THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Product Modularization-
Coordination in the Design/Manufacturing Interface

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Cover:
Product modularization illustrated as an enabler of a lasting design/manufacturing relationship. Illustration by Jonna Eklind Wendel

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Abstract

The product modularization concept has developed in different directions, since its breakthrough in the nineties. This being mainly a means to structure and divide a product into manageable units, attributes such as ‘customization tool’, ‘product development organizer’ and ‘sustainable upgrader’ characterizes the concept’s scope. The ‘embedded coordination’ associated with product modules enhances outsourcing of manufacturing, and this thesis investigates the long-term influence from such external manufacturing on the organizational interface between one’s own product design and manufacturing.

Furthermore, in-depth case studies in two Swedish multinational companies, presented in four different papers, have resulted in several findings both adding to theory and bringing implications for practitioners. Here, a useful tool set of coordination mechanisms for the investigated interface is identified, which ought to be handled with care, and adaption to the situational dynamics different modularized products’ properties bring.

It can be concluded that whether or not manufacturing is located close to the design unit it will affect the character of the improvement work. The need for coordination increases the greater the distance and the focus of the improvement work tends to shift from small-steps improvement to redesign issues according to claims from customers and suppliers. The geographical distance does make a difference, but could be handled by different means.

External manufacturing of product modules can cause knowledge problems, and difficulties in improving products and processes because the distance between design and manufacturing may lead to the product development engineers having less direct contact with the product modules. Therefore, even if this could be balanced by dedicated persons emanating from the design function working cross-functionally, an alternative is to keep some manufacturing internally, as it is important not to lose the required long-term manufacturing skills. This aspect is vital to take into consideration as early as possible when implementing a sourcing strategy.

Keywords: Product modularization, Design-Manufacturing interface, Coordination mechanisms

List of appended papers

Paper 1 Eklind, M.J., Persson, M., and Winroth, M. (2013) "Managing customization by product modularization", *Paper presented at the EurOMA 20th annual conference, Dublin, 7-12 June 2013.*

Empirical material collected jointly by Eklind and Persson, who also authored the paper jointly with Winroth.

Paper 2 Eklind, M.J. and Persson, M. (2013) "Managing continuous improvement by product modularization", *Paper presented at the CINet 14th annual conference, Nijmegen, 8-11 September 2013.*

Empirical material collected jointly by Eklind and Persson, who also authored the paper jointly.

Paper 3 Eklind, M.J., Persson, M., and Winroth, M. (2014) "Coordinating external manufacturing of product modules", *Paper under third round of reviews for Decision Sciences Journal.*

Empirical material collected jointly by Eklind and Persson, who also authored the paper jointly with Winroth.

Paper 4 Eklind, M.J., Persson, M., and Winroth, M. (2014) "Combining internal and external manufacturing of product modules", *Forthcoming paper at the EurOMA 21th annual conference, Palermo, 20-25 June 2014.*

Empirical material collected jointly by Eklind and Persson, who also authored the paper jointly with Winroth.

Preface

This research project has been initiated through the Swedish education authorities, Skolverket, aiming to give high school teachers the possibility to do research in a field related to their teaching. Primarily the project's purpose is to bring high school closer to the university, not necessarily with a pedagogic or didactic focus. More pinpointed is that the academic network formed under the research years will be used to build useful connections for the future.

My research project about 'product modularization' has been conducted as other projects at the Division of Operations Management, but it seems to end up with a direct practical application in my future teaching situation. In the end of the thesis there is a presentation of how product modularization also could be used as a learning tool. "TeknikCollege Kungsbacka" collaborates with the local businesses and an integrated high school course about product modularization is now planned to be implemented next year. This will be an opportunity to practice experiences from the research project, to develop both learning methods and emerging networks.

Acknowledgements

I am grateful to getting this opportunity to do research in the frame of the Swedish endeavour to bring the high school closer to the university. Thanks to authorities involved in this and to Karin Ekman and Per Lundgren who support us high school teachers here at Chalmers. I hope to continue with some sort of collaboration to strengthen the now formed platform.

These two and a half years spent at the Division of Operations Management have been lined by amazing people and experiences enough to fill the double time and to make me feel half my age. My tandem supervisors, Magnus Persson and Mats Winroth, have always been there for an advice or a chat. What a wonderful support! To all colleagues and PhD student fellows at our department and at ProViking national research school: you all play a part in giving me an unforgettable memory for life. Sure, there were also hard times, of course. As when my ideas got wings but could not find any ground to land on. As when the ideas then flew away and seemed to be gone. But as migratory birds, they came back with springtime and landed in this thesis, healthy and grown-up.

I feel honoured to be a part of this scientific society which is working hard to find solutions based on simplicity and sustainability. Together with the enthusiasts in the companies I have been lucky to collaborate with, together, we make a difference.

Finally, I would like to express my gratitude to my three beloved women; mother Ingegerd who I could not see so often, Ulla-Britt who always supports my whims and our daughter Jonna, my idol.

Martin Jan Eklind

Gothenburg June 11, 2014

Table of Content

1. Introduction

This introductory chapter presents the background to the chosen research area and the emerging situation which leads up to the purpose and the research questions for the thesis. An outline of the thesis closes the chapter.

1.1 Background

Product modularization is a way of gaining several benefits and meeting different needs (Gu and Sosale, 1999; Umeda et al, 2009). Moreover, through product modularization, components are grouped into modules with the aim of developing a product in which the different modules are decoupled from each other, which makes it possible to make changes in one module without affecting the other surrounding modules (Brusoni and Prencipe, 2001; Mikkola, 2003). By dividing a complex product, or a complex system, into smaller pieces it also becomes easier to understand and manage (Gershenson et al., 2003).

This thesis highlights the organizational dimensions connected to product modularization, emanating from the standardized product interfaces between the different modules. As long as the developed modules conform to the defined interfaces, the design of different modules can be loosely coupled, and much of the product development work is coordinated by these module interfaces (Sanchez and Mahoney, 1996). Furthermore, so called 'embedded coordination' is brought into the modularized subsystems (Baldwin and Clark, 1997; Hong and Hartley, 2011), which means that modularization creates a high degree of independence, something that facilitates outsourcing of product modules to different suppliers (Brusoni and Prencipe, 2001; Gadde and Jellbo, 2002). Thus outsourcing is often chosen rather than keeping manufacturing in-house. This facilitates customization, with an increased number of product variants that meet individual customers' needs, add more complexity to the operations of a company and outsourcing reduces the number of activities to manage and the capital invested (Hendry, 1995). The trend to focus on core activities as product development (Quinn and Hilmer, 1994) has long since been a common practice, and is also used to continuously reduce cost and meet time-to-market demands (Le Dain et al, 2011) and today product modules are often manufactured by external suppliers.

Another aspect to consider here is that required product interfaces must be designed in advance (Baldwin and Clark, 1997). A high degree of systemic knowledge is needed to implement a modular product structure, e.g., since future manufacturing aspects must be considered at an early stage. Therefore extensive cross functional work between the design and the manufacturing units is initially needed to foresee interactions between modules (Sanchez, 1996). This extensive work could also help to organize a lasting relationship between the units, enabling the matching of different upcoming situations with appropriate level of collaboration. Thus, product modularization restructures the relationship and becomes more than just another link in the relationship between design and manufacturing, illustrated in Figure 1. The way in which product modularization affects the relationship is important to clarify in order to be able to manage the relationship properly.

