements were communicated to the product design teams. Therefore, the NPD practices identified earlier were surveyed in order to investigate how they served the purpose of managing assembly requirements. The result of the analysis is presented in Figure 5.1.

In the studied cases, one of the early activities performed by assembly function was to perform SWOT and FMEA analyses. The purpose of these analyses was to obtain requirements on a particular part from an assembly process perspective. After performing these analyses, the results were provided to the design team, who needed to interpret, analyse, and understand them. In other words, assembly requirements were not presented as a solid list, but were expressed rather inexplicitly. Hence, they needed interpretation and further work. According to several interviewees, the challenge in the elicitation of requirements via SWOT and FMEA arose when the product was radically new and manufacturing had no previous experience with it. This is due to the fact that SWOT and FMEA are practice-oriented based on previous experiences (Lakemond et al., 2013). In such situations, manufacturing provided little input to the design teams at the CD stage. Therefore, there appears to be a need for mechanisms (tools/methods) to enable manufacturing to elicit and set certain requirements at the CD stage.

The findings of the thesis indicated that DFA/DFM guidelines and ergonomics checklists tended to be established and often utilised, which is in agreement with previous research. In the studied cases, these guidelines and checklists were developed by manufacturing function and addressed to the design teams, in fact, as a way of communicating some of their requirements. The problem with such checklists and guidelines indicated both in the empirical findings and in theory (for example Meerkamm & Koch, 2005; Molloy et al., 1991; Synnes and Welo, 2016) is

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**Figure 5.1. Types and example of practices used to manage assembly requirements.**

- Elicit the requirements
  - Failure Modes and Effects Analysis
  - SWOT analysis
- Inform the requirements
  - DFA guideline
  - Ergonomics checklist
- Evaluate and assess the fulfillment of requirements
  - Digital and physical test assemblies
  - CAD tools
that they are generic and do not offer any recommendations to product designers. Therefore, they only convey general requirements and not-case specific ones.

Other practices reported in the cases were digital tools, for example, CAD systems or other computer tools to perform simulations and digital test assemblies. Physical test assemblies could also be performed during the CD stage; however, this did not happen that often due to design immaturity during the CD stage. Analysing these practices based on their purpose showed that they were suitable for evaluating and assessing if the product design fulfilled the requirements. This implied that requirements had to be obtained, communicated, and known. In addition, in order to employ these practices, the product design had to get to a certain level of maturity to be able to make prototypes or perform digital/physical test assemblies and simulations.

The empirical findings indicated that assembly representative in the project team was considered to have the responsibility of evaluating and assessing the fulfilment of requirements. Often, this was done rather informally during project meetings, when design engineers explained the concept.

In early stages of NPD, a computer model of the design did not always exist. Occasionally, the designer would explain their solution verbally or through hand drawn sketches. Therefore, sometimes the evaluation of the design to assess its compliance with assembly requirements or its consequences for the assembly system had to wait until later stages in the NPD.

5.2. Assembly requirements raised in the early stages of the NPD process

The second research question was formulated as “What assembly requirements are raised in the early stages of NPD process?” and its aim was to investigate what assembly requirements were actually raised and discussed between assembly and design functions in the early stages of NPD. The empirical findings together with the investigation of available research on assembly requirements contributed to answering this question and also highlighting the requirements that were underattended.

Many enterprises strive to achieve flexibility and reconfigurability in their manufacturing systems as these two aspects contribute to higher productivity in manufacturing companies (Koren, 2010). This applied to the case companies and, therefore, their strategy was to use their existing manufacturing systems for the manufacture of new products to the highest possible extent. Consequently, they could manufacture old and new generations of products in the same facility, gradually ramping up the new product while phasing out the old product. An advantage of this strategy was that it involved lower investments and running costs, which was favourable for the case companies. However, on the other hand,
achieving this goal necessitated that manufacturing requirements should be known (in the manufacturing function), be communicated to product designers, and be taken into account when designing the product as much as possible. As pinpointed in earlier research, the communication between the design and manufacturing functions is particularly important if product designers are ignorant of extant factory capabilities (Langowitz, 1988), which is more likely to happen when design and manufacturing are in separate or distant locations. Thus, the requirement related to the physical barriers in manufacturing shall be identified and expressed clearly.

