Improving new product manufacturability: Stimulating inter-organizational collaboration through knowledge sharing

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Master Thesis Supply Chain Management

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Management summary

Today, companies involved within New Product Development projects constantly face the challenge of being faster, better and cheaper. An important performance indicator for this is manufacturability, which is often endangered due to lack of communication between Engineering and Manufacturing. New Product Manufacturability determines the degree of fit between the new product design and capabilities of the manufacturing company for a specific product. Within the Brainport Region in the Southeast of The Netherlands, various New Project Development projects take place amongst several companies. The Knowledge Sharing Centre, which is the founder and owner of an independent, non-profit knowledge sharing platform, wants to ensure the future of the Brainport Region. One of the goals is improving new product manufacturability. Involving Manufacturing companies at an earlier stage of an New Product Development project can reduce lack of communication. Various researches revealed the impact of Early Supplier Involvement on New Product Manufacturability. However, what has not been discussed to date is the influence of a knowledge sharing platform which aims to stimulate inter-organizational collaboration and the emergence of newly bilateral contacts on Early Supplier Involvement and how this can impact New Product Manufacturability. This has led to the following problem statement:

How can the Knowledge Sharing Centre stimulate collaboration in order to improve manufacturability of (semi)finished products during intercompany 'new product development projects?

An exploratory qualitative multiple case study research was conducted. Five cases were selected for the purpose of data collection. The data consist of semi-structured in-depth interviews conducted with people involved within design and manufacturing stages of five selected new product development projects. Results show that early supplier involvement can have positive impact on manufacturability, but negative as well. The results reveal that the platform will be used for creating awareness of production process steps and design constraints earlier during the development process and to find suitable suppliers for project participation. Results also highlight the importance of sharing at least information regarding manufacturing processes, materials, the product, design/manufacturability and general company information on the platform or during bilateral contact between participants. Participants should feel safe about the financial basis and proprietary and confidential knowledge sharing and management should deal proactively with opportunistic behavior since all factors influence willingness to collaborate. Future research should focus on factors influencing manufacturability when suppliers are actually involved earlier, the role of purchase departments within development projects and what this means for the platform, determinants of the moment of manufacturing involvement and which knowledge is required per process stage in order to facilitate designers in making design decisions and manufacturers in providing feedback, possible trade-offs between early supplier involvement an new product manufacturability and for which types of project the platform is suitable.

Preface

This thesis is my final work of the master Supply Chain Management. This master was an extension to my bachelor, Industrial Engineering and Management. During this bachelor I discovered my interest in the organization and management of primary processes, with purchasing in particular. This is also the reason I really wanted to do a project within the field of purchasing. The thesis was written for the Knowledge Sharing Centre which is an initiative of United Brains and ASML. The outcomes will not only contribute to the setup of the Knowledge Sharing Centre, but will also have impact on a larger target group, namely all future participants of the Knowledge Sharing platform. This project has helped me extending my knowledge in the field of purchasing, particularly for Early Supplier Involvement.

At first, I would like to thank my supervisor, Bart Vos, for his intensive support, supervision and the large amount of feedback opportunities that he provided. Next, I would like to thank my company supervisors, Frank van der Chijs and Arno Sprengers, for their great input during the search for cases and interviewees and their time, guidance and substantive contribution. Thirdly, I would like to thank all employees from the 9 different companies for voluntarily taking part in the interviews. Lastly, I would like to thank Stefan van Trigt, Edward Goudsmits and Marlon van de Kelft for spending a considerable amount of time reviewing this thesis and providing valuable feedback.

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1. Introduction

1.1. Background

New Product Development (NPD) often happens amongst several companies. Different companies are involved in different stages within this process. Together they constantly face the challenge of being faster, better and cheaper. They need to find ways to reduce time to market and at the same time improve product quality and reduce product costs. Effective integration of suppliers into these projects can achieve benefits like reduced costs and development time, improved quality of materials and access to technologies (Ragatz, Handfield & Scannell, 1997).

The Brainport Region in the Southeast of The Netherlands is among the very top when it comes to high tech knowledge in Europe. Within this region, various NPD-projects take place which have to deal with the above mentioned challenges. The region has been declared 'Most Intelligent Community of the Year' in 2011 by the Intelligent Community Forum (ICF) of New York, but this is no guarantee for the continuation of this position in the future. The economic success of the Brainport Region is important to the internationally competitive position of The Netherlands: together with the Airport Region (Amsterdam) and Seaport Region (Rotterdam), the Brainport Region forms the largest part of the Dutch economy (van der Zee, 2013).

An observed phenomenon in this region is a lack of communication between Engineering and Manufacturing which leads to sub optimized product designs. This is confirmed by several companies within the Brainport Region. According to Hermann et al. (2004), ignoring downstream issues, like production constraints from the manufacturing company, can lead to poor product designs that may cause unforeseen problems and costs later in the process. Sometimes, when problems are found during design verification or testing, the problems can be corrected by redesign. However, the cost of redesign at this late stage can be extremely high. Indeed, previous research suggests that as much as 80% of production decisions and resulting production costs are the result of decisions which have been made during the product design stage (Stoll, 1986). Therefore it is very important to take into account that decisions made during the design process can have a significant impact on the quality, cycle time and costs of a product. Further down the new product development process it becomes more difficult and costly to make changes within the design (Ragatz, Handfield & Scannell, 1997). One way to reduce this problem, is to involve the manufacturing companies at an earlier stage (ESI). Increased involvement of suppliers in the design process allows greater focus on design for manufacturability (DFM) (Wasti & Liker, 1997). In addition, theoretical research indicates that early and extensive supplier involvement results in a faster development process (Dyer and Singh, 1998; Handfield et al., 1999; Petersen et al., 2003).

The challenge and ambition of staying at the top triggered ASML and United Brains to cooperate. ASML is a company operating in the High Tech industry. Their vision is to enable affordable microelectronics that improve the quality of life and want to achieve this by inventing, developing, manufacturing and servicing advanced technology for high-tech lithography, metrology and software solutions for the semiconductor industry. United Brains is a so-called ‘bridge builder’ between companies and knowledge institutes within the Brainport Region. It aims to help those parties with questions regarding production processes, re-positioning and innovation by using its broad network to bring different parties in contact. The two organizations started a foundation called the Knowledge Sharing Centre (KSC). The Knowledge Sharing Centre is the founder and owner of an independent, non-profit knowledge sharing platform which main goal is increasing open innovation and crossovers within the Brainport Region to ensure the future of this High Tech Region. The KSC recognizes that sharing knowledge among participants is key for enabling bilateral contact between these parties. The platform therefore facilitates sharing (non-confidential) knowledge and connects participants from different parties. The platform distinguishes four pillars with regard to these participants:

1 Original Equipment Manufacturers (OEM)
2 Engineering companies
3 Manufacturing companies
4 Knowledge institutes

The platform of the Knowledge Sharing Centre is still under construction. An important goal of the Knowledge Sharing Centre is to improve manufacturability of new developed products, also known as New Product Manufacturability (NPM) (Swink, 1999). It is viewed that if information can be shared early and accurately in the design process, it would allow product development teams to create designs that would be better aligned with the whole supply chain. This would reduce the number of redesigns, the time-to-market, and development and manufacturing costs and improve the customer’s experience (Herrmann et al., 2004). If this could be achieved, the competitive power of supply chains within the Brainport Region would increase which contributes to ensuring the future of this region.

1.2. Problem statement

The following problem statement is formulated for this research project:
“How can the Knowledge Sharing Centre stimulate collaboration in order to improve manufacturability of (semi)finished products during intercompany new product development projects?”

1.3. Research questions

The following research questions are derived from the problem statement. The first three are theory oriented. The latter three are practical driven.

1. How can early supplier involvement within NPD-projects be defined?
2. What are attributes of the manufacturability of (newly developed) products?

3. What is the impact of early supplier involvement on the manufacturability of (semi)finished products within NPD-processes?
4. How can (early) involvement of manufacturing companies be improved and stimulated within a NPD-project?
5. How does the involvement of manufacturing companies within design processes influence product manufacturability?
6. How can the platform stimulate bridge building between engineering companies and manufacturing companies?

1.4. Thesis structure

In this section, the outline of the thesis is described. The background to this research study is provided in chapter One. It is explained why ESI and NPM are chosen fields of research with regard to the Knowledge Sharing Centre, resulting in the formulation of the problem statement and associated research questions. Existing literature is reviewed in chapter Two, exploring what is currently known about both research fields and where a contribution to knowledge may be situated. This chapter starts by explaining early supplier involvement with great emphasis on the design-manufacturing interface of Twigg (2002). It also zooms in on attributes of new product manufacturability and eventually on the influence of ESI on NPM. The chapter ends with research gaps based on the literature review. In chapter Three, the methodology chapter, the approach and structure of this research are explained. It starts with an explanation of the research design including the conceptual model which later was operationalized into a topic list for the semi-structured interviews. Further information is provided about five cases which formed the basis for the empirical part of this research. Processing and analyzing techniques are explained, including attention for reliability and validity issues. The results are presented in chapter Four whereby the practical research questions were answered per paragraph and concluded with a discussion, highlighting important results and combines those with literature. Lastly, in chapter Five, conclusions are formulated, answering the research questions along with managerial and future recommendations.

2. Literature review

This literature review is divided in several parts. First, early supplier involvement is defined. Secondly, more focus is given on the specific part of NPD which is of great importance for this research, the design manufacturing interface. Thirdly, attributes of new product manufacturability (NPM) are discussed. Lastly, the impact of ESI on NPM is explained.

2.1. Defining Early Supplier Involvement within NPD

Early Supplier Involvement (ESI) occurs when a customer involves its supplier at an early phase into New Product Development (Eisto et al., 2010). Early and extensive involvement of key suppliers during NPD projects is a key factor in ensuring DFM. 'Early' implies that suppliers are involved during the concept stage or during early feasibility studies to ensure that suppliers can influence early design decisions (Vuori et al., 2016). This research defines a supplier as a manufacturing company who provides operational capabilities.

Advantages and drivers

ESI happens since it brings several advantages which can be divided into short-term and long-term. Short-term advantages are characterized by a link to one or more specific projects. Examples of contributions to performance results are time saving, cost savings and improved quality (Eisto et al., (2010). Long term advantages do not become visible immediately from supplier involvement within a specific project (Wynstra & Van Echtelt, 2001). Learning from each other and the intercompany collaboration can result into efficient and effective future collaborations, which is an important example of a long-term advantage (Wynstra & Van Eechtelt, 2001). In addition, mutual trust and good communication are key factors to improve the buyer-supplier relationship (Monczka, 2000; Petersen, Handfield&Ragatz, 2005).

Challenges

Eisto et al. (2010) found two challenges for ESI, namely lack of trust and benefits which are not clear to involved parties. Lack of trust can lead to customers involving suppliers too late within their NPD-process, poor communication and information exchange. Late involvement has bad impact on design outcomes, since only minor design changes can be made when the design is frozen, which often is the case within a late phase in NPD-processes. Customers often do not share enough product information, which makes it difficult for suppliers to propose design improvements. In addition, lack of trust can result in suppliers being unwilling to participate in designing when there is no contract agreed for the suppliers input. It also makes involved companies want to protect their knowledge since they are afraid of losing competitive advantage.

The other challenge they discovered, is that benefits are not clear for all involved parties and not all companies benefit from ESI. If advantages cannot be proved, it is difficult to think of why to start a new collaboration or to continue an old one. If it is not beneficial to all companies, relationship will probably fail in the long run.