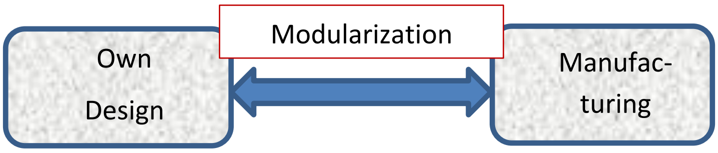

Figure 1: Modularization and the relation between one's own design and manufacturing are in focus in the thesis.

Linked to organizational considerations is product modularization's potential to customization and improvements as long as the changes mainly stay in a certain module with low impact on other modules (Ericsson and Erixon, 1999; Hsuan, 1998). Such changes, often made in small-steps, are not generally enhanced when different companies have to collaborate around them. Instead, the distance external manufacturing brings to one's own product design, together with the loose coupling of modules; make more innovative issues more likely to be successful (Chapman and Corso, 2005). Simultaneously, such more radical changes often involve several functions and modules, and more intermodular coordination efforts becomes necessary (Persson and Åhlström, 2013). This conflicting result about improvement work, together with product modularization's organizational potential is paramount to the purpose.

1.2 Purpose

Since product modularization enhances external manufacturing by the embedded coordination standardized interfaces bring, a growing part of product modules is manufactured by suppliers, located more or less distant from where the modules are designed. This, i.e., to use external manufacturers, is part of an outsourcing movement from the beginning of the eighties connected to findings from resource-based theory (Rumelt, 1984), stating that a company ought to keep such core activities as product development in-house, and preferably outsource manufacturing (Quinn and Hilmer, 1994). The ongoing globalization has amplified the outsourcing trend (Kotabe and Murray, 2004), but knowledge about how such external manufacturing harmonizes with other characteristics for product modularization is still missing. Therefore, *the purpose of this thesis is to investigate the organizational interface between one's own product development/design and manufacturing when product modularization is used, with the emphasis on external manufacturing.*

1.3 Research questions

Product modules are preferably manufactured internally, since a close collaboration between designers and one's own manufacturing staff is likely, something that increases the possibility of obtaining a good impact on performance from product modularization (Danese and Filippini, 2010). Although, today the sourcing potential of the concept is accentuated, and product modules are often manufactured by suppliers. Thus less proximity limits close collaboration (Hinds and Bailey, 2003) and the required coordination efforts are increased compared with one's own in-house manufacturing. Moreover, identifying coordination mechanisms becomes relevant, in being able to match different situations, which leads to the first research question:

RQ 1: How can design and manufacturing of product modules be coordinated?

Decisions concerning use of suppliers for manufacturing are often made on behalf of short-term views (Hendry, 1995) and focus on cost reduction. Long-term aspects, such as how to upgrade the product, and how to improve manufacturing processes, risk being neglected and, therefore, the second research question is relevant to consider concerning such strategic decisions:

RQ 2: How does external manufacturing of product modules affect improvement of product realization?

The concept ‘product realization’ includes both product and production development (Bellgran and Säfsten, 2010). Here, in this thesis, three delimited parts are emphasized, i.e., the development of a new product, the upgrading of an existent product, and the improvement of manufacturing processes.

1.4 Outline of the thesis

Here, after having introduced the background to the research study together with purpose and research questions, next in Chapter 2 an overview of the literature related to the research purpose is presented, starting with product modularization.

Chapter 2 also puts focus on the relationship between product development/design and manufacturing, and what the literature says about improvement work of product modules.

Chapter 3 presents the methods used and the underlying research strategy, before the appending four papers are summarized in Chapter 4.

The research questions are analyzed, answered and discussed in Chapter 5, before conclusions and implications from the research study are presented in Chapter 6. This final chapter also includes a discussion about further research where a learning perspective on product modularization is also introduced.

The appendix presents the four papers on which the thesis is based.

2. Frame of reference

Three areas of literature relevant to the research purpose are presented in this chapter. Section 2.1 characterizes product modularization's organizational benefits and challenges, and the feasible directions for the concept. Section 2.2 will then focus on the literature about the relationship between product development/design and manufacturing, and since this context is essential for the research purpose, before section 2.3 concludes the chapter, it will highlight the literature about improvement work and external manufacturing of product modules.

2.1 Product modularization

Modularization has its origins back in the early industrialization era. The essence of Taylorism and Scientific Management was to divide products into standardized units, and then to assemble them at the end of a line (Taylor, 1911). This thinking had a lot in common with what we today mention as "product modularization". When, in the 1990s, the globalization trend accentuated, several companies started to develop the concept 'product modularization' as a way of dealing with emerging customers' needs, and thereby the management of growing product variety (Sanchez, 1995; Ulrich and Tung, 1991). This globalization trend coincided with the rapid development of the computer industry to which product modularization was also an enabler (Baldwin and Clark, 1997) thus helping the concept gain a strong breakthrough.

A concept closely related to product modularization, especially at that time, was mass customization. Mass customization helps companies to combine product differentiation with cost efficiency (Blecker and Abdelkafi, 2006; Pine, 1993). "The term mass customization denotes an offering that meets the demands of each individual customer, but that can still be produced with mass production efficiency" (Piller, 2007, p. 631). This is consistent with the ideas of product modularization where the grouping of components into modules, and the definition of standardized interfaces between modules (Baldwin and Clark, 1997) opens up for flexible production. The module interface makes it possible to have a large variety within a module, but without causing disruptions in other modules (Sanchez and Mahoney, 1996). Ideally each functional element is mapped to just one physical component, i. e. one-to-one mapping (Simpson, 2004) which brings the purest modularity as shown in Figure 2.

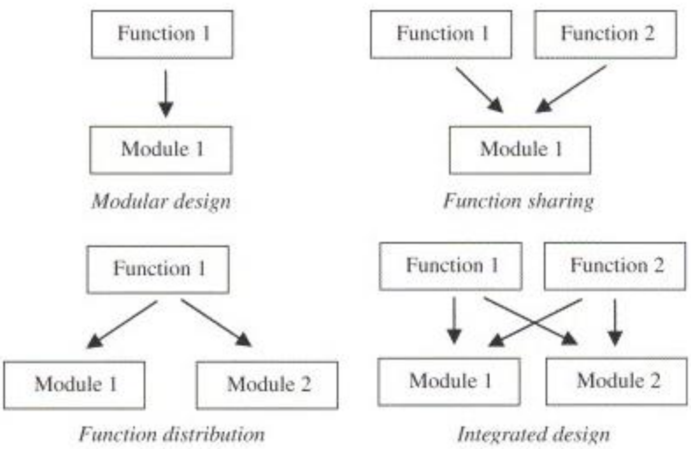

Figure 2. Different ways to distribute functions into modules (Persson and Åhlström, 2006)

Although, instead of pure one-to-one mapping, in most products there are different gradations of modularity (Baldwin and Clark, 2000) when functionality is mapped into two or more physical components, exemplified in Figure 2.