In study II, it was expected that the requirements should be in accordance with the aforementioned strategy. Table 5.1 presents a list of requirements that were discussed and raised by the assembly function in the CD stage of the two projects (see paper C).

<table>
<thead>
<tr>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of the part/component within the accepted limits</td>
</tr>
<tr>
<td>Minimise risk of the part causing injury to the operators during assembly</td>
</tr>
<tr>
<td>Minimise part’s sensitivity to damage (e.g., if dropped during assembly)</td>
</tr>
<tr>
<td>Ease of access to assembly points/places for the assembly operator</td>
</tr>
<tr>
<td>Clear marking on parts</td>
</tr>
<tr>
<td>Colour coding for parts</td>
</tr>
<tr>
<td>Confirmation that the assembly task is performed correctly (e.g., clicking sound)</td>
</tr>
<tr>
<td>Possibility to hang/place the part to have both hands free to perform the assembly</td>
</tr>
<tr>
<td>Impossibility for the assembly operator to pick a wrong part or assemble parts wrongly</td>
</tr>
<tr>
<td>Utilisation of the current assembly equipment (as much as possible)</td>
</tr>
<tr>
<td>Similarity of the assembly sequence for the new and existing product</td>
</tr>
<tr>
<td>Avoid sub-assemblies (as much as possible)</td>
</tr>
<tr>
<td>Avoid support tools and fixtures (as much as possible)</td>
</tr>
<tr>
<td>Minimise use of lubricants</td>
</tr>
<tr>
<td>Possibility of utilising the current material handling equipment (as much as possible)</td>
</tr>
<tr>
<td>Possibility of using existing pallets/shelves within the assembly line</td>
</tr>
<tr>
<td>Reduction in the number of part variants</td>
</tr>
</tbody>
</table>

This list comprises requirements that were either mentioned explicitly and discussed during various meetings and workshops, or were collected from standards and documents that the companies used. It is important to note that these only pertain to the CD stage and not the subsequent stages of product development.
Mapping out the requirements from study II (presented in Table 5.1) against the categories of assembly requirements mentioned by Asadi et al. (2014), resulted in the conclusion that, from the seven categories, three showed to be raised and handled during the CD stage. In paper C, these requirements were grouped into three clusters labelled “requirements on the physical properties of the part,” “requirement from the assembly process perspective,” and “requirements from the material handling and line-feeding perspective.”

The first cluster included physical properties of a part, for example, its weight, sensitivity to damage and scratch, or its potential risks to the operator. The second and the third clusters pertained to how the product fitted into the existing assembly and material handling systems.

Even though there was no requirement in study II that explicitly referred to quality or cost, several of the mentioned requirements could be linked to quality (product or assembly quality) and to cost.