Internal process matters for ESI facilitation

Supplier selection is an important step of early supplier involvement and is of particular importance for this research, since a knowledge sharing platform can operate as the starting point for the search of new suppliers. According to Dekkers, Chang & Kreutzfeldt, (2013) the selection of suppliers during product design and engineering has an enormous impact on the later performance of both new product development processes and manufacturing. Suppliers are chosen based on criteria which are important to the client company. It is, for instance, demonstrated that technological competence is a common driver for supplier selection in NPD (Handfield et al., 1999; Petersen et al., 2003, 2005). Moses & Åhlström (2008) identified three main problem areas which affect the sourcing decision process of NPD negatively: functional interdependency, strategy complications and misaligned functional goals. First, it became clear that departments, like R&D, quality, purchasing, finance, logistics, and manufacturing, depend on each other's work, time management and information adequacy. Some examples of problems they found within this area are information dependency, lack of designed system-support, ad hoc decisions and process-design related problems. Secondly, companies face strategy complications like problems with translating goals into actions, employees making decisions not only guided by the strategy and company strategies which are not constructed to support the decisions sufficiently in practice. Thirdly, misaligned functional goals can lead to problems because of different interests, wasted resources, missed opportunities and competitive actions. Strategic alignment between disciplines and involvement of all disciplines is important to come to an adequate selection of suppliers. Furthermore, Servajean-Hilst & Calvi (2016) describe the relevance for companies to involve the purchasing department within NPD. Involvement of purchasing in the very beginning of a NPD project can contribute to firm's innovativeness through thinking of new (external) resources and new components. Later, they are contributing through the generation of a "make-or-buy" analysis and by aligning and secure internal interfaces. They also manage the relationships of external parties involved in the NPD-process through their scouting, selection, by defining contract and organizing the follow-up stage. Gimenez & Ventura (2005) conclude that coordination between internal functions facilitate coordination with external partners. Takeishi (2001) who studied supplier involvement in product development, found that integrated problem-solving processes with suppliers are related to effective internal functional coordination between, among others, engineering and purchasing. Kragh, Ellegaard & Andersen (2016) argue that high levels of interaction-based R&D-purchasing integration creates an organizational setting that facilitates supplier involvement.

2.2. The design-manufacturing (DM) interface

The previous section described advantages, challenges and important matters to take into account for the internal process regarding facilitation of ESI. The focus of this research is primarily on the stages which consider product design, prototyping and manufacturing. When potential suppliers are selected and involved, the collaboration and knowledge sharing process between design and manufacturing should be managed. ESI and adequate knowledge sharing will be beneficial to both product design and engineering management and production management (Dekkers, Chang & Kreutzfeldt, 2013). Therefore focus on the DM-interface is important. DM interface refers to communication of all kinds between design (companies) and manufacturing (companies). Effective DM interface management means that in Design and manufacutring activities, the interface of various functional departments between the design company and manufacturing company can respond to market environmental changes in the communication and connection of elements as for example technique, knowledge, information and talents, and achieve a harmonious state with dynamic equilibrium (Zhu, 2009). Several previous studies focus on different parts of the DM interface.

Liker (1999), for example, found that differentiating mechanisms, such as a tall hierarchy and job specialization, are negatively associated with design–manufacturing integration, particularly for new designs. Socio-integrative mechanisms, including such flexible practices as cross-functional teaming and collocation, are positively related to design–manufacturing integration for new designs only. Adler (1995), made a typology of design/manufacturing coordination mechanisms for internal use. These mechanisms facilitate the internal coordination of product development activities by a firm. VandeVelde & Dierdonck (2003), found mechanisms that smooth the production start-up and improve NPD performance. However, those studies are not specifically focused on the inter-firm DM interface. Since this research is explicitly about the inter-firm collaboration and communication, the research of Twigg (2002) and the work of Zhu (2009) give a better understanding of the important aspects and mechanisms of managing this inter-firm DM interface.

Zhu (2009) proposes 5 factors which influence this interface. First, early manufacturing involvement has several advantages, like an increased manufacturability, therefore the timeliness of manufacturers' participation and design influences the DM interface. Secondly, the design scope assumed by the manufacturer will also influence design cycle and design alteration. Thirdly, frequent unobstructed communication will make communication more transparent and enhance the DM interface management efficiency. Fourthly, partnership duration will have positive impact on mutual trust. The channel of information circulation will become smoother and the efficiency of interface management will be higher. Lastly, learning ability of both parts will determine the efficiency of interfacial communication.

Twigg (2002) adapted and expanded the previous mentioned typology of Adler (1995) but in contrast focused more on the inter-firm coordination mechanism (see Table 1).

A typology of inter-organisational coordination mechanisms

	Pre-project phase	Design phase	Manufacturing phase
A Standards	A1 Compatibility standards A2 Electronic data interchange A3 CAD/CAM data exchange A4 Cost management	A5 Designers' tacit knowledge of manufacturing A6 Design rules	A7 Early manufacturing start with early design data A8 Manufacturing flexibility
B Schedules and plans	B1 Capabilities development schedules B2 Relationship assessment	B3 Sign-off	B4 Production prototypes engineering fit build-test cycles
C Mutual adjustment[a]	C1 Supplier development committee C2 Gatekeeper	C3 Producibility design reviews C4 Producibility/ manufacturing engineer C5 Guest design engineer	C6 Engineering changes C7 Site engineer C8 Product support engineer
D Teams	D1 Supplier development team D2 Joint development	D3 Joint product/process design team	D4 Transition team

Note: [a] an additional mechanism is available, that of post-project appraisal (C9)

Table 1 A typology of inter-organizational coordination mechanisms (Twigg, 2002)

Twigg's (2002) research indicates, for example, in more detail at which steps specific employees from the manufacutring firm should be involved within the design stage and what their role should be at that moment. The model is divided in three stages (pre-project stage, design stage and manufacturing stage and four categories of mechanisms (standards, schedules & plans, mutual adjustment and teams). The mechanisms are discussed below per category. A detailed and extensive description is provided into the paper of Twigg (2002).

2.2.1 Standards

Compatibility standards (A1) enable firms to reduce the need for give-and-take discussions. Electronic data interchange (A2) enables computer-to-computer transfer of information (intra and inter-firm) with for instance integrated electronic mail systems. Many firms select systems on the basis of exchanging CAD/CAM data (A3) with their customers. Cost management (A4) enables understanding design, development and production costs which helps focusing on the total design. Designers' tacit knowledge of manufacturing (A5) can achieve avoidance of manufacturing-related engineering changes because design engineers may have tacit knowledge of manufacturing practices which were gained over time from previous projects or experience. Design rules (A6) means codifying formal procedures in the form of decision rules and design rules that take next project steps, like proto and manufacturing activities, into account. By releasing design data earlier (A7), manufacturing could start earlier with its manufacturing process. It can for instance start with preliminary work on checking manufacturability problems of the design, as well as advise about the development of process design which happens at the same time. Manufacturing flexibility (A8) enables building flexibility into manufacturing operations.

2.2.2 Schedules and plans

Capabilities development schedules (B1) means all parties work uniformly to a prescribed set of objectives and schedules and enables planning in the knowledge of the activities of other functions. This enables reduction in inappropriate design specifications or process expectations. Relationship assessment (B2) stimulates coordination through displaying shortages in existing mechanisms and processes. Sign-off (B3) means that a manufacturing company can accept or refuse responsibility for making the product according to the design specifications. Between firms, this decision is mostly based on ability of the manufacturing firm to deliver the final product to schedule, cost and required quality. When the design is finished, prototypes (B4) can be build which is a schedule-based form of coordination. Prototypes can have several purposes, for instance examining the design, finding process/product fit issues and addressing specific integration concerns.

2.2.3 Mutual adjustments

A supplier development committee (C1) provides an inter-firm forum to assist in improving supplier development programs. Gatekeepers (C2) gather information from suppliers and advise on technological matters. Producibility design reviews (C3) occur during the design phase and adjustments can be made based on those reviews. A product design review is a detailed reassessment of the configuration and tolerances of parts manufactured by a process and aim to improve product quality. Producibility/ manufacturing engineers (C4) are employees from suppliers who are asked to join the design team and advice on DFM/DFA (design for assembly) matters. Guest design engineer (C5) are technical specialists who are employees of a supplier and are located at customer (semi-)permanent. Those experts ensure effective integration of a supplier’s technological expertise with the customer’s needs and differ from C4 by content of work and involvement duration. Engineering changes (C6) can be proposed by manufacturing, marketing and customers and are changes within the product design. A site engineer (C7) is a customer employee who is used to provide specific input at the supplier firm to tackle ongoing difficulties at the prototype or manufacturing stage. Product support engineers (C8) assist quality, fit and finish issues at assembly and give feedback about valuable insights to the product designers.

2.2.4 Teams

Supplier development teams (D1) are set up with the purpose of raising supplier competence. They are formed by customers and assist suppliers in improving their operations performance regarding quality and reduction of manufacturing problems. Joint development (D2) is the involvement of suppliers at the pre-concept stage which enables manufacturing issues to be resolved upstream in the process. A joint product/process design team (D3) enables manufacturing engineers to begin developing process designs at an early stage and offer informal advice to product designers on manufacturability aspects of up-coming designs. Transition team (D4) means that design engineers are temporary brought full-time into the manufacturing process, after design sign-off to manufacturing. This enables quickly resolving of problems in the early stages of manufacturing.

2.3. Attributes of New Product Manufacturability

In the previous section it was described how design and manufacturing activities can be integrated successfully within a NPD project. Manufacturability is an important factor within these projects since this determines whether a design is actually producible. Within new product development projects manufacturability is often called new product manufacturability (Swink, 1999) and determines the degree of fit between the new product design and capabilities of the production process for a specific product (Adler, 1995). NPM indicates the ease and reliability with which a product can be produced using a certain manufacturing company's resources (Stoll, 1986; Susman and Dean, 1992; Youssef, 1994). In addition, this means design goals and manufacturing constraints have to be considered at the same time in order to identify and reduce manufacturing problems during the design process, thereby reducing the lead time and improving the product quality (Gupta & Nau, 1995). Gupta, Nau & Zhang (1993) also mention costs as a determinant for manufacturability. Manufacturability analyses are used to indicate potential manufacturing problems during the design phase and providing suggestions on how to eliminate them (Gupta, Regli, Das, & Nau, 1997). Various literature and calculation models can be found to measure the manufacturability of a product. Skander, Roucoules & Meyer (2008) propose a knowledge synthesis method that aims at integrating manufacturing constraints as early as possible during the product definition in order to reach high manufacturability. Gupta & Nau (1995) propose a systematic approach for analyzing the manufacturability of machined parts. According to them, the manufacturability of a design depends on the ability to produce the design within the specified specification, with low production costs and with low production time. In order to analyze the manufacturability, information about the proposed design, available manufacturing resources, available machining operations and information about process capabilities and dimensional constraints is needed. Kerbrat, Mognol & Hascoët (2011) determined indexes, based on an analysis of which design parameters have a big impact on time, cost and quality for a machining or an additive manufacturing process. Those indexes were linked to factors like: maximal dimension, cutting-tool flexibility, volume, skin surface, material hardness and surface roughness. However, to give a very detailed and extensive described method to measure the manufacturability is beyond the scope of this research. Costs, quality, lead time and ease and reliability with which a product can be made using a manufacturing companies resources, are used as manufacturability attributes for the purpose of this research.