2.1.1 Characteristics of product modularization

The breakthrough for product modularization in the nineties leaned against the strategic flexibility the concept brings. A company can react quickly to changes in demands (Sanchez, 1995) as far the changes could be managed by module specific adaptions. Research at that time focused on the more technical aspects of product modularization. How to divide a product into modules, combined with the purpose to define interfaces between the modules in such a way that they become decoupled from each other (McClelland and Rumelhart, 1995) was, and still is, necessary knowledge in order to be able to modularize a product. Connected to this, performance metrics such as reduced product development lead-time and cost (Baldwin and Clark, 1997), became focused, achieved by using common components across different products (Ulrich and Tung, 1991), and standardization implying economy of scale and scope (Jacobs, Vickery and Droge, 2007). Gradually, the modularization ideas became extended to the design of product development organizations (Brusoni and Prencipe, 2001). The standardization of module interfaces allows processes for developing component designs to become loosely coupled (von Hippel, 1990; Sanchez and Mahoney, 1996), leading to decoupling of tasks. This decoupling makes it possible to accomplish different development, as well as manufacturing activities in parallel (Ulrich and Tung, 1991; Baldwin and Clark, 1997), shortening the development lead-time.

The potential by product modularization to bring sustainable solutions, has been pinpointed for many years, both since the module interfaces facilitate product maintenance and remanufacturing (Seliger and Zettl, 2008) and as a single worn out module could be interchanged, allowing the whole product to last longer (Takata et al, 2004). Since modules could be recycled and reused if they are designed to be disassembled into pieces at the end of product life (Jovane et al, 1993), the product modularization concept is sometimes presented as an enabler of meeting future requirements in a cycle economy (Seliger and Zettl, 2008). Moreover, in addition to the sustainable features already mentioned, the possibility of upgrading modules continuously to be in line with the latest technical solution in order to reduce energy waste and environmental pollution (Gu and Sosale, 1999) is worth mentioning as an example of how customer driven upgrading reducing waste may effect sustainability.

From the beginning, the mentioned ‘embedded coordination’ (Sanchez and Mahoney, 1996) was not seen as a facilitator for external manufacturing of modules. Embedded coordination means that the development processes can be effectively coordinated simply by requiring that all developed components conform to the standardized component interface specifications. Coordination can thus be achieved with a minimum of managerial effort. Thus most of product development work is then coordinated by standardized module interfaces, and the need for other coordination mechanisms is moderate. This also opens up for external manufacturing of product modules since the embedded coordination diminishes the need for further coordination of the used suppliers. Furthermore, in spite the growing use of external manufacturing, literature about how product modularization impacts the interface between product development/design and manufacturing is scarce, and mainly focusing coordination efforts (e.g., Pasche and Persson, 2012; Persson and Åhlström, 2013), stating that the embedded coordination most often must be supported by further coordination.

2.1.2 Product modularization's organizational challenges

The product modularization concept has, for many years, been questioned as being static (Ulrich and Tung, 1991) and today some authors claim that it is in need of being scrutinized in order to better focus business performance (Boer and Hansen, 2013). According to their literature review (ibid.), most articles stress the benefits with product modularization without having much clear evidence of successful business performance. Modularization, due to the functional independence it creates, has been called the goal of good design (Gershenson et al, 1999), which may have led to an uncritical view upon the concept with the unintentional thought "the more modularization, the better". Boer and Hansen (2013) mean that less modularization or even no modularization could also be optimal. Pasche (2011) identified three main challenges connected to a product modularization strategy. First, as mentioned in the introduction, the systemic knowledge needed to implement a modular product structure is high, and a type of 'know-why' knowledge (Sanchez, 1996), is crucial in order to be able to foresee interactions between modules. Second, a modular structure affects the kinds of innovations which may take place. In-depth changes may affect the modular structure so much that instead minor incremental changes tend to be fostered in the long run (Galvin, 1999). This is mentioned as the 'modular trap' (Chesbrough and Kusunoki, 2001) where radical innovations become less likely to arise, (Henderson and Clark, 1990). The third challenge is somewhat related since modular product architecture also risks inhibiting radical systemic innovations, which are quite costly, and in the long run could lead to a loss of flexibility and market orientation (Pahl and Beitz, 1996), contradictory to the customization potential product modularization preferably brings (Piller, 2007).

Two paths of development for product modularization organizational potential could also be identified, although somewhat counteracting each other. First, product modules' embedded coordination opens up for a sharpening of the concept as a sourcing tool. The trend to extended use of external manufacturing seems continuously strong. Many companies use specialized manufacturers to come closer to customers all around the world or as a way of manufacturing at a lower cost than before. Also, in line with the extended use of suppliers, the influence of a company's supply chain management (SCM) grows (Kotabe and Murray, 2004) and product modularization could then be seen as a facilitator building up a firm's sourcing strategy. Terjesen, Patel, and Sanders (2012) have studied how modularization, combined with supply chain integration (SCI), affects the operational performance in a company with external manufacturing. Drawing on the well-studied concept of "differentiation-integration", introduced by Lawrence and Lorsch back in 1967, the authors connect "differentiation" with modularization and "integration" with integration activities in the supply chain. Lawrence and Lorsch (1967) mean that high differentiation and integration in tandem brings the best operational performance. Moreover, in the same way, Terjesen et al. (2012) show that the combination of a high level of modularization and high SCI levels raises performance in all their investigated cases.

Second, the initially extensive work needed to form product modules with standardized interfaces and well mapped functions into the physical modules (Danese and Filippini, 2010) could be seen as an enabler of forming a lasting relationship between design and manufacturing. The collaboration initially needed to design the modules for manufacturing brings the parts close together, and Howard and Squire (2007) show in their studies that modularized components require collaborative sourcing practices in order to co-develop products and reduce interface constraints. Danese and Filippini (2010) claim that interfunctional integration, not only enhances modularization's positive impact on performance, it is a necessity for getting such a positive impact. Howard and Squire (2007) examine this relationship "co-development/partnership" vs "arm's-length" and their results support the idea of modularization as being closely tied to collaboration and information exchange not only in the modularization phase, but during the whole design-to-delivery process. They mean that the prospect of switching to an alternative source of supply is complex, costly, and high risk. This conflicts with the active sourcing strategy mentioned above where a prototyping supplier could be substituted by another when it comes to commercialization, despite the difficulties that this could bring to the designers in communicating with a new inexpert manufacturer and building a new relationship.

2.2 The interface between product development/design and manufacturing

Therefore, in order to understand how the realization of a modularized product could be managed, different aspects of the interaction between the design and manufacturing units need to be highlighted. Thus, in some situations, differentiation of the units is preferred, while in others their integration is stressed, leading to a matching issue to coordinate.

2.2.1 Identifying integration barriers

Traditionally the organizational interface between product development/design and manufacturing (the DM interface) has been treated as a challenge, a gap between two divergent functions that is difficult to bridge. However, in Wolff (1985) this gap between the functions is characterized as "a focal point of total corporate interaction since within its bounds occurs the inevitable confrontation of human resistance to change, urgency to meet product schedules, new technology infusion into products, interdisciplinary language problems, continuing design alterations, and corporate cash commitments, to name but a few."