Table 5.2 presents the requirement from study II along with the tools used by the companies to address them. The column “Effect of requirement” highlights how satisfying/not satisfying a certain requirement can lead to the increase or decrease in the desired characteristics in the assembly system.
The findings of study II indicated that there was some discrepancy in how aware designers were of assembly requirements and attempted to incorporate them in their work. This trend appeared to be more prevalent among designers with fewer years of experience in the companies. Further, this tended to apply to requirements from the assembly and material handling perspectives and not to the requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Tools to address the requirement in the cases</th>
<th>Anticipated effect of the requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of the part/component</td>
<td>Ergonomics standards</td>
<td>Ergonomics, quality</td>
</tr>
<tr>
<td>No risk of injury to the assembly operators</td>
<td>Ergonomics standards</td>
<td>Ergonomics</td>
</tr>
<tr>
<td>Low sensitivity to damage</td>
<td>DFA checklist, discussion in meetings</td>
<td>Cost</td>
</tr>
<tr>
<td>Easy access to assembly points/places for the assembly operator</td>
<td>DFA checklist, ergonomics standards</td>
<td>Assembly time, quality, ergonomics</td>
</tr>
<tr>
<td>Confirmation of the right assembly (e.g. clicking sound)</td>
<td>DFA checklist, ergonomics standards</td>
<td>Assembly time, quality</td>
</tr>
<tr>
<td>Possibility to hang/place the part to have both hands free for assembly</td>
<td>DFA checklist, ergonomics standards</td>
<td>Assembly time, quality, ergonomics</td>
</tr>
<tr>
<td>Assembly times</td>
<td>Discussion in meetings</td>
<td>Delivery, cost</td>
</tr>
<tr>
<td>Impossible for the assembly operator to pick a wrong part or assemble parts wrongly</td>
<td>DFA checklist, ergonomics standards</td>
<td>Assembly time, quality</td>
</tr>
<tr>
<td>Utilisation of the current assembly equipment</td>
<td>Discussion in meetings</td>
<td>Assembly time, cost</td>
</tr>
<tr>
<td>Similarity of assembly sequence for the new and existing product</td>
<td>Discussion in meetings, design reviews and test assemblies</td>
<td>Assembly time</td>
</tr>
<tr>
<td>Physical limitations in the assembly facility</td>
<td>Discussion in meetings</td>
<td>Cost, delivery</td>
</tr>
<tr>
<td>Reduction in the number of part variants</td>
<td>DFA checklist</td>
<td>Cost</td>
</tr>
<tr>
<td>Possibility of using current material handling tools</td>
<td>Discussion in meeting</td>
<td>Cost</td>
</tr>
<tr>
<td>Possibility of using existing pallets/shelves within the assembly line</td>
<td>Discussion in meetings</td>
<td>Cost, flexibility</td>
</tr>
</tbody>
</table>
concerning part properties. The reason could be that requirements on part properties tended to be mentioned in company-specific standards and guidelines and were well-established and accepted in the companies.

To ensure that requirements were understood and met, the assembly representative had a key role. This was particularly significant with regard to the requirements from an assembly and material handling perspective, since understanding these requirements needed a deep understanding of the existing assembly system and how an assembly process works. These requirements did not appear to be obvious for the design team. Hence, the assembly representative had the responsibility of highlighting and discussing the requirements. This was mostly achieved in discussions during project meetings, design reviews, test assembly sessions, and even email conversations. It was also noted that the case companies did not use job-rotation plans between design and assembly functions. Nor were these functions collocated. In addition, there appeared to be a lack of a person serving as the integrator for creating a balance between the design and assembly functions. These mechanisms have been recurrently mentioned in literature as facilitators of design-manufacturing integration (e.g., Gray et.al, 2015; Nihtilä, 1999; Trygg, 1991).

With regard to material handling and logistics requirements, several respondents believed that the requirements needed to be discussed more in early stages of NPD. In fact, material handling requirements were only briefly addressed in the DFA checklist. Apart from that, it could be discussed in meetings or workshops, which made the handling of these requirements rather unstructured and subjective. In the various meetings and workshops attended during study II, logistics and material handling were not discussed, nor was the material handling department involved or present in the project at that stage.

Table 5.3 provides an overview of the requirement clusters and the NPD mechanisms utilised to address the cluster.

*Table 5.3. An overview of assembly requirement clusters and the corresponding NPD practices in study II.*
5.3. Reflections on the challenges of managing assembly requirements through assembly involvement

Throughout the studies, several challenges regarding management of assembly requirements were identified. Similar to earlier findings of Almefelt et al. (2006), the result of the studies showed that the responsibility of managing the assembly requirements is mostly on the assembly function. In the projects that were studied in this thesis, this responsibility fell almost solely on the assembly representative who had to ensure that the requirements are collected and informed to the design teams. However, that was not enough to ensure that the requirements were understood and would be incorporated in the product design. Again, the assembly representative was expected to follow-up on the requirement and ensure that they were not forgotten. Our results indicated that there was no structured and formal way to do this, making the way of working rather subjective and dependent on the assembly representative and his/her experience and competence.