2.4. The impact of ESI on the manufacturability of (semi)finished products

Researchers have different points of views regarding the impact of ESI on NPM. Swink (1999) found that the influence of suppliers is strongly associated with improved product manufacturability. Early supplier involvement leads to more communication between designers and downstream users like manufacturing and assembly, of product designs and also design support personnel. This increased communication on its turn leads to better new product manufacturability results (Fleischer& Liker, 1992). In addition, Zhu (2009) also confirms that early involvement of manufacturers improves manufacturability and helps accelerating product launch and reduce costs. Furthermore, product designers are better enabled to incorporate manufacturing related concerns such as manufacturability, maintainability and testability at the design state of a product (Swink & Nair, 2007) when more attention is given to design-manufacturing integration. Bonaccorsi & Lipparini (1994) conducted a case study and suggest that greater consistency among product tolerances and process capabilities, increased refinement of process designs and better availability of detailed process data are all advantages of early supplier within NPD which have positive impact on NPM. Lastly, manufacturing can play different roles in NPD according to Susman & Dean (1992), namely: informing designers about existing capabilities, suggesting design changes and designing a process concurrently with product design.

However, some research suggests that early and intense manufacturing involvement when conditions are highly uncertain can lead to more redesign rework and a longer development time (Ulrich et al., 1993; Ha & Porteus, 1995). The higher the numbers of organizational departments and technical specialists, the more difficulties NPD-processes face regarding coordination, evaluation of design trade-offs and in the simplification of designing steps (Clark, & Fujimoto, 1991; Griffin, 1993; Meyer & Utterback, 1995). In addition, the presence of too many people in the project makes the decision making, especially for early decisions, more difficult (Gerwin, 1993). When complexity increases, the dimensions of new product manufacturability dependencies increase as well. Besides this, it hides many facets of product-process fit that must be addressed to achieve high new product manufacturability (Swink, 1999). Lastly, it is often hard to find employees with broad practical manufacturing knowledge in combination with a strong understanding of new product development practices. This limits the success of early manufacturing involvement (Swink, 1999).

2.5. Research gaps

Based on the literature review, various research gaps can be identified. First, it was concluded that better NPM results are achieved when manufacturing and supplier personnel get more closely involved in NPD (Swink, 1999). According to this Swink (1999), empirical evidence of the direct impact of intense manufacturing involvement in NPD on new product manufacturability has been quite weak and their own evidence was also less conclusive than they desired.

Secondly, Swink (1999) findings suggest the need for more focused research studying the timing and the different types of early manufacturing involvement in NPD.

Lastly, what not has been discussed to date is the effect of a Knowledge Sharing Platform, aiming to stimulate inter-organizational collaboration and the emergence of newly bilateral contacts on early supplier involvement and product manufacturability. The aim of this research is to determine how the Knowledge Sharing Centre can stimulate collaboration between Manufacturing companies and Engineering companies which are involved within a NPD-project in order to improve the manufacturability of (semi) finished products.

3. Research method

In this chapter the research methodology is explained in more detail, paying attention to the overall research design, case selection and sampling, data collection and analysis, and validity and reliability.

3.1. Research design

The purpose of this research is exploratory. Exploratory research aims to seek new insights, ask new questions and assess topics in a new light (Saunders & Lewis, 2012). This type of research is used to explore those situations in which the intervention being evaluated has no clear, single set of outcomes (Yin, 2013). The reason to choose this type of research was, that no previous research has been done on how ESI with impact on NPM can be translated into the Knowledge Sharing platform. Exploratory research made it possible to find new insights which could contribute to the setup of the platform and belonging organization. Furthermore, it was chosen to use a multiple-case study approach. A multiple case study allows to analyze within each case and across cases (Baxter & Jack, 2008). Several cases were examined to understand the similarities and differences between cases. This was more appropriate than a single case study since great diversities exists among NPD-projects and the platform is not only intended for one single type. In other words, this type of research contributed to the understanding of several project types wherefore the platform could be useful. In order to answer the research questions and eventually the problem statement, qualitative semi-structured in-depth interviews with employees from engineering companies and manufacturing companies were conducted. Semi-structured means that questions were asked about a set of themes with some predetermined questions, but with a varied order in which the themes were covered and questions were asked. It was allowed to skip topics and ask additional questions (Saunders & Lewis, 2012). This type of research was of added value because it was unsure how respondents would answer and more in-depth questions could be asked when interviewees introduced new topics. The research started in January 2016 and finished in June 2016. The conceptual model for this research is shown in figure 1.

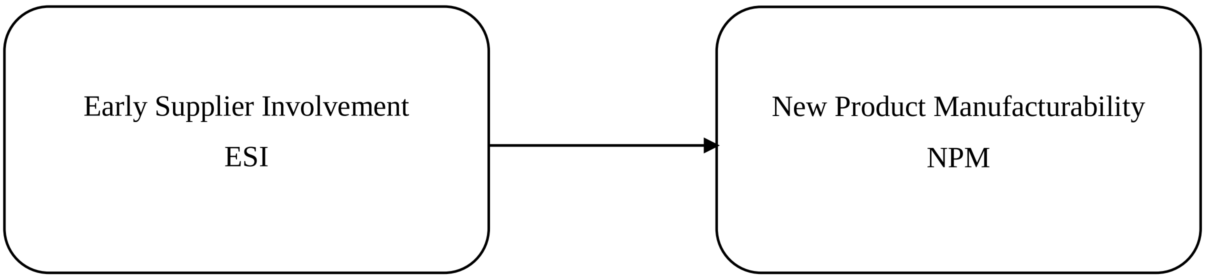

Figure 1 Conceptual model

3.2. Case selection

Five suitable cases were selected. With regard to the conceptual model and suitability for this project, four requirements were determined for case selection. First of all, it was required that a project had taken place with the purpose of developing a new (machine) part or new product. Secondly, manufacturing and engineering activities should have taken place at different companies. Thirdly, the project should preferably have taken place within ten years. Lastly, project data should be available through the possibility to conduct interviews with at least one expert. In addition, the successfulness of projects and the size of companies were also taken into account which has led to more diversified cases. In tables 2 and 3, case information is given. More specific company information like FTE, type of business etc. is not included because of confidentiality concerns.

Case	**Innovation type**	**Project duration**	**Interviews**	**Interviewees**	**Research remarks**
1	New technology and new machine part	2+ years	3	4	- Team leader present during interview with two manufacturing companies
2	New industrial product	4-5 months	2	2	- No interview with designer. - Director of Company 4 is also ex-owner of company 6
3	New industrial product	1,5 year	2	2	- No interview with Designer. - Ex-owner of company 6 is also director of Company 4 - Interview with manufacturing company was translated from dialect
4	New part for consumer product	Unknown	1 (and one preliminary interview)	1	- No interviews with other parties - Co-founder of platform present during interview
5	New machine part	2-2,5 year	2	3	

Table 2 Information on case studies

3.3. Sampling strategy

The primary data collection started with interviewing experts, as shown in table 3. At the beginning purposive sampling was used to collect data in cases one, four and five. It was important to collect cases that could give enough insight with regard to the conceptual model. Extreme and heterogeneous sampling was done in order to find patterns which are of particular interest and value, representing key themes and understanding or explaining more typical cases (Saunders & Lewis, 2012).

Case	Company number	Function	Referred to as interviewee	Field/role
1	1	Team leader	1	Design
	1	Designer	2	Design
	2	Owner	3	Manufacturing
	3	Account manager	4	Manufacturing
2	4	Division director	5	Client/ basic design
	5	Co-owner	6	Manufacturing
3	6	Ex-owner	5	Client/ basic design
	7	Co-owner	7	Manufacturing
4	8	Owner	8	Manufacturing
5	1	Supply Chain Engineer	9	Design/ supply chain performance
	1	Designer	10	Design
	9	General director	11	Manufacturing

Table 3 Interviewees per case study

One of the company clients of this research was closely involved within case one and five. It was therefore possible to determine which persons were most suitable to interview. A preliminary interview was done at company eight in order to understand and assess the potential cases. The most suitable case which could give the best insight was selected. The results of the case selection were two cases whereby manufacturing companies were involved very early and intensively and one case whereby no contact between design and manufacturing occurred. Convenience and snowball sampling were used to collect case two and three. These sample techniques contributed to the feasibility since the short time span of this research project was an issue.

3.4. Data collection and analysis

For the literature study, articles were gathered through Google Scholar and the database of Tilburg University and were often found with citation tracking, also known as reversed snowballing. This technique makes it possible to see which articles have cited a specific article. Existing papers about ESI and NPM were used for reviewing the literature and to build the conceptual model. This theoretical framework was the foundation for the topic list which was used during the semi-structured interviews (see Appendix I).

For the interview questions involving the NPD process, a V-model was used to indicate the phases (visualized in figure 2). The model has been selected because it is comprehensible and also used by the KSC.

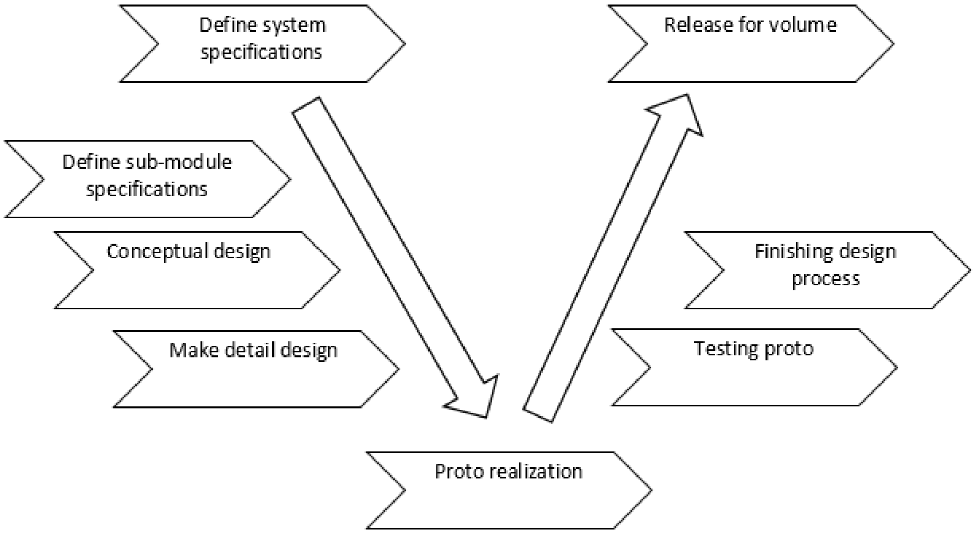

Figure 2 V-model KSC

Empirical data was collected in a case study setting. In total 10 semi-structured interviews with 11 experts from the companies who were involved during design and manufacturing stages of a NPD-project were conducted (see table 3). Five cases were investigated, making this a multiple-case study. This type of data collection ensures that the issue is explored through various lenses instead of one lens, which enables revealing and understanding multiple facets of the phenomenon (Baxter & Jack 2008). To answer research question 6, the third empirical research question ("How can the platform stimulate bridge building between the two pillars: engineering companies and manufacturing companies?"), primary empirical data was used from the interviews. Additional primary data has been collected by a project group consisting of international students Industrial Engineering and Management (IE&M) from the Fontys University of Applied sciences. The group did a qualitative research about the needs and the attractiveness of the Knowledge Sharing Centre for several types of companies. Their research was conducted during the same period of this master thesis and the group was under supervision of the author of this thesis. They defined communication disruptions that were recognized by companies involved in the new product development process, assess whether the initiation of the Knowledge Sharing Centre be useful to resolve the bottlenecks and how the Knowledge Sharing Centre should be set up to enable and support an efficient and effective communication within the new product development process.