Typically, for many years, the design function has been upstream and dominating the product development process, and the manufacturing function has mainly had to produce what the designers have decided. As a consequence, the "us and them"-syndrome has been possible to apply to both the functions, and the contact area in between them has often been loaded with conflicting barriers. Vandevelde and van Dierdonck (2003) have done a literature review, and thereafter highlighted five main integrating barriers, focusing personality, cultural, organizational, physical and language differences. The authors found several examples of conflicting views between the designers and the staff in the manufacturing, as project orientation versus process orientation, long-term time horizon versus daily delivery-at-time focus, just to mention a few. They stress that the geographical DM distance may restrain physical contact and collaboration. Such integration barriers cause poor-quality inter-functional relationships which hinder communication of important information through the DM interface (Vandevelde and van Dierdonck, 2003).

Integration facilitators and barriers in the DM interface are most often not identified, and just presented as a vague grey zone between the functions as the upper model in Figure 3 shows. Instead, if the function is represented as two independent units as in the lower model, phenomena which construct the DM interface could be stated and investigated more rigorously one by one. Gadde (2004) is one of several authors who use this model when the manufacturing is external, as in the supply chain, but the model could well be used by internal manufacturing.

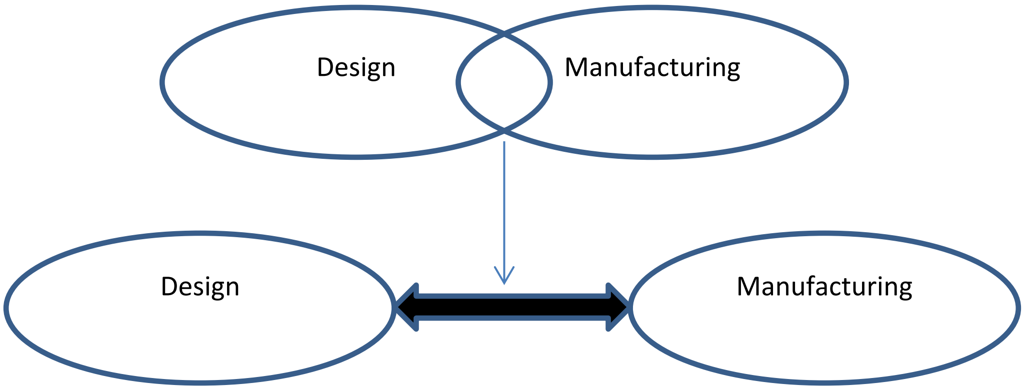

Figure 3. A vague DM interface could be visualized by use of a relationship arrow (adapted from Gadde and Håkansson, 2001).

Gadde (2004) uses "relationship atmosphere" and "level of involvement in the relationship" as key words to explain how to handle the relations to different suppliers, and how to integrate them with the focal firm. As the model is mainly used for different, independent companies in the supply chain, the term "involvement" is natural. The companies could become involved in the relationship to a greater or lesser degree, and also change the engagement. The word "involvement" well reflects the reciprocity in such a mutual relation. Instead, when just one company is studied, the term "integration" is used to describe how different functions are connected to each other. Since modularized products often have a mix of internal and external manufacturing both "involvement" and "integration" is sometimes relevant to use, but to avoid complications, in this thesis, the "integration"-term will be stressed for both situations. The integration concept is widespread in literature about the DM interface, and by external manufacturing when different types of supplier integration are discussed.

2.2.2 Identifying integration facilitators to coordinate the DM interface

After having identified such integration barriers, Vandevelde and van Dierdonck (2003) investigated how to best to promote a smooth start-up of manufacturing by hypothesizing the usefulness of integration factors for the DM interface. 212 potential success factors were tested according to 125 Belgian companies' project experiences. The results from the study emphasis "formalization" as one of two main success factors, and examples of such organizational formalization are clear goals, schedules, roles and responsibilities. Standardized manufacturing rules and formal documents such as technical guidelines are other ways of formalizing the product development process. Moreover, in spite of being so fundamental for integration, the authors also warn that in innovative projects characterized by much uncertainty, designers need a creative environment instead of processes restricted by formalization. Ultimately, if leaving such room for designers 'creativity, it is still important to formalize at least the production startup through transparency in order to help manufacturing staff understand the design.

Managers' ability to increase the empathy from design towards manufacturing by stimulating DM communication, and by involving design in the production start-up is seen as the second success factor. More empathy is associated with better process performance, but in a similar way as formalization, designers' manufacturing considerations may embarrass their creativity. Besides "formalization" and "managing empathy", Vandevelde and van Dierdonck (2003) investigate other means such as cross-functional teams and kick-offs which help integration in the DM interface. Furthermore, in literature such integration facilitators are mentioned as "coordination mechanisms", stating that dependencies between activities force actors to carry out coordination efforts, to find an appropriate level of integration of the activities (Malone and Crowston, 1994).

March and Simon (1958) are central in the field of coordination mechanisms. They stated that organizational coordination can be done by standardization, coordination by plan, or coordination by mutual adjustment. These are described as (March and Simon, 1958):

- *Standardization* involves the establishment of routines or rules that constrain the action of each unit into paths consistent with those taken by others in the interdependent relationship.
- *Coordination by plan* involves the establishment of schedules for the interdependent units, by which their actions may be governed.
- *Coordination by mutual adjustment* involves the transmission of new information during the process of action. It refers to informal communication, implying that coordination rests in the hands of the doers.

The theory on coordination mechanisms has since the work by March and Simon (1958) been further developed, for example, by Mintzberg (1979) and especially by Twigg (2002), building on Adler (1995). Table 1 at next page brings an overview of these different coordination mechanisms proposed by these three authors.

Table 1. Overview of mechanisms for coordination suggested in literature.

Mechanism: Author:	Standardization	Planning and scheduling	Mutual adjustment	Direct supervision	Team work
March and Simon (1958)	Standardization	Coordination by plan	Coord. by informal communication		
Mintzberg (1979)	Standardization of work output skills		Coord. by informal communication	Direct supervision	
Twigg (2002)	Standards	Schedules and plans	Coord. by informal communication		Teams

Vandevelde and van Dierdonck's (2003) concept "formalization" could then be linked to "standardization" and "planning and scheduling", and their other concept "managing empathy" could be linked both to "mutual adjustment" and "direct supervision", since the empathy is evoked by senior management.

2.2.3 Matching integration with different situations through coordination

The level of integration could be low or high in a relationship. High integration in a relationship means that a large part of activities, resources and actors are shared between the two focused units. Although, it is costly to get such high integration and a company has to have a mix of high and low integration in different relationships. Gadde (2004) also claims that low integration could sometimes be the optimal solution in a relationship. Attention needs to be given to the fact that there is a lack of stringency in the term "integration", which in the product development field has e.g., been defined as "various departments working collectively toward common goals" (Kahn, 1996). Turkulainen and Ketokivi (2012) question a lot of literature which presumes that integration automatically leads to better performance. They claim that the nuances of "integration" and "performance" must be investigated further, for example, in the DM dyad.