Ahlström (2002) asserted that the assembly knowledge needed for the development of assembly efficient products is associated with assembly operators, manufacturing engineers, and product introduction engineers. Among these three, assembly operators were said to have the most knowledge about the assembly processes, whereas product introduction engineers were said to have the most knowledge about product development and least knowledge about assembly process. Yet, the findings indicated that assembly operators and manufacturing engineers were not involved in early stages of NPD, since there was a disagreement regarding whether or not assembly operators could contribute with their knowledge during the concept development (see, for example, paper A).

Designing a product has an iterative nature (Ullman, 1992) in which the design becomes more complete and mature with each iteration. Further, uncertainty is an inherent characteristic in design work, particularly during CD, where there is some uncertainty and ambiguity due to lack of knowledge (Ullman, 1992). Design and manufacturing functions are different when it comes to ambiguity tolerance and time orientation (Vandevelde and Van Dierdonck, 2003). This could explain the difficulty in assembly involvement during concept development work and setting, making specific requirements on a product that is radically new for the assembly function. Further, the results showed that traceability of the assembly requirements and how they were considered and handled by design engineers was a problem area. This was extra critical considering that each iteration in the design included decision-making, making trade-offs between various requirements, and changing priorities.

NPD encompasses a broad spectrum of newness in the product and in the manufacturing system that calls for different approaches to efficiently manage it. Most companies use one type of NPD process model for all types of NPD projects
without considering the extent of the project, the newness of the product, and the workshops/processes being affected by the new product. Based on the results of the studies, it appears advisable to pay attention to the particularities of each individual project to include additional measures if needed. Contextual and organisational characteristics in each NPD project should also be taken into consideration in order to devise and implement suitable NPD practices.

Further, it must be noted that the design-manufacturing integration includes alignment of both action and interest (Heath and Staudenmayer, 2000). Inter-organisational communication barriers together with the knowledge-intensive nature of the NPD process can hinder alignment of action and interest between stakeholders (Petersen et al., 2003).
6. Conclusions and future research

In this chapter the conclusions from this research are laid out with a focus on the fulfilment of the research objective and response to the research questions. Additionally, the academic and industrial contributions of the research are presented. The chapter concludes with an outline of potential future research.

6.1. Conclusions

Two research questions were formulated to be answered throughout the research. They focused on “How assembly requirements are managed and communicated” and “What assembly requirements are raised in early stages.”

Working cross-functionally in a team that included both design and assembly function was a central part of NPD projects in the case companies. Apart from including an assembly representative in the project, several practices were used for the management and communication of assembly requirements to the product design function. These included FMEA and SWOT analyses, checklists and guidelines developed by the companies, digital and physical test assemblies, as well as CAD and simulation tools. Additionally, discussions during project meetings and design review sessions played an important role in the communication of the requirements. In literature, mechanism such as collocating design and manufacturing and job rotation between these too is mentioned as a means to bring these two functions closer and facilitate their communication. However, these mechanisms were not used in the studied companies.

Manufacturing is influenced by the design of products in various ways. Cost, delivery, quality, flexibility as well as safety are some of the performance parameters influenced by the design of parts/products to be manufactured. For an assembly plant, these parameters can be broken down and translated to a list of assembly requirements that a new part/product should fulfil. Even though the concept development and system-design stages of NPD provide a precious window of opportunity for manufacturing to set requirements on the new product, the opportunity is only seized partially.