When all empirical data was gathered and transcribed or summarized, codes were made based on the conceptual model and interview data. Interview fragments were coded with the coding scheme shown in table 4.

Code	Word	Meaning
ESI-D	Drivers	Drivers to get involved early or involve parties earlier within a project
ESI-IS	Issues	Impediments to get involved/involve parties earlier
ESI-C	Conditions	Conditions to get involved/involve parties earlier
ESI-KS	Knowledge sharing content	Knowledge which should be shared earlier during a NPD project
ESI-M	Moment of involvement	Moment when manufacturing company got involved during case project and what the ideal moment would be
ESI-SC	Selection criteria	Selection criteria for choosing supplier
ESI-Con	Way of getting in contact	Way a designing company and manufacturing company got in contact
ESI-Com	Commitment	Determinants which show manufacturers commitment to a project
DFM-I	Improvements	Proposed solutions and measures to improve manufacturability
DFM-R	Reason	Reasons for certain manufacturability
DFM-P	Problems	Problems and symptoms which determined manufacturability
DMI	Design manufacturing interface	Everything which has to do with the model of Twigg (2002)
KSC-C	Conditions	Conditions which should be met in order to get a party wiling to join the platform
KSC-J	Joining or not?	Motivation to join the platform
KSC-Con	Content	Proposed knowledge/information content for the platform
KSC-IS	Issues	Problems interviewees expect with the platform
KSC-Use	Usage of platform	How and wherefore a company want to use the platform

Table 4 Coding scheme

Those fragments were compared to determine important matters. For the first empirical question, information was bundled and presented in a descriptive way. For the second question, relations from each case were found within the data and compared with the other cases and completed with descriptive data. For the last question, information from the first two questions was translated into platform information, also incorporating additional insights from interviewees and the group of IEM students.

3.5. Validity and reliability

Reliability

Reliability is the extent to which data collection methods and analysis procedures will produce consistent findings (Saunders & Lewis, 2012). All interviews were recorded. Recording the interview can have a bad influence on the reliability because experts might be afraid to tell everything, because it is possible for other people to hear what they have said. However, all the information is considered confidential and this has been made clear to every interviewee. Recording can also have a positive impact on the reliability since parts that are not noted well during the conversation can be processed within the conversation report. Data coding also increased reliability. In addition, reducing interviewer and interviewee bias increases reliability. Interviewer bias was avoided by preparing well for the interview, listing well, focusing on the facts and testing findings by checking important parts with other interviewees. Interviewee bias was reduced by making them feel comfortable through showing respect and giving more background information about the research.

Moreover, bias is expected especially for the data regarding the third empirical research question. Because several interviewees are relations from the founders of the platform and the founders were present during 2 interviews with other parties, the opinion of some interviewees can be influenced, also known as subject bias (Saunders & Lewis, 2012). Moreover, some of them were very up to date of the idea and some never heard of the KSC. Besides, the concept of the KSC changed during the project since it was still an idea concept which adapted during the research. Therefore, most interview questions were focused on the case without mentioning the KSC. Research questions 4 and 5 were fully answered without the information that involved the KSC. Furthermore, in case 2,3 and 4, it was not possible to speak with the designer therefore there is a lack of information within these cases. The client, who also was basic designer, was interviewed in case 2 and 3 in order to get more information which was missing due to lack of interview with the designer. In addition, within case 2 and 3, the same person was involved at the client/design side. This is taken into account during analysis and the opinion of this person has not been counted twice were this would be inappropriate. In case 3 there was one interview translated from dialect to Dutch. Since the interviewee and author speak exactly the same dialect fluently, this is not a problem for interpretation of the results. Using multiple data sources provides increased reliability of data (Barratt, Choi, & Li, 2011), therefore the data from the student group was used and findings were compared with existing literature within the discussion chapter.

Validity

Validity is the extent to which data collection methods accurately measure what they were intended to measure and the research findings are really about what they pretend to be about (Saunders & Lewis, 2012). Regarding internal validity, it is important to point out that no conclusions could be drawn about causal relationships since it is not possible to say which factor causes another from anecdotal events (Sekaran & Bougie, 2013). Furthermore, to improve validity, interview questions were formulated in such a way that the interviewee had knowledge about it. Besides this, the topics that were discussed during the interview are based on the literature study. External validity was less important for this research since there was no explicitly formulated purpose of producing a theory which is generalizable to all populations (Saunders & Lewis, 2012).

4. Results

This chapter presents the results which should answer the practical research questions formulated in section 1.3. Section 4.1 gives relevant information regarding ESI in a descriptive way. Next, the influence of ESI on NPM is determined in 4.2. Section 4.3 contains information about how KSC can stimulate bridge building between manufacturing and design companies. This chapter is concluded with a discussion on the research findings in section 4.4.

4.1. Improving and stimulating early supplier involvement within NPD-projects

In the first sub-section the preferred moment of manufacturing involvement during NPD projects is explained. Next the drivers which motivate companies to involve parties earlier or get earlier involved are presented. The third sub-section presents impediments which hold companies back from ESI and the last one discusses conditions a project situation should meet in order to enable ESI.

4.1.1 Moment of involvement

First it was determined which moment manufacturers were involved during the NPD projects based on the phases of the V-model. Then, all interviewees were asked which moment of manufacturing involvement would have been most suitable. These results are visualized in figure 3.

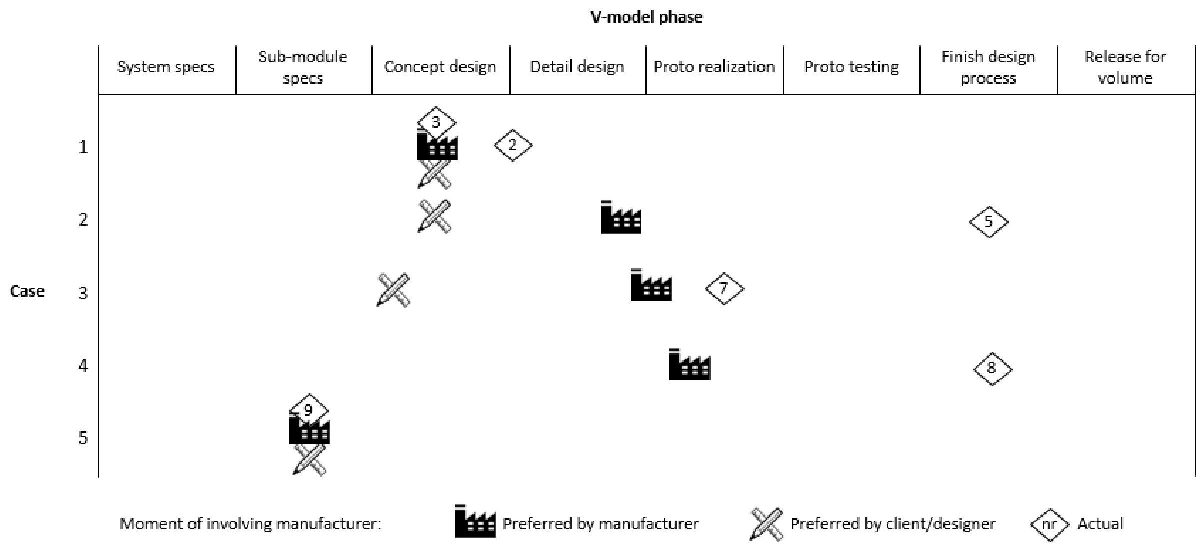

Figure 3 Moment of manufacturing involvement

It turns out all designers agreed that most suitable moment of manufacturing involvement is before or within the conceptual design phase. For three cases, however, the manufacturers were involved in a later stage. According to the designers, reasons were lack of knowledge about how to handle such projects, unexpected large sales so another manufacturing company was needed and for one case it is unknown. The designers from the other two cases knew that their projects could not be done without very early manufacturing involvement because of unfamiliarity with the technology or lack of a solution for the concerned problem. Interviewee 1 (case 1) states: *The image we have as a company is: we cannot do it alone and we need our suppliers to achieve good solutions.*

From the manufacture's point of view, for three cases the best moment was between/during make detail design and proto realization. According to them, just a concept is not complete enough and lacks too much information. Interviewee 7 (case 3) states: *At the concept phase, you can't say anything, it's just an idea. Thus getting involved before detailed design adds no value.* In addition, according to interviewee 11 of case 5, it depends on the manufacturing knowledge of the design party to determine the best moment of involvement. He states: *Starting before concept phase is important when design companies are not familiar with the techniques and technology. You should know the basics if you want to make the project a success. It is very difficult to talk about concepts if the technology is completely new for a designers company*. Interviewee 1 (case 1) states that *projects are too diverse and people are too diverse within a project, it is therefore not determinable where in the V-model, a company should get involved.* All in all, the exact moment of manufacturing involvement depends on several factors. It should, however, be before the end of the 'proto realization' phase and after the 'define system specifications' phase.

4.1.2 Drivers for ESI

Companies do not just involve parties earlier or stay earlier involved without reasons. All companies mentioned drivers or potential drivers for the other parties, as summarized in table 5. Some interviewees mentioned commercial drivers like making profit from it and the increased chance of getting a project. Interviewee 7 (case 3) states: *For us it is important to get new projects, preferably for a longer period.* Some drivers are non-commercial and short-term focused for example: increased project results and motivation to find solutions. Some examples of drivers which are focused on long-term advantages are knowledge gaining and bonding with/meeting companies. Lastly, other drivers were more personal like loyalty to other parties, believe and commitment from client, technical drive/challenge and fun they get from being involved early within the project. Interviewee 3 (case 1) indicated: *Because we were two companies who didn't want to give up on each other, we survived.* In conclusion, companies are driven to involve parties earlier or get involved earlier because of a combination of (non-)commercial short-term, long-term and personal drivers.

Interviewee	Loyalty to other parties	Believe and commitment from client	Earning money	Bounding/meeting company	Increased chance of getting project	Technical Drive / challenge	Motivation to find solution	Fun	Knowledge gaining	Increase project results
1						X	X			
2				X		X	X	X	X	
3	X	X				X	X			
4	X	X		X		X	X			
5										X
6			X		X					
7				X	X	X		X		
8			X		X					
9									X	X
10									X	X
11										X

Table 5 Drivers mentioned by interviewees

4.1.3 Impediments

The previous section indicates why companies may want to be involved earlier or want to involve suppliers earlier. However, there are also impediments which hold companies back from ESI, as shown in table 6. Firstly, there are organizational impediments like amount of involved parties, capabilities of the involved parties and the size of the companies. Interviewee 1 (case 1) declares that involvement of too much parties within a project causes problems and delays, stating that *innovating with too many parties often leads to nothing.* One interviewee from a manufacturing company explained that cooperating with large design/client companies can cause bureaucracy issues. Another manufacturing company's focus is not on 'thinking' with other companies since the size of the company is too small and they need all employees for production activities. One of the designers mentioned that the supplier is not always chosen at an early stage and design employee is not always in the position of choosing the supplier since that's the task of purchasing personnel. This makes it harder to enable ESI. Sometimes suppliers are not suitable for the job of thinking along with the other party because for instance they are not familiar with the field of expertise of the other party or employees cannot think outside the box.