Rubera et al. (2012) has studied the integration between the R&D and the marketing function. One of their main findings is that high or low integration should be obtained between the functions depending on the situation. Low integration is best in pure exploitative projects in well-known markets, using well-tried technology; high integration fits better in some other situations, e. g., in pure explorative projects with unknown context factors. Ibid. have summed up in Figure 4 at next page, what happens in different situations when the integration is high respectively low. The authors also find it remarkable that each company uses either high or low integration for every project, with no thought of changing the integration level.

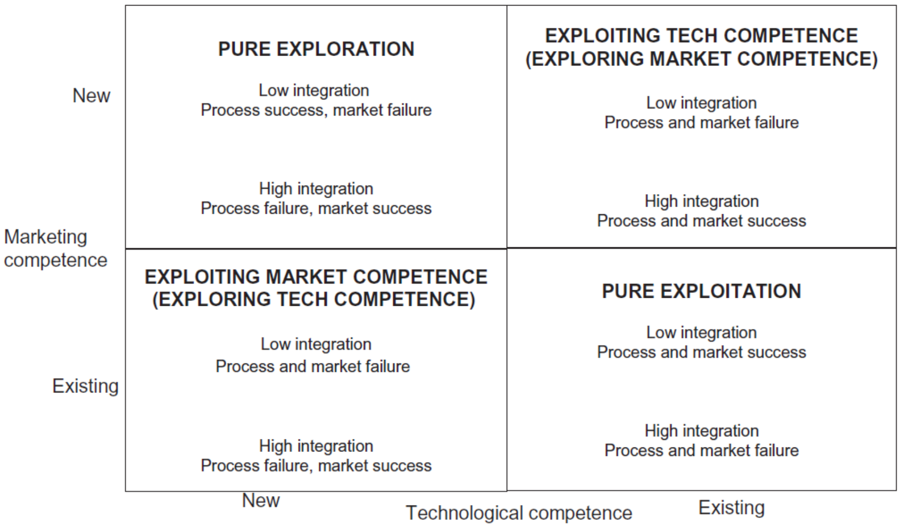

Figure 4. "Performance outcomes" from Rubera et al (2012)

Four different types of product innovation, and how they are connected to the market situation are distinguished by Rubera et al. (2012), from a low to a high level of uncertainty:

- Pure exploitation, both well-known technology and market
- Exploiting technical competence (and exploring market competence)
- Exploiting market competence (and exploring technical competence)
- Pure exploration, both new technology and new markets

Similarly, Adler (1995) distinguishes four different product development issues with a growing level of uncertainty:

- Proven carryovers
- Minor refinements
- Major changes
- Unproven new approaches

Rubera et al. (2012) stress that different situations need different levels of integration. Though there are examples of such a matching in literature, they are less than expected. A lack of instruments to evaluate the appropriate level of integration (Turkulainen and Ketokivi, 2012) seems to be one natural explanation to this, but even more remarkable is the common absence of the grading of integration. Both too much and too little integration could cause difficulties, but "optimal integration" is seldom sought after.

Product modularization could be a strategic concept in handling this matching issue (Brusoni and Prencipe, 2001). Terjesen et al. (2012) have studied how product modularization, combined with SCI, affects the operational performance in a company with external manufacturing. The authors show that the combination of a high level of modularization and a high SCI level raises performance in all their investigated cases. According to what Lawrence and Lorsch (1967) suggested, the result is contingency based on firm-specific and environmental factors. The relationship between SCI and operational performance form a reversed U-shape and, therefore, after a certain point, further integration will be costly and will not result in better performance. A reversed U-shape, ∩, means that the performance peaks at the inflection point, at the top, as shown in Figure 5. Since this inflection point is difficult to identify the authors suggest a contingency perspective since they also show that fit between differentiation and integration is critical, especially when the uncertainty is high in the environment. It depends on the context if the integration in the DM relationship ought to be high or low, and this could be managed by the use of different coordination mechanisms (Crowston, 1997).

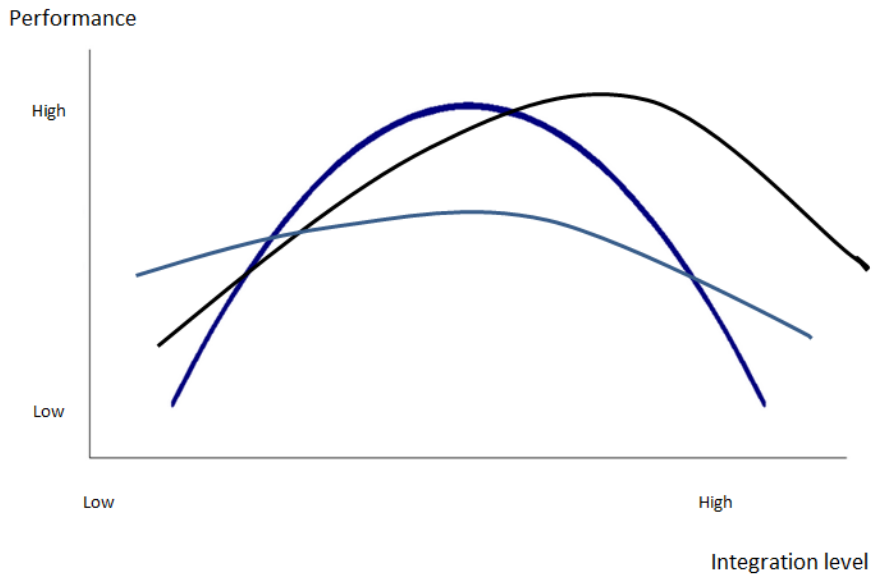

Figure 5. Optimum level of integration is dependent of the situation (after Terjesen et al., 2013)

Also Danese and Filippini (2010) have identified the need to match the integration level with the type of situation. If the technological challenge in the development of a new product module is at a high level, it is preferable to bring design and manufacturing close together in order to be able to handle different problems and for face-to-face communication. When the product development is not very complicated, i. e., certain improvement issues or by a more integrated product, it is better if the integration is low and thereby opens up for other aspects concerned. Contrary to this, when the technological turbulence is low and cross-functional teams are used, there is a risk that the team ignores information from outside the team, which in fact may be necessary in shortening the development time (Fernandez et al., 2010). "Too friendly" relations or too much integration could make each function consider that the other area has its exclusive area of experience and irreproachable behavior, so they do not question or judge the assumptions on which each works, and information important for the project may be overlooked (Souder, 1988). A flexibility to change between low and high integration seems suitable for handling improvement issues emanating from product modularization.