Roughly categorised, assembly requirements deal with three dimensions: requirements on the physical properties on the part, requirements from the assembly process perspective, and requirements from the material handling perspective. These three requirements dimensions connected to functions are linked to corresponding anticipated effects in cost, quality, productivity, ergonomics, environment, etc. Requirements on the part and its physical properties are intended to reduce risks of personnel injury and part’s damage sensitivity, thereby resulting in higher quality and lower costs. Requirements from the assembly process perspective emphasise the use of an extant assembly system and are intended to increase productivity and quality and lower investments and assembly costs. Similarly, requirements from the
material-handling perspective intend to increase the use of the material handling system and lower material handling costs. There seems to be a tendency in the studied companies to under-attend material handling requirements in the CD stage of projects, as this stage is regarded to be too early to discuss any material handling issues. This is true to a certain extent, yet, some of the properties of the part are frozen in the CD and system-level design stage which will have an impact on the material-handling system. Therefore, the material handling function might benefit from getting engaged in the NPD projects earlier.

Empirical evidence indicate that requirements are nuanced, thereby implying that some of them are absolutely necessary while others are negotiable. This can be contributed to the sources of requirements. Digging into company cultures and established practices, it becomes evident that the necessary assembly requirements being discussed early in NPD often have their origin in the XPS (company-specific production system) and/or well-established best practices as well as health and safety regulations.

Negotiable requirements can usually be down-prioritised in discussion with the product design function and other relevant stakeholders. Therefore, it is advisable that the manufacturing function makes a clear distinction between necessary and desirable requirements and discusses them with the design teams and is informed about the consequences of a requirement which is not met in the redesign of the manufacturing system.

6.2. Research contributions

With regard to the interface between design and manufacturing functions, much of the existing body of knowledge focuses on mechanisms to manage the interface to achieve best project results, for example, through use of cross-functional project teams. However, less is written about what requirements exist from the manufacturing function on the new product. This has to be clear before mechanisms can be suggested to efficiently manage and communicate the requirements. Moreover, existing theory often recommends similar mechanisms regardless of the type of industry, complexity of the new product, size of the organisation or the timespan of the NPD project. Hence, the contribution of this research is in creating a better understanding of the management of assembly requirements in NPD projects and highlighting the challenges in case of complex products and large organisations. This research contributes to the theory by shedding light on assembly requirements in the NPD project together with a synthesis of the tools and mechanisms to manage the requirements.

From a practical viewpoint, this research can aid companies in realising that different NPD projects might require different levels of manufacturing involvement and at different points of time during the course of a project. This depends on the
scope and extent of the project and the magnitude of change which the new product would impose on the manufacturing system. Hence, it is necessary that manufacturing makes an evaluation of the impact of the new product on the manufacturing system and plans its involvement accordingly.

Having manufacturing function represented is an important step toward integrating assembly requirements in the design; however, it does not guarantee it. Manufacturing function needs to place clear requirements early on in an NPD project and follow up on the fulfilment of requirements.

First, “the right requirements” should be identified on the basis of the value they create for the plant. Then, the manufacturing function can focus on “communicating the requirements in the right way.” In other words, to improve the manufacturing involvement in NPD projects, the requirements should be incorporated effectively and efficiently in the NPD project.

6.3. Future research

This research work at the licentiate level has a descriptive nature. It was directed toward understanding the research area, identifying research gaps, and indicating preliminary theories and frameworks. The current research touched upon three dimensions in the design-manufacturing interface—namely process, organisation, and tools/mechanisms. Each of these dimensions offer several directions for future research.

For example, considering the organisation, further research can be directed toward identifying which individuals from manufacturing function should be involved in NPD based on their competence and knowledge. With regard to the process aspects, one direction to investigate in the future could be how to apply agile development methods in the development of complex products. Moreover, a direction for further research can be investigating how the use of product lifecycle management (PLM) systems and model-based enterprise (MBE) can support and facilitate incorporation of manufacturing requirements/information in the context of NPD to make this process more robust and reliable. Ultimately, a framework can be proposed to assist manufacturing function in their requirement management efforts in NPD projects.
References