Secondly, there are also issues regarding cooperation like different focus/culture and opportunistic behavior. Design and manufacturing do not always have the same focus. The designer is often concerned about the functionality and the looks of the product, whereas manufacturing is more focused on manufacturability.

Interviewee	Too much parties involved	Party not able to help thinking	Bureaucratical problems	Different focus or culture	Not enough earnings	Opportunistic behavior	Supplier unknown at early phase
1	X			X			
2		X					
3			X				
4							
5				X			
6		X			X		
7						X	
8					X	X	
9					X		
10							X
11		X				X	

Table 6 Impediments mentioned by interviewees

Involvement of parties with all different kinds of focus can give conflicts of interest. Opportunistic behavior is explained several times as a situation whereby a party involves a manufacturer early to gain information and knowledge and after the finishing of design goes to another party, bypassing the involved manufacturer. Interviewee 6 (case 2) argues: *And then a customer goes to other parties which may be cheaper, but did they spend half an hour with those parties around the table? No, exactly. That is the dilemma we are facing every time*.

Lastly, there are commercial impediments. For several manufacturers it is hard to get involved early when there are no agreements regarding return on investment, time and energy. When a company has been intensively involved in a very early stage while not getting an order at the end of the project or no budget was agreed for the time they spent thinking with the other party, it can cause problems in terms of negative earnings. Several interviewees stated that earlier involvement was pleasant but not always affordable.

In conclusion, various organizational, cooperation and commercial impediments can cause companies to be reticent when it comes to ESI.

4.1.4 Conditions and signs of commitment

The NPD project situation should meet some requirements and show commitment from both sides to enable ESI (see table 7).

Interviewee	Help thinking	Relationship with other party	Trust	Knowledge sharing	Respect	Order/ budget	Not going to other party with knowledge	Way of working	Be proactive
1	X	X	X	X	X				
2									
3			X	X					
4			X	X					
5	X								
6		X	X			X	X		
7		X		X	X	X	X		
8						X	X	X	
9	X								X
10	X			X					X
11	X			X		X	X	X	X

Table 7 Conditions and signs of commitment

First of all, some relational conditions were mentioned. Trust and respect were mentioned several times as very important. Other factors mentioned in the interviews were: being familiar with each other, a connection between the involved parties and the presence of a long-term relationship. However interviewee 7 (case 3) disagreed about the latter stating: *No, for us it doesn't matter, the company I'm talking about said from the very beginning: help thinking.*

Secondly, the project environment has to meet some behavioral conditions. Very important is that all parties are willing to share relevant information. The purpose, order quantity and product function is for instance important information for the manufacturer in order to decide which production methods are most suitable. More about knowledge sharing content can be found in section 4.2.3. Moreover, all manufacturers declared that when specific knowledge is shared and the other party goes to a competitor, there will be no collaboration between those companies in future. This is also acknowledged by most of the designers/clients. Interviewees indicated that help thinking and being proactive seem to be important indicators for showing the other party is committed to the project. Additionally, it is important that manufacturing companies help by providing solutions and help solving problems. From the 5th case it turns out that being proactive is needed in a form of providing and processing feedback. Interviewee 9 (case 5) states: *Here we expect from the manufacturing company proactively approaching and industrializing of feedback in order to realize producible batches.* Other matters regarding way of working are that project managers and purchasers must be aware of common product cost and the field of interest. All parties must also agree on the same way of working and create understanding for each field of expertise.

Finally, almost all manufacturers want to have commercial safety in the form of an agreement about getting the order or a confirmed budget when they are involved early. This can depend on the size of the project, the time and energy required from the manufacturer and whether general or specific information is shared. In conclusion, within the ESI environment there have to be signs of commitment and the situation has to satisfy specific relational, behavioral and commercial conditions.

4.2. Influence of ESI on new product manufacturability and DMI

In the first sub-section information is provided about the influence of ESI on manufacturability. Sub-section two elaborates on the design-manufacturing interface (DMI) of Twigg which gives detailed insights in the mechanisms to integrate design and manufacturing activities. In the last sub-section more insights are provided on the types of information contents that have to be shared during a NPD process.

4.2.1 Influence of ESI on manufacturability

Early supplier involvement has impact on the manufacturability of newly developed products in terms of costs, quality, lead time and ease and reliability of with which a product can be produced. Some examples and relations on these determinants are discussed below. In appendix II more information can be found about the manufacturability of new developed products and causes per case.

Costs

Costs is an important determinant for product manufacturability. First of all, two companies from different cases state that advising about material use will eventually result in cost reductions. For example, Interviewee 8 (case 4) stated: *If the end user would involve me before the proto phase and says: we want to make a product and it can only cost 3 euro's and 51 cents, than you know what kind of material can be used an we can say: dear customer, you should use a different material. This is knowledge we have to offer.*

In addition, advising on tolerances has an impact on costs, as was found in two cases. The price can be lowered since for instance design post processing steps are reduced. Interviewee 2 (case 1) states: *They could indicate that with certain tolerances the model could be made and therefore less post processing steps would be necessary, thus that was very interesting for the price.* Furthermore a company can give an estimation of the impact of a design on the production process which can also result in lower costs. No involvement of manufacturing within design can lead to corrective solutions to, for example, solve design mistakes in a more costly way than should be necessary.

The lock-in effect is a negative impact on costs which can arise when manufactures are involved early. It occurs when a designer is committed to a specific manufacturing company and its technology because the design is adapted to the manufacturers process capabilities and constraints . Furthermore, feedback on design and advice about the way a part should be assembled in a machine would lead to reduced designs and therefore lower cost.

Quality

Secondly, a relation which occurred in cases 4 and 5 was ESI leading to advice on material behavior which had a positive impact on the quality of a product. Interviewee 8 (case 4) states: *We would not have been able to go into detail as we can do now, we became smarter during the project. But for example about the color black, we could have given the following advice: every pollution is visible.* Material behavior can have much impact on the quality of a product of which a designer isn't always aware due to lack of experience with a certain production technique. With ESI designers can be informed about those matters and enable designers to take certain aspects into account during the designing process.

Lead time

Thirdly, ESI leads to advice on material behavior which can have a positive impact on NPM like in the following example: Interviewee 8 (case 4) argues *Then we could have told at the beginning: if you want to make or have this product, be aware of the size of the purchased raw materials. We need to cut it in smaller pieces which leads to mechanical stresses. The material deforms when this happens which means that it becomes more difficult to mill and suppress and then we need on average 'this amount of' time for milling and handling.* Advising on costs and manufacturability matters and feedback on the design would lead to reduction of useless designs like interviewee 6 (case 2) states: *They didn't realize that there were operations added which were not necessary, milling a part for instance. Some of them told me: if we would have known this from the beginning, we would never have designed this.* ESI would have led to a reduction of superfluous production steps which in turn would have reduced process lead time.

Ease and reliability

Lastly, the impact of ESI on the ease and reliability with which a product(part) can be made with available manufacturing resources was indicated in some cases. Advice about tolerances impacts the ease and reliability of the production process according to interviewee 8 from case 4 who states*: We were not asked to think about tolerances of this thing. Making this device, can be done with a certain tolerance. When it becomes smaller, the straining has to be smaller as well. When the straining is smaller, less products can be made and the price increases. We can indicate the effect of high tolerances in terms of price, size of raw material and amount of products which can be made with one piece of raw material.* According to interviewee 11 (case 5) advice on the design of the production tools to be used during the production process would impact the ease and reliability of production: *When someone from* *the manufacturing side thinks a mould should be made in a certain way because the result will always be sufficient and someone from the design side with general designing knowledge, but no specific material/field of expertise knowledge, thinks it should be done in a different way, then it can result in a disappointing mould design for both parties. While talking from the beginning would probably have led to a different mould design.* Additionally, discussing possible problems and advising about material behavior also impact the ease and reliability.

4.2.2 Design-manufacturing interface and the influence on manufacturability

The design manufacturing interface of Twigg (2002) can be used to integrate design and manufacturing operations in product development. Table 8 indicates per case which mechanisms were present, absent and not mentioned in order to indicate relevant mechanisms which may can contribute to stimulating and improving collaboration between those two parties. Since not all mechanisms were thoroughly discussed during the interviews, the author's interpretation of the case data has led to table 8. . Case descriptions including the present use of coordination mechanisms are included in appendix II.

Case		Present	Absent	Not determinable
1	A Standards	A4 (partly), A5, A6, A7	A4 (partly)	A1, A2, A3, A8
	B Schedules and plans	B4		B1, B2, B3
	C Mutual adjustment	C7, C3, C4, C6		C1, C8
	D Teams	D1, D2, D3, D4,		
2	A Standards	A4 (different phase)	A1, A2, A3, A5, A6, A7	A8
	B Schedules and plans	B4 (partly)	B4 (partly)	B1, B2, B3
	C Mutual adjustment	C3(different phase), C6	C1, C2, C4, C5, C7	C8
	D Teams		D1, D2, D3, D4	
3	A Standards	A4 (different phase),	A1, A2, A3, A5, A6, A7	A8
	B Schedules and plans	B4		B1, B2, B3
	C Mutual adjustment	C3 (different phase), C6	C1, C2, C4, C5	C8, C7
	D Teams		D1, D2, D3, D4	
4	A Standards		A1, A2, A3, A4, A5, A6, A7, A8	
	B Schedules and plans		B4	B1, B2, B3
	C Mutual adjustment		C3, C4, C5, C6, C7	C1, C8
	D Teams		D1, D2, D3, D4,	
5	A Standards	A1, A5, A6	A2, A3, A4	A7, A8
	B Schedules and plans	B4		B1, B2, B3
	C Mutual adjustment	C7, C3, C4, C6,		C1, C2, C5, C8
	D Teams	D1, D2, D3, D4,		

Table 8 Coordination mechanisms

A first conclusion based on table 8 and appendix II is that cases 1 and 5 deploy much more mechanisms compared to the other cases. In these cases manufacturing was involved during early phases. The less timely involvement of manufacturing, the less mechanisms were present. However, from the case descriptions in appendix II it also becomes clear that this doesn't necessarily lead to higher manufacturability. The scope of this research was not to give a detailed explanation of the case outcomes related to this model. Since the presence or absence of all mechanisms could not be established for all cases, it is not possible to state what the exact influence on manufacturability is of all mechanisms. More research is needed on this relationship. Examples of mechanisms that contribute to manufacturability and were explicitly mentioned during the interviews are designers' tacit knowledge of manufacturing, cost management, CAD/CAM data exchange, design rules and producibility design reviews. Lack of designers' tacit knowledge of manufacturing was, quite surprisingly, mentioned several times as a cause of lower manufacturability. They also declared that the education institutes of the designers could have major impact on their level and amount of Manufacutring knowledge, which is often limited. It can, however, not be determined from the case results whether these are more important than the other mechanisms and how big their influence exactly is on the manufacturability.

4.2.3 Knowledge sharing content

When manufacturing companies are earlier involved, feedback and advice can be given on design and manufacturability matters. It seems that the shared knowledge between design and manufacturing contributes to manufacturability. More in-depth questions were asked about the specific content that should be shared between design and manufacturing within NPD projects. An overview of the interview findings is given in table 9.