2.3 Improvement work related to external manufacturing of product modules

Furthermore, through product modularization, both smaller and larger product improvements are supported as long as they are mainly defined to a specific module (Hsuan, 1998), otherwise coordination efforts are needed. Moreover, concerning process improvements, most literature is focused on single companies and the possibilities the close collaboration of one's own manufacturing of product modules could create (Boer et al. 2000). If the manufacturing of product modules has been outsourced to different suppliers in different parts of the world the ability to continuously work with manufacturing improvements is made more difficult. The improvement process could be affected by the greater distance caused by such outsourcing (Howard and Squire, 2007). There could also be suggestions coming from one of the module suppliers that not only affect the modules that this specific supplier is manufacturing, and which makes it more complicated, when such changes must be coordinated with several suppliers. Small-step improvements are not generally enhanced when companies have to collaborate around them; on the contrary, more innovative issues are more likely to be successful (Chapman and Corso, 2005). The authors claim: “But while inter-company collaboration in radical innovation is a reality, collaboration in small-step innovation (or continuous improvement) of products and processes is considerably less common. Although apparently simpler, continuous innovation within a network of companies requires a much deeper integration between companies along the supply chain, and a change in culture that not only involves selected teams, but is extended to the key business processes within the participating organizations” (Chapman and Corso, 2005, p.339). Product modularization decouples the processes, and the companies could work quite independently with their modules. The integration level diminishes and thereby the natural ground for the continuous improvement work is weakened.

The work with manufacturing improvements becomes affected (e.g., Greasley, 2009) also, in another indirect way, if all manufacturing becomes external. Designers risk losing manufacturing skills on a long-term basis (Kotabe and Murray, 2004) if their direct contacts with the manufacturing process disappears. The resulting risk when designers have less manufacturing competence is that improvement issues thereby become difficult to communicate with suppliers. Similarly, adaptions to customers’ needs could become more difficult to communicate when the manufacturing unit is located far away from the design unit. However, the ability to continuously upgrade product modules according to customers and manufacturers suggestions is essential for the product modularization concept (e.g., Erixon, 1998; Gu et al., 1997). Olausson and Magnusson’s study (2011) strengthens the need for internal manufacturing competence at a contracting or outsourcing firm, a statement which has been identified in several previous studies (Prencipe, 1997; Bengtsson and von Haartman, 2009). Olausson and Magnusson’s cases show that firms are also capable of improving their manufacturing competence when all manufacturing activities have been outsourced. Therefore, in order to compensate for the lack of having one’s own manufacturing, the suppliers ought to be engaged at an early stage of the new product development (NPD) project, so that visits to suppliers are frequently taking place, and formalized standards and checklists are being used to enhance both the formal and informal communication process with the suppliers. Applying such an early involvement of suppliers to modularized products in the initial extensive work, which form the product modules, could also create a strong lasting relationship between the design and manufacturing units that were appointed in the introduction.

To summarize, the improvement activities related to external manufacturing of product modules are quite narrow:

- Improvement of **manufacturing processes** is complicated, and could be done by suppliers if they only lead to minor design changes to the product modules (Hsuan, 1998). Otherwise coordination efforts are needed.
- Suggestions from suppliers or customers for more innovative changes to a **single product module** could preferably be developed together with the design function if they are affecting other modules to a lesser extent (ibid.).
- Other improvement suggestions ought to be examined before an improvement project could start, since changes to **several modules** must be managed and coordinated (Persson and Åhlström, 2013). The coordinating persons need developed manufacturing competence to conduct the improvement process.
- **Small-steps improvement** of products or processes need a high inter-company integration level, which is difficult to support through external manufacturing of product modules, compared to those of internal manufacturing (Chapman and Corso, 2005).

Moreover, as mentioned in the introduction, product modularization could be used as a sourcing tool, since outsourcing to several suppliers is enhanced by the 'embedded coordination' (e.g., Gadde and Jellbo, 2002). The long-term consequences on the improvement work have often been less focused, though they are also important when considering whether or not to outsource. Here, the Japanese example is worth mentioning, where outsourcing has primarily been a means of improving the efficacy and quality of a company's own processes, instead of the western focus on cost reduction. Quinn and Hilmer (1994) mention "hold on tightly to high value-added activities that are crucial to quality" and "cooperate closely in process and product development on the suppliers premises" as two Japanese key factors, which today are not often highlighted in literature.

3. Methods used

This chapter introduces this research process, and how the process continued with method choice, data collection and analysis. Trustworthiness and research quality is discussed at the end of the chapter.

3.1 Introduction

The organizational aspects of product modularization, and the challenges it brings when it comes to organizing manufacturing of modules, is an area that is not very well researched. Instead, focus has been on the technical aspects of product modularization. Literature studies only show a limited number of studies that have had the organizational focus. Since the phenomena is not thoroughly researched, and cannot be explained in isolation due to its complexity in reality (Flick, 2009:15), qualitative research methods seem more likely to be used than quantitative methods. Additionally, qualitative methods are preferable in the first exploring phase of the study, and also in the rest of the study, since the research questions consider both the physical and human aspects of the DM relationship (Voss, 2009). Therefore, qualitative case studies have been the main method used throughout the two and a half year research period.

The research has been linked to the learning project funds, mentioned in the preface. The direction for the research emerged widely diffused; to find connections between "product modularization" and "the DM interface", i.e., the interface between product development/design and manufacturing, through empirical studies. The research process used an iterative manner from the start. During the first six months, intense literature studies were conducted parallel in these two areas, "product modularization" and "the DM interface" to find out the impact between them. This dualistic research approach converged to a starting point for empirical studies, and real-life observations made further theoretical studies natural, though without that dualistic perspective, focusing product modularization.

3.2 Research process

Three case studies in two companies have led to three conference papers and one journal paper, shown in Figure 6, and related to the research questions as illustrated in Figure 7.

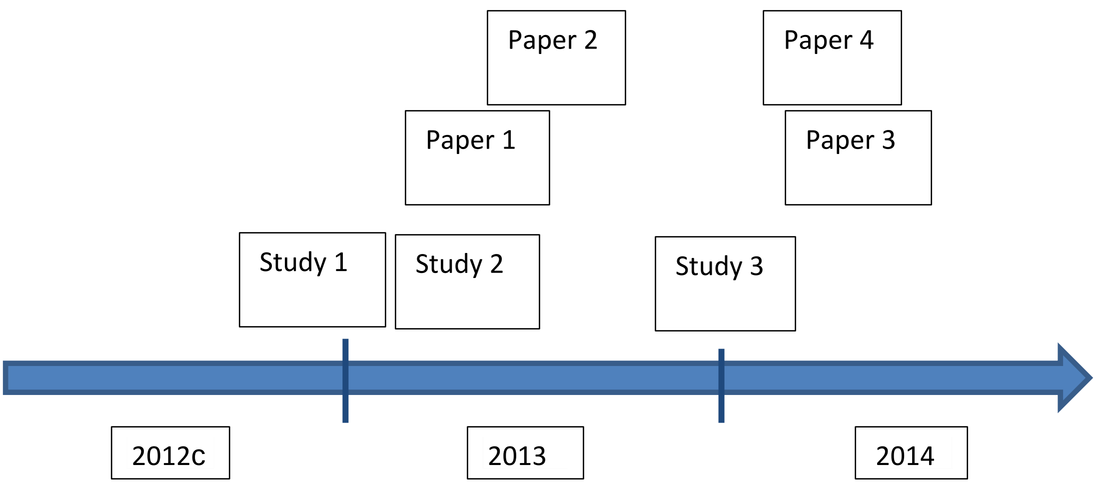

Figure 6. Research timeline

Studies 1 and 2 have been done at Company A, at two design units in Sweden and in Italy, at an international Swedish packaging and processing manufacturer. The company sales for 2011 were about 10 billion euros, and the number of employees about 20 000, worldwide. A complementary case study, study 3, at Company B, another Swedish engineering company with both one's own and external manufacturing, aim to investigate how the company's interface between one's own design and one's own manufacturing differentiates, compared with when all manufacturing is external. This company's sales for 2012 were about 0.65 billion euros, when the number of employees was about 1 600, worldwide.