Interviewee	Material	Tolerances	Manufacturability matters	Manufacturing resources	Test/project results	Product information	Order quantity	Price target	Environmental advice	Matters field of expertise
1	X				X					
2	X	X	X	X	X					
3	X				X	X				
4	X									
5		X		X		X	X	X		
6			X	X						
7	X	X	X			X	X			
8	X	X	X							
9	X	X							X	
10	X	X	X	X		X				
11	X				X					X

Table 9 Knowledge sharing content in the five case studies

The five content categories which were mentioned in most different interviews are material information, tolerances, manufacturability matters, available manufacturing resources and product information. First of all, material information can be material characteristics like a friction coefficient, hardness, roughness or behavior under specific circumstances. Secondly, tolerances was mentioned in several cases. The chosen tolerance accuracy has significant impact on the ease and reliability with which a product can be made using a manufacturer's resources. Interviewee 6 (case 2) stated: *Tolerances are often misused. When accuracy is too high, the product becomes unnecessarily expensive*. Thirdly, manufacturability matters can be potential problems a manufacturer thinks that will occur, the impact of design decisions including material choice on manufacturability, process times and other production constraints. For example, sometimes designers include special forms which require a lot of processing time but are not necessary. Fourthly, available manufacturing resources concern available materials, tools and operation processes. The first two are important because sometimes a designer picks a material which is not standard available at the manufacturer and the manufacturer has to buy this specially for the customer, while another material type could also be used. The same goes for tooling. If for instance the designer designs a hole of 1.1 mm, maybe the manufacturer needs to buy new tools for this hole. But 1.2 mm was also fine and the corresponding tool was available at the manufacturer.

In contrary of the other four, product information has to come from the client or designer. This can for instance be the function, environment it is going to be used/installed in, bill of material and the purpose of the product. When the manufacturer is aware of these things, it can help them by proposing design improvements.

When information content is communicated earlier in the NPD process, it often leads to a more efficient design process and design changes. The process becomes more efficient because less unusable designs will be made. Design changes can prevent useless prototypes. These changes and increased efficiency will have impact on lead time, costs, quality and the ease and reliability with which a product can be produced like already explained in sub-section 4.2.1.

4.3. Stimulating bridge building between engineering and manufacturing

Results from the research of the IEM group of students and additional information from the interviews are used to answer the research question: "How can the platform stimulate bridge building between the two pillars: engineering companies and manufacturing companies?". Within this section results regarding the usage, impediments, conditions and knowledge sharing content of the KSC are presented.

4.3.1 Usage and impact on manufacturability

Interviewees mainly mention two ways to use the KSC platform, namely: looking for the right supplier and find important information earlier in the process. First, from cases 1, 2, 4 and 5 it seems that the KSC could have created awareness of production process steps and design constraints earlier during the development cycle. The advantage of this awareness are the ability to speed up subsequent process steps, prevention of problems, reduction of review moments and reduction of time explaining designers which matters they should take into account during designing. A designer for example declared that when he designs something which hardly can be made, he would go to the platform and try to find whether it is possible or try to contact a company. However, for easy design purposes, the platform was considered less useful stating: *When I am going to design just an easy party with a hole, I hardly need to contact companies. Usually I will get it done, it's low risk. I only contact companies if it is very difficult.*

Secondly, in cases 1 and 3 it was mentioned that exploring the supplier market with the KSC would be useful. Additionally, in Case 5 this would have been the case if there were at least two companies with the required expertise participating within the platform. Interviewee 5 (case 3) mentions: *The KSC could stimulate earlier and more in-depth communication between the parties. A second advantage would be that a broader discussion forum could arise. Now it was between me and one other person. Imagine you could have involved more persons, it may have resulted in another idea..*

Lastly, interviewee 2 (case 1) mentioned that the platform could be useful for determining requirements which happens during the high level design phase if knowledge institutes are also participating.

4.3.2 Impediments

Impediments can cause potential participants to hold back from participating within the KSC. Five interviewees did not mention impediments while the other five did. First of all, one interviewee from the design side is afraid that companies, especially the ones with complex and unique techniques, are not willing or afraid to share their knowledge because competitors can misuse this. Interviewee 2 (case 1)explained: *and then you reach the spectrum of companies which are probably not willing to share because they can do something very uniquely. That is why I am rather reluctant.* Interviewee 6 from case 2 confirms this by stating: *When you share all your knowledge, it is very easy to find everything because all knowledge is there. Why are you going to A and not to B? Because it is better at one of the two. When everything is shared, maybe every company will be the same at the end since everything is public.*

Secondly, two interviewees think the platform is not suited for all projects. One thinks the platform is not suited for very complex projects. The other states it would have been barrier since as less as possible involved parties were preferred. Several parties think the structure of the platform will be too complex and therefore is not going to work. Interviewee 7 (case 3) for instance states: *I'm not sure whether it will function. I have my doubts about it. I think it will be costly as well.*

Thirdly, interviewees think the platform will be too complex and costly and other matters are more decent to increase manufacturability.

Lastly, it was indicated that it is not only up to designers to approach a manufacturing company since purchasing often has a history with (potential) suppliers. If purchasing would not be involved, it could lead to problems like wrong selection of supplier and approaching companies which should not be contacted. Interviewee 5 (case 3) explained: *Purchasing departments have historical information about those companies. Something could have happened in the past like a quality issues which was not solved properly. Then a purchaser can say to the designer: nice that you approached this company, but we are not doing business with them. Those situations occur regularly. The designer can impossibly assess whether something like that happened in the past.* This phenomenon was confirmed by interviewees 9 and 10.

In conclusion, companies can be afraid to share knowledge, doubt platform fit with project, fear complexity and usability of the platform and think it's not going to work if purchasing is not involved.

4.3.3 Conditions

Conditions which were mentioned are very diverse. Examples from the manufacturing side were up-to-datedness and the platform should stimulate bonding. If the knowledge provided at the platform is not up to date, participants will stop using it after a while. One point which was already mentioned in the previous section is purchasing involvement. Three interviewees think it is a must to involve purchasing since they are always involved within those projects. Also the supply chain from first tier suppliers has to be taken into account according to Interviewee 9 (case 5): *not only first tiers should be participating, but also companies with critical process steps otherwise they would be involved too late and things you want to tackle early appear too late. The designer should be aware that there is more than just the first tier*. Doing business with a company means often doing business with companies were the first tier outsources processes. Further mentioned aspects regarding the information are protection of intellectual property should be taken into account, very specific knowledge should be included and for every field of expertise more than one manufacturing company should be participating. Lastly, A helpful and cooperative culture is considered as important. Interviewee 4 (case 1) states: *This working style should fit the participating companies. You can't work with companies who need a detailed design from A to Z.*

4.3.4 Knowledge sharing content

Interviewees were asked which company information is considered as relevant platform content and which knowledge should be shared during bilateral contact moments.

General company information

Two interviewees mentioned content regarding general company information. Interesting for them to know is the niche or industry a company is operating in. The strategy and core competences are important (customer intimacy, operational excellence) as well which was explained by interviewee 5 (case 3) as follows: *Are they at the customer intimacy side or operational excellence? One company is able to give me more attention than the other. I want to know the niche market of a supplier. Am I* *interesting to them?* Further aspects were back up production locations and whether the organization is suited for new product introduction processes (like ability to provide support during proto phase).

Company's manufacturing process

The student group mentioned manufacturing & production techniques of a company as important content and differentiated into basic and specialized knowledge. In addition, many aspects were mentioned about the manufacturing processes of a company. General process information was mentioned several times and also found by the student group, for example the explanation of the process per production step and which operations a company can perform. Difficult techniques which can't be done by all companies in that field of expertise are of particular interest. Available machines and tooling (like drill types) information, surface roughness and accuracies that can be reached with examples of products are relevant. Also important is the ideal batch size since the batch size influences the cost price of a product.

Company's supply chain

In two cases, the supply chain of a company was mentioned. Most companies outsource some process steps. Designers want to know which processes are outsourced and to which companies because this can have impact on, for example, preferred tolerances. Interviewee 9 (case 5) stated: *Sometimes I talk to first tier companies with their own supply chain and most of the time I don't know where processes are outsourced. First tiers always determine the tolerances, but when I go to the second tier sometimes they say: no, this doesn't work for us. They prefer other tolerances. The supply chain of manufacturing companies is important. A mismatch occurs often.*

Design/manufacturing constraints

The student group identified design constraints as a general category. Do's and don'ts, consequences of design decisions in terms of costs and other design constraints and rules are very important information contents for the platform. Depths and sizes of holes and possible tolerances all described including involved costs were mentioned by several interviewees. Also measurements was mentioned by one interviewee and the IE&M group also indicated this as important information. In addition, interviewee 5 wants to know how much a design has to be specified before the manufacturing company will be willing to get involved.

Material knowledge

Material types that a company can process, material combination possibilities and potting materials were mentioned as interesting information for the platform. In addition to that, the IE&M group indicated material risks and properties as important platform content.

Other types of knowledge

Knowledge gained from new projects and testing results are of value and should be made available for participants according to the student group and two interviewees. In-depth knowledge and specialized knowledge are also important for some parties, which was also found by the student group. The group indicated that the usage of the parts is important. Furthermore, they identified the most preferable form wherein the knowledge should be presented, namely:

- Images, videos, explanations
- Examples from practice
- Technical documentations
- Specification of products
- Templates, datasheets
- Case study
- Company information (specialization, machines)

4.4. Discussion

In this section, important findings are discussed and compared with and related to existing literature. Discussed elements are about the project environment in order to support ESI, what this means for the platform and how it impacts manufacturability.

Moment of involvement

Swink (1999) stated that more focused research studying the timing and the different types of early manufacturing involvement in NPD is needed. The data results of this research indicate that companies should get involved between ‘Define sub-module specifications phase’ and ‘proto realization phase’ of the V-model. The factors which could influence the moment of involvement are the ‘complexity of the project’ and ‘designer’s knowledge of manufacturer’. However this is open for future research.

Role of purchasing

The role of purchasing was not explicitly taken into account in this research, yet it should have a role in the platform according to the interviewees. This finding is in line with Servajean-Hilst & Calvi (2016) who pointed at the relevance for companies to involve the purchasing department within NPD. According to them it contributes to firm’s innovativeness through thinking of new (external) resources and new components, the generation of a “make-or-buy” analysis and by aligning and secure internal interfaces. Purchasing departments also manage the relationships of external parties involved in the NPD-process through their scouting, selection, by defining contracts and organizing follow-ups.

Drivers

The KSC should take long-term, short-term (commercial and non-commercial) and personal drivers into account. Short-term drivers are increased profit, increased chance of getting a project, increased project results, motivation to find solutions. Eisto et al. (2010) confirmed that improved project results is an advantage and named time saving, cost savings and improved quality as indicators for this short-term driver. Some examples of drivers which focus on long-term advantages are knowledge gaining and bonding with/meeting companies. Wynstra & Van Eechtelt (2000) gave the following examples for long-term advantage: increased efficiency and effectiveness of future collaboration, access to technologies and knowledge, long-term alignment of technological strategies and possibilities to influence future technology. Lastly, other drivers were more personal like loyalty to other parties, trust and commitment from client, technical drive/challenge and satisfaction they get from being involved early within the project.

Platform usage

The KSC will mainly be used for creating awareness of production process steps and design constraints earlier during the development cycle and to find suitable suppliers for project participation. However, some interviewees doubt the added value of the platform due to the expected complexity of the platform structure and the expected unwillingness of participants, especially for the one with unique expertise, to share their specific knowledge. It was also doubtful whether the KSC is a suitable facilitator for all project types. Various differences could be determined from the case data in terms of duration, complexity, development goal, involved FTE's and amount time and resources which were spent.

Knowledge sharing

Knowledge that should be shared during the project and may should become platform content or shared knowledge during bilateral contact is general manufacturing process information of a company (like available resources), product information, material information, information regarding the company's supply chain and design/manufacturing constraints (like tolerances). In addition, Kerbrat, Mognol & Hascoët (2011) determined indexes, based on an analysis of which design parameters have a big impact on time, cost and quality for a machining or an additive manufacturing process. Those indexes were linked to factors like: maximal dimension, cutting-tool flexibility, volume, skin surface, material hardness and surface roughness. Product information has to be revealed by the designing company. Eisto et al. (2010) state that those parties often do not share enough product information when there is a lack of trust, which makes it difficult for suppliers to propose design improvements. Furthermore, the platform content has to stay up-to-date and of good quality. Intellectual property should also be taken into account when proprietary information is shared. The case findings indicated that parties are sometimes afraid to share their knowledge, because they are afraid competitors can misuse this. The latter was also found by Eisto et al. (2010).

KSC culture and environment

Agreeing on the same way of working, willingness to share information and knowledge and creating understanding for each field of expertise are important elements for the success of a NPD project. Help thinking, providing solutions, help solving problems and a proactive attitude show manufacturers' commitment to the project. Trust and respect for each other are also important. Trust was also mentioned by Wynstra & Van Eechelt (2002) and Eisto et al. (2010). Conflicts of interests should be solved and opportunistic behavior should be prevented or dealt with otherwise future projects are difficult to achieve with the same parties. Wasti & Liker (1997), Farr & Fisher (1992) and Wynstra & Van Eechtelt (2000) state that past experience of collaborations is an enabling factor for integrated product development and sourcing processes. Swink (1999) argues that a collaborative new product development environment has important influence on new product manufacturability.

Financial safety

For several manufactures it is hard to get involved early when there are no agreements regarding return on investment, time and energy. No agreement on budget or order guarantee can lead to negative earnings. Almost all manufacturing companies want to have some form of commercial safety. In which form depends on the size of the project, the time and energy required from the manufacturer and whether general or specific information is shared. Eisto et al. (2010) discovered that benefits are not clear for all involved parties and not all companies benefit from ESI. If advantages cannot be proved, it is difficult to start a new collaboration or to continue an old one. If it is not beneficial to all companies, the relationship will probably fail in the long run. Furthermore, a possible explanation for the required financial safety is lack of trust. According to Eisto et al. (2010) lack of trust can result in suppliers being unwilling to participate in designing when there is no contract agreed for the suppliers input.

Impact of coordination mechanisms on NPM

Early involvement of manufacturing companies does not automatically lead to high manufacturability. Examples of Twigg's (2002) mechanisms that contribute to manufacturability are designers' tacit knowledge of manufacturing, cost management, CAD/CAM data exchange, design rules, the use of prototypes and producibility design reviews. However, based on this research it cannot be determined whether these are more important than the other mechanisms.

Impact of ESI on NPM

Early manufacturing involvement leads to manufacturing companies advising and giving feedback to designers about manufacturability matters like material behavior, tolerances and process capabilities. This corresponds with findings of Susman & Dean (1992), who stated that manufacturing personnel can inform designers about existing capabilities, suggest design changes and design a process concurrently with product design. According to the data this leads to design changes and increased efficiency in the design process, which leads to higher quality, less costs, reduced lead time and increased ease and reliability with which a product can be produced using a manufacturing companies' resources. Fleischer & Liker (1992) stated that increased communication between manufacturing and design personnel leads to better new product manufacturability results. An explanation can be that product designers are better enabled to incorporate manufacturing related concerns such as manufacturability, maintainability and testability at the design stage of a product (Swink & Nair, 2006) when more attention is given to design-manufacturing integration. Bonaccorsi & Lipparini (1994) suggested that greater consistency among product tolerances and process capabilities, increased refinement of process designs and better availability of detailed process data are all advantages of early supplier involvement within NPD which have positive impact on NPM.

An example which shows a negative impact of ESI on NPM is being locked into a particular manufacturing company which can potentially result in high costs. This was also stated by Petersen, Handfield & Ragatz (2005) who state that this is especially a disadvantage when there are many competing technologies trying to become the industry standard. Furthermore, involvement of too many parties can slow down the NPD process. When more parties are involved there are more difficulties facing NPD-processes regarding coordination, evaluation of design trade-offs and in the simplification of designing steps (Clark, & Fujimoto, 1991; Griffin, 1993; Meyer & Utterback, 1995) and it can make decision making, especially in early phases, more difficult (Gerwin, 1993). It was also found that involving companies which are not really suited for a certain project can cause a lot of quality problems. Swink (1999) states that it is often hard to find employees with broad practical manufacturing knowledge in combination with a strong understanding of new product development practices. This limits the success of early manufacturing involvement (Swink, 1999).

5. Conclusions, limitations & recommendations

5.1. Conclusions

The main objectives of this research project were to determine the impact of early supplier involvement on new product manufacturability and to indicate how the Knowledge Sharing Centre could facilitate this by stimulating inter-organizational collaboration. The results of this research show that ESI has impact on manufacturability of newly developed products.

Firstly, early supplier involvement (ESI) occurs when a customer involves its supplier at an early phase into New Product Development (Eisto et al., 2010). 'Early' signifies that suppliers are involved during the concept stage or during early feasibility studies to ensure that suppliers can influence early design decisions (Vuori, M., Johnsen, T. & Viitamo). Secondly, new product manufacturability indicates whether a design which has been made during the design phase, is actually producible and determines the degree of fit between the new product design and capabilities of the production process for a specific product (Adler, 1995). Moreover, it indicates the ease and reliability with which a product can be produced using an organization's manufacturing resources (Stoll, 1986; Susman &Dean, 1992; Youssef, 1994). It involves considering design goals and manufacturing constraints at the same time in order to identify and mitigate manufacturing problems while the product is being designed, thereby reducing the lead time, improving the product quality (Gupta & Nau, 1995) and reducing costs (Gupta, Nau & Zhang, 1993). Thirdly, ESI can indeed have a positive impact on manufacturability, but can have a negative impact as well. ESI enables more communication between design companies and manufacturing companies enabling manufacturers to inform designers about existing capabilities, suggesting design changes and designing a process concurrently with product design. This increased communication leads to better new product manufacturability results (Fleischer & Liker, 1992) like greater consistency among product tolerances and process capabilities, increased refinement of process designs and better availability of detailed process data (Bonaccorsi & Lipparini, 1994). However, involvement of too much parties can lead to more difficulties NPD-processes face regarding coordination, evaluation of design trade-offs and in the simplification of designing steps (Clark, & Fujimoto, 1991; Griffin, 1993; Meyer & Utterback, 1995) and makes the decision making more difficult (Gerwin, 1993). Early and intense manufacturing involvement under conditions of high uncertainty can also lead to more redesign rework and a longer development time (Ulrich et al., 1993; Ha and Porteus, 1995). Moreover, it is often hard to find employees with broad practical manufacturing knowledge in combination with a strong understanding of new product development practices. This limits the success of early manufacturing involvement (Swink, 1999).

Fourthly, Involvement of manufacturing companies can be improved and stimulated by taking drivers, conditions, the preferred moment of involvement and impediments into account. Drivers are determined by short-term and long-term advantages and personal reasons. The nature of conditions are relational, behavioral and commercial. Impediments are organizational, cooperation and commercial. The moment of involvement is different for every project and depends on several aspects like designer's manufacturing knowledge and project complexity. Fifthly, manufacturing companies can give feedback on proposed designs and advice designers on matters like material information, tolerances, available manufacturing resources and other manufacturability matters. The designer can also give product information which enables the manufacturer to give design input proactively. All input leads to design improvements and improved efficiency of the design process. This leads to better results regarding product costs, quality, production lead time and ease and reliability with which a product can be produced. Finally, the KSC should create an environment wherein bonding will be stimulated and parties will benefit from participating otherwise there will be no or limited willingness to participate. Opportunistic behavior and conflicts of interest should be prevented. Fears like too much complexity, no up-to-date information and give away specific knowledge should be taken away.

5.2. Limitations

The biggest limitation is bias which can exists due to the fact that several interviewees were known and informed about the platform by the company clients of this research. Furthermore, the idea of the KSC was a concept that was regularly adapted during this research project which may could have influenced the introduction talk about the KSC during the interview and therefore the interviewees perception of the platform. In addition, the presence of the founders of the KSC at some interviews could have created subject bias and influenced their view regarding the KSC.

5.3. Managerial implications & future recommendations

It is advised that the proposed KSC platform should contain certain information and knowledge which should continuously be kept up-to-date:

- General company information like strategy, supply chain (outsourced activities) and industry
- Manufacturing process capabilities information like tooling information
- Material knowledge like behavior and properties
- Design/manufacturing constraints of a certain process like tolerances and do's and don'ts

This information can support design companies in finding a suitable design input and corresponding suppliers and starting bilateral contact. The non-confidential knowledge which can be found as information on the platform, makes it possible to postpone the supplier involvement to avoid the lock-in effect and postpone the sharing of their confidential product information. Therefore it is important to provide suitable knowledge content. During the bilateral contact, the designer should be willing to share knowledge about the product and its features. This stimulates and improves the value added by the manufacturer. During this contact, also more proprietary and confidential knowledge will be shared. Therefore the management might want to take intellectual property and other types of confidential information of participants into account otherwise participants may would not be willing to participate in NPD projects. The fear of information leakage exists. Reducing this, can for instance be done by providing (bilateral) non-disclosure agreement templates. Management beware of opportunistic behavior as this can impede future collaboration (for instance moderators with the authority to remove participants from the platform could be used to safeguard this issue). Aside from the tender-process, manufacturers consider the risk that they deliver significant input, spending considerable amount of money and time, but won't receive the order or any form of budget. The management could create awareness for financial safety (for instance by providing financial agreement templates which could be used during the bilateral contact) and aim for advantages of ESI being shared among project members.

Based on this research, various suggestions for more future research regarding the relationships between ESI, NPM and the KSC can be made.

Firstly, when manufacturing companies are involved early within a NPD project, it does not necessarily result in high manufacturability. Future investigation is needed to reveal which factors influence manufacturability when manufacturing companies are actually involved early. It should be determined how manufacturability can be increased in such situations and how the coordination mechanisms of Twigg (2002) can contribute to this. What, for instance, was mentioned several times in the case studies, is that manufacturing knowledge of the designer has great impact on manufacturability. Which is also one of the coordination mechanisms of Twigg's (2002) model: A5 designers' tacit knowledge.

Secondly, it became clear that there are several types of NPD-projects. Future research should establish which NPD-project can be determined, for which project types the KSC platform can be of added value and how the KSC can provide suitable support per project type. It is for instance interesting to explore whether the platform is valuable for very short and simple NPD projects whereby all manufacturing knowledge is already available at the designer and enough potential suppliers can be indicated. Additionally, it should be determined how the platform can facilitate several project types through help ensuring financial safety, safety of proprietary information and availability of required knowledge and company information. Furthermore, it should be determined which coordination mechanisms should be present for different types of projects. For small projects with small companies, the presence of every coordination mechanism is bound to be excessive. On the other hand, large projects may require all mechanisms or even more than mentioned in Twigg's (2002) model. The model of Twigg splits mechanisms up into three phases. It could be determined how the mechanisms would work within the phases of the V-model. When all these matters are known, it would probably be beneficial for the participants if it is communicated through the platform, in for example the form of guidelines, since parties agreeing on the same way of working contributes to manufacturability.