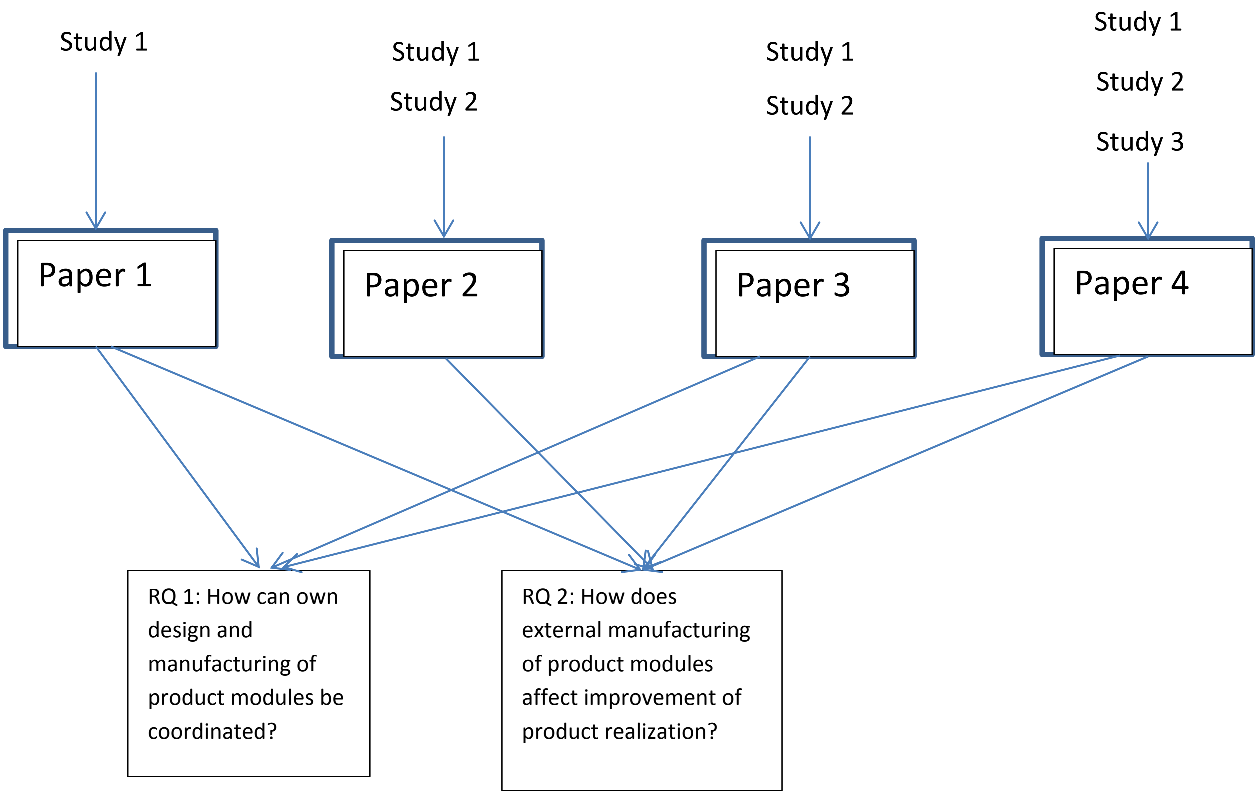

Figure 7. Contribution and relation of research studies and appended papers to research questions.

Company A has a clear product modularization strategy, as a way of dealing with product customization, in being able to meet customers' different needs. The company has already, since the beginning of the fifties, relied on external suppliers for almost all of its manufacturing. The extensive use of external suppliers, together with the modularization strategy, makes this company an exemplary case (Yin, 2009), suitable to study for what happens in the long-term when external manufacturers are used. Some characteristics for the company's four platforms are summarized in Table 2. A platform for this company is a group of products designed with a common set of modules, which could be modified to customized products.

The company has a clear sourcing strategy connected to product modularization. The supply chain function is strongly positioned in the product development process, and has power to decide both which suppliers to utilize and when to replace a supplier. The supply net is growing worldwide, though the base is still in Europe.

Table 2. Characteristics for the four studied platforms

Platform	A	B	C	D
Type	Established, medium complexity product family	Established, medium complexity product family	Newly launched, high complexity product family	Complementary distribution systems
Suppliers location	In China	Mainly in Italy	Mainly in Austria and Sweden	Mainly in Sweden and USA
Design location	Sweden	Italy	Sweden	Sweden and Italy

Figure 8 shows how the three case studies are positioned in the DM interface. However, for strategic trademark reasons most of the product development and design is done by the main case company, and the concept "modular sourcing" is less relevant to consider. Modular sourcing means that the manufacturing supplier also does the design of the modules, according to the black-box concept (Miltenburg, 2003). The black-box concept says that the supplier is free to develop and manufacture a demanded product as he wishes, as long as modular interfaces and functionality follow given specifications (Hsuan, 1998). Therefore, only internal product development/design is considered in the studies, as Figure 8 below shows.

		Manufacturing	
		Internal	External
Design	Internal	Complementary case company, Company B,(study 3)	Main case company , Company A, Swedish design plant (study 1) Main case company , Company A, Italian design plant (study 2) Complementary case company, Company B,(study 3)
	External		

Figure 8: The relationship between own design and manufacturing is in focus of the study.

3.3 Research strategy

Therefore, as mentioned in the introduction to the chapter in Section 3.1, qualitative methods were used in all three conducted studies, mainly because the organizational aspects of product modularization are not very well researched. Accordingly to this, the research areas were first explored in case studies 1 and 2, before it was possible in study 3 to compare dimensions in another type of organizational unit, Company B, as a comparative study.

Quantitative methods could be used complementary to qualitative methods (Wilson, 1982), for triangulation (Kelle and Erzberger, 2004) and even mixed, by integration (Tashakkori and Teddlie, 2003). Moreover, in future studies built on this research, a survey could be given with the aim of validating the findings obtained by qualitative methods, and to gain a fuller picture of the issue (Bryman, 1992). Rigorous, empirical qualitative research studies in the operations management field could already stand on by themselves, while most qualitative methods still need to rely on quantitative methods to generalize their findings (Barratt et al., 2011). Even if the result from this research project already stands alone, to some extent as derived from an exemplary case, it would surely benefit from the further scrutiny quantitative methods could bring.