Thirdly, according to both the case data and literature, management should take purchasing involvement into consideration since they are almost always involved within NPD projects. In addition, they can contribute through thinking of new (external) resources and new components, generating "make-or-buy" analyses and managing relationships with external parties involved in the NPD (Servajean-Hilst & Calvi, 2016). Future research could focus on the role of purchasing within the KSC, when they should be involved and how the platform content and structure should be adapted or extended for this purpose.

Fourthly, previous research and results from this research indicate both positive and negative manufacturability results when suppliers are involved earlier. In order to ensure positive new product manufacturability outcomes, future research should explore possible trade-offs. ESI should only be considered if the potential benefits outweigh the potential negative side-effects in terms of costs, quality, lead time and ease and reliability with which a product can be produced. Those trade-offs should be made transparent for platform participants.

Fifthly, Designers make design decisions based on the knowledge and information shared in the platform. This research provides general insight in relevant platform content. It should, however, be determined which information is required per project stage in order to facilitate the designer in making the right design decisions and preventing the lock-in effect.

Finally, Swink (1999) findings suggest the need for more focused research studying the timing of early manufacturing involvement in NPD. This research confirmed the optimal moment of involvement depends on the NPD project, but most likely the optimal moment of involvement is between 'Define sub-module specifications phase' and 'proto realization phase'. Future research is needed to establish how a company can determine the optimal moment of involving manufacturing companies for a specific project and focus on which variables determine this. Researchers could create a model which can be used by companies operating in NPD projects.

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Appendices

Appendix I: Topic list

- *Uitleg onderzoek*
- Bespreking case algemeen: project
    - Rol van bedrijf/interviewee binnen het project
    - Andere betrokken bedrijven, afdelingen en medewerkers
    - Onderdeel/product waar het project over ging
    - Succesvol/niet succesvol en waarom?
        - Hoe beoordeelt u de uiteindelijke maakbaarheid?

- ESI / DM interface
    - Relatie met betrokken partijen tijdens project
        - Hoe goed?
        - Waarop is die beoordeling gebaseerd?
    - Betrokkenheid van betrokken partijen → laat procestekening zien
        - Vanaf welk moment werd de andere partij betrokken en hoe intensief?
            - Welke medewerkers van welke afdelingen en waar in het proces?
        - Wat bepaalt de mate van betrokkenheid van het andere bedrijf? (bv. Vertrouwen, elkaar al kennen etc..)
        - Wat was goed/ging minder?
        - Hoe had de (vroege) betrokkenheid binnen dit project over het algemeen beter gekund?
        - Wat had u en het andere bedrijf kunnen doen om betrokkenheid te verhogen?
    - Selectie betrokken partijen
        - Waar en hoe gevonden?
        - Selectiecriteria
    - Kennisdeling → laat procestekening zien
        - Momenten waarop kennis werd gedeeld en welke kennis?
        - Momenten waarop kennis gedeeld had moeten worden
        - Verschil en oorzaak verschil

- Maakbaarheid
    - Hoe heeft de betrokkenheid van het andere bedrijf en kennisdeling invloed gehad op de maakbaarheid?
    - Door welke activiteiten m.b.t. betrokkenheid/kennisdeling is de maakbaarheid gestegen? (bv. Communiceren design/manufacturing constraints)
    - Hoe had de maakbaarheid hoger gekund door invloed van manufacturing/engineering?
        - Welke momenten betrekken?
        - Welke info nodig t.b.v. maakbaarheid?
- KSC Platform
    - *Uitleg platform*
    - Heeft u zelf wel eens tijdens een NPD project vragen m.b.t. bv productieprocessen/materiaal etc.. waarvan u niet weet waar u deze kennis kunt vinden?
    - Hoe lost u dit op? Hoe zou u het vinden als dit in een dergelijk platform te vinden is als structurele oplossing?
    - Hoe zou dit platform in het algemeen bij kunnen dragen aan een NPD project en het verhogen van de maakbaarheid?
        - Welke info zou gedeeld moeten worden in het platform?
    - Hoe kan het platform bijdragen aan het zoekproces naar potentiële project partners?:
        - Zoekcriteria
        - Toegankelijk voor afdelingen
    - Bij welke fases in het V-model platform gebruiken?
    - Hoe kan het platform het betrekken van maakbedrijven/design bedrijven stimuleren?

Appendix II: Case descriptions

In this appendix, descriptions of the 5 cases can be found. In table 10, symptoms of the manufacturability of the developed products and reasons for this can be found. Within the descriptions, examples of coordination mechanisms of Twigg (2002) are included to illustrate in which way they were present during the projects.

	1	**2**	**3**	**4**	**5**
Symptoms DFM	Delivery problems, Re-design, Unusable parts, Wrong tolerances	High costs, Expensive material/manufacturing process Design had to be made again Hard to produce	High costs Product too big/robust Product part hard and time consuming to produce, wrong tolerances	Product became way more complex than necessary and therefore high cost price	Products not according to specs and low quality
Reasons in this case	High complexity, Early switch project member (design side)	Too late manufacturing involvement Designer not aware of best suitable materials and available machines Lack of manufacturing experience	Too late manufacturing involvement Lack of manufacturing knowledge	No involvement and no design changes allowed, No manufacturing knowledge at designer, Ignorance field of expertise	Organizationa Internal quality, communicatio n. Project process matters, Manufacturer no experience in industry no proper supplier selection process, lack of manufacturing input

Table 10 Manufacturability per case

Case 1

During this NPD project, a machine part was made for a machine operating in the High Tech industry. The reason to start this project was that wear had to be reduced which was caused by two parts constantly rubbing against each other. The goal was to reach a lifespan equal to the life cycle time of the machine. The friction coefficient which was barely known within this industry and had to be determined first.

Four parties were involved: the client/designer, two manufacturing companies and a company which at the end buys all parts and assembles the machine. This last company was not involved during the development project and has therefore been excluded from this case description. Research and testing institutes were also involved at some stages to bring in extra knowledge.

Both manufacturing companies were involved very early (D2; before detail design). All parties could learn and improve their own processes with the newly developed knowledge (D1). Someone from the manufacturing side was involved within the designing phase (C4). He was a sort planner who functioned as a project leader between planning, operations and technology. Together (D3), they changed the design completely compared to the design they started with. Especially to enable batch production, much things had to be changed. The manufacturing companies gave a lot of input (C4) on producibility and manufacturing matters and during the process there were a lot of design reviews (C3). Some parts could easily brake during production, therefore design changes were proposed which would make the product more robust. However, it was not always possible to implement those changes because of lack of space. The account manager from company 3 had a lot of material knowledge, but less about the engineering and functional piece. He always asked experts from the production location and in this way gave a lot of input. The manufacturing companies also helped thinking with reducing the costs (A4). However no price target was set at the beginning, which made this part harder. Therefore A4 was present in the wrong phase. The manufacturing companies were also asked to use the documentation style of the design/client company in order to standardize communication (A3). During the entire manufacturing process the designing company stayed involved (D4). The manufacturer from company 2 also participated in the manufacturing process of company 3 together with the designer of company 1, which was a very unique situation according to them. However, no one from the designing company was physically present during the proto phase and the head designer was switched to another project which caused information losses within the project.

The designer indicated that at the end of this project, some manufacturability issues could be determined like: delivery problems, unusable parts and wrong tolerances. However, those were not due to lack of ESI but due to high complexity and the switch of an important project member from the design side.

Case 2

Competitors were inventing solutions to solve a mechanical problem which final customers were facing in the field of drive engineering. Since the client company, company 4, had no such solution, this was a threat to the competitive position. In order to stay competitive, the company had to find its own solution to this mechanical problem and therefore came up with a new product. This product had to be designed and manufactured, which company 4 could not do itself.

A designer was asked to make the detailed design and the proto types (B4). This process was going well until production had to go to another manufacturing company due to capacity reasons. From this moment manufacturability issues arose. Costs turned out to be high and the product could become 50% cheaper, other materials were cheaper and unnecessary manufacturing steps were included, drawings had to be made again and the design in the at that time presented version was hard to produce. Reasons for these causes were too late involvement of manufacturing (after proto), no awareness from the designer of the available materials and machines and a lack of manufacturing experience. No communication standards (like A2 and A3) were taken into account at the beginning of the process which contributed to the fact that the company had to re-make the design. Design changes were proposed by this company and the end user of the product (C6). Those changes improved ease and reliability of the production of this product and decreased costs significantly. They should, however, have been communicated earlier according to the involved parties.

Case 3

Owners of a certain machine, which is used in the food industry, faced accuracy and precision problems. The movement of the machine should always be exactly the same, but this was hard to accomplish. Therefore company 6 had to provide a solution to this problem. The company discovered that an independent additional part could solve this problem. After making a concept design, the company was looking for other companies with the expertise of making detailed designs and of producing the parts. A designer was found who could make the design for this product. At the beginning, the client company thought that only 50 products would be sold and therefore costs were not very important to take into account. The product was very robust and big at that moment and high costs were involved. However, after a while it became clear that the sales would increase up to 500 pieces. Then, costs became important and the selection of suitable Manufacturing company as well. When the design was finished, the Manufacutring company 7 received the product design and was free to change several aspect in order to reach a lower price and a better manufactural product (C3). Then it became clear that parts were hard, time-consuming and costly to produce and too accurate tolerances were determined. This was due to the lack of Manufacutring knowledge (A5) at the designer and the lack of early supplier involvement.

Interviewee 7 from the Manufacutring company stated that there was no need to involve the designer during this reviewing-process, since the client had enough understanding to interpret the design changes. Also the final customer and client gave input for design changes (C6) in order to increase the quality of the product.

Case 4

A product part for the consumer industry was designed by a customer who outsourced their whole (sub)assembly to another company. That assembly company was looking for a supplier capable to produce this part. Company 8 was found and asked to produce the part. The client/design company did not involve the Manufacutring company. Even the proto phase was done without them. Interviewee 8 only declared that after a long time of producing for the assembly company, they were allowed to think about possible solutions to lower the price of the product part after the proto. However, the assembly company was hardly able to allow any design changes for this product, since the final customer wanted this part like it was designed by them. The manufacturability of the product was low. The product became way more complex than necessary which resulted in a high cost price. This was due to the lack of involvement and designers knowledge about the Manufacutring process. The project leaders also underestimated the importance to take the field of expertise of this Manufacutring company into account. In addition, there could no presence of coordination mechanisms be determined for this project.

Case 5

Machine-parts with the purpose of reducing vibrations was needed. The client/designer was looking for a company that had experience with the production of those parts and found one who, however, had little experience in the industry the client was operating in. They started a project together at an early phase, namely: define sub-module specifications phase. The designers wanted to learn more about the material combination the company used for its production (A5). They wanted to know more about the properties and design constraints in order to be able to design the machine parts in a suitable way themselves. They spent 1,5 year learning about the process. Another team from Company 1 also had to design a sort of equal part and started the same process. This process went less successfully which according to the manufacturer, had to do with the way of working and the amount of information they received from the previous team. The designers from the first team gave lots of input for the development of the manufacturers tooling (C7, D1). But this input wasn't always used to improve the production process. After a lengthy project, product deliveries were not according to specifications and were of low quality. Furthermore, delays extra costs, and extra iteration layers were necessary. Reasons were organizational (internal quality, communication) and project process matters, no experience of manufacturing company in the specific industry and lack of experience with belonging quality requirements, no well executed supplier selection process of the designer company, lack of manufacturing input and no agreement on the same way of working.