3.4 Data collection methods

Semi-structured in-depth interviews have been done at the two case companies, with 22 representatives from both design and manufacturing units. 17 persons, mainly designers and supply chain managers, were interviewed at Company A and five persons, designers and manufacturing staff, were interviewed at Company B. All interviews were done together with another researcher, and were taped and thoroughly re-listened to clarify the notes taken during the interviews. Interviewing in teams is highly recommended by Eisenhardt (1989), since the use of multiple investigators opens up for different and conflicting perceptions, which in the interpretation phase may converge and lead to higher confidence in findings.

The interviews followed a semi-structured approach, but were systematically asked in the following areas, with the focus on how the collaboration between own product development and the manufacturing units are organized:

- The product development work
- The modularization work
- Design for Manufacturing, DfM
- How changes in the product are implemented
- Collaboration with suppliers

The respondents were also asked to rate some interview related statements according to a nine-degree scale. This was not for statistical usage but to clarify the interview responses. Also, in addition to the interviews, process documents were studied and informal discussions were held with other people involved in the product development process, combined with the aim of using multiple sources of evidence (Yin, 2009).

Additional to the interviews with people in the product development units, one of the main case company’s external suppliers was also interviewed. Almost the same questions (see above), only with minor adjustments, were used in this interview. The purpose of this interview was to investigate how the collaboration with the main case company is perceived by a supplier, and not to obtain a complete supplier picture. Therefore, in a similar way, a sales engineer at a marketing company belonging to the main case company was interviewed regarding customization issues. The same semi-structured questions were used for this interview, although slightly modified. Concerning the level of evidence from the interviews (Yin, 2009), on a direct question from this sales engineer in a mail conversation about how honest he could be, the sampling R&D Manager at Company A recommended "full transperancy for the company's best" and, as several respondents phrased critical standpoints, it seems reasonable to presume that transperancy is achieved throughout the interviews.

The purpose of study 3 was to characterize the situation for a complementary company with both internal and external manufacturing, not to investigate all aspects of the studied process. Table 3 summarizes the characteristics of the interviewees.

Table 3. Roles for the interviewed persons.

	Study 1	Study 2	Study 3
Product development and design: module managers and designers	5	4	2
Supply chain representatives: purchasing, supply strategy, production technician	4	1	-
Design support group	-	1	-
Manufacturing staff: production leader, production technician, quality technician	-	-	3
Own market company representative	1	0	-
Long-term strategic supplier	1		-

These twenty-two interviews give a reasonable level of data saturation according to the focus of the study, since the interview guide was systematically followed, and the last completed interviews brought no new information that was contradictory to the previously originated data (Guest, Bunce, & Johnson, 2006).

3.5 Research quality

To ensure trustworthiness of findings, the collected data were grouped based on the five areas in the interview guide; the recordings were discussed and analyzed by the interviewers with the aim of finding patterns and relationships (Miles & Huberman, 1994). The analysis was guided by the steps described by these authors. The initial step of data reduction; focusing, simplifying and abstracting data (Miles & Huberman, 1994), was helped by displaying tables and figures on sticky notes and whiteboards. These visualized data where analyzed by the author, and another researcher, and the conclusions drawn were validated by agreement both from respondents and top management of the companies when the results were presented. This agreement, together with the triangulation by multiple sources of evidence as interviews, documents and informal discussions (Yin, 2009), strengthen the studies construct validity.

Langley (1999) suggests seven different templates for process data analysis in order to clarify both the analysis and presentation of a studied process. The author opens up for combinations of templates and underlines the importance of leaving room for creativity in the sense-making process. Furthermore, in these studies such an open-minded approach is used to combine the "narrative" template in a linear-analytic structure (Yin, 2009) with important elements of the "visualizing mapping" template to analyze and present the results. The emergence of the studied process in the case companies; the design/manufacturing (DM) interface; is described both in words and figures, and the analysis is guided by the visualization different tables may bring.

The generalizability of results from qualitative case studies is limited (Yin, 2009) compared with quantitative studies. Nevertheless, the case studies findings could be generalized in an analytical manner instead of a statistical one (Miles and Huberman, 1994; Yin, 2009). This means that theory developed in case studies could be generalized to defined areas in line with the scope of the theory that emerged in the case studies (Yin, 2009). From this research study, the findings could be useful for companies with any of the two following characteristics. First, for companies those use product modularization for rather complicated products in limited series, with a low or high share of external manufacturers. Second, for companies with a clear sourcing strategy with SCM well positioned in the company, and not necessarily using product modularization.

4. Summary of the appended papers

The four appended papers are briefly presented in this chapter. Figure 7 in sector 3.2 gives a picture of how the different research studies are related to the papers, as well as to the research questions. The two studies done in the main case company are presented in three different papers. Paper 4 stress both two research questions by investigating and comparing a contrasting company with the main case company.

4.1 Paper 1: Managing product customization by modularization

The purpose of this paper was to investigate the interface between one's own design and external manufacturing in a company with different product platforms. The company relies heavily on external manufacturers. Focus is on how customization issues are handled. It is possible to recognize long-term effects from external manufacturing since all manufacturing has been done by suppliers already from the company's start fifty years ago. The two main findings from the study help to answer RQ 1 and RQ 2. First, concerning RQ 1, between design and manufacturing, there arose a distance which needed to be communicated, after which different coordination mechanisms emerged. The case study could identify how the company handles this situation by using different solutions (facilitators), which are strategically based or influenced by the contextual situation. To summarize, the coordination mechanisms are categorized into different groups such as "Structured process working", e.g., suppliers join the same corporate framework, "Concurrent engineering", e.g., frontloading, where suppliers join the design process early, and "Supplier partnership", supplier collaboration mainly grounded on trust, after which their effect on the different platforms are analyzed.

The second finding concerns customization issues and RQ 2. Though there is a regulated process for how to handle customization and needed changes to products, it does not work out very well. Reported problems are logged into the system, but the given feedback is both rare and slow. Both customer demands and wishes tend to be logged by the market company but seldom reach the point where decisions about appropriate changes ought to be taken. Here, problems of communicating through the DM distance seem to play a part.

Additional to nine interviews with people in the main product development unit, two other interviews were conducted. One of the external suppliers was interviewed with the purpose of investigating how the collaboration with the case company is perceived by a supplier, and not to gain the complete supplier picture. Additionally, a sales engineer at a marketing company belonging to the case company was interviewed to broaden the perspective regarding customization issues.

4.2 Paper 2: Managing continuous improvements by product modularization

Study 1 and 2 was done at the same multinational company relying heavily on external suppliers, but at a different design unit. The main purpose of this paper is to investigate how a company's ability for continuous improvement (CI) is affected by external manufacturing of product modules. Product modularization facilitates product improvements defined to a specific module. However, the ability to work with manufacturing improvements becomes more difficult since the embedded coordination unleashes the modules to be manufactured independently by external suppliers. The improvement work then tends to be transformed and become more project oriented according to logged issues, instead of focusing on incremental changes, which need a closer collaboration. Concerning RQ 2, we could identify how the company deals with this logging system in different ways at different locations. The solution which seems to work out best is when a "design support group" manage the logging system of reported improvement issues, and also coordinates designers and suppliers when development projects are initiated, illustrated in Figure 9.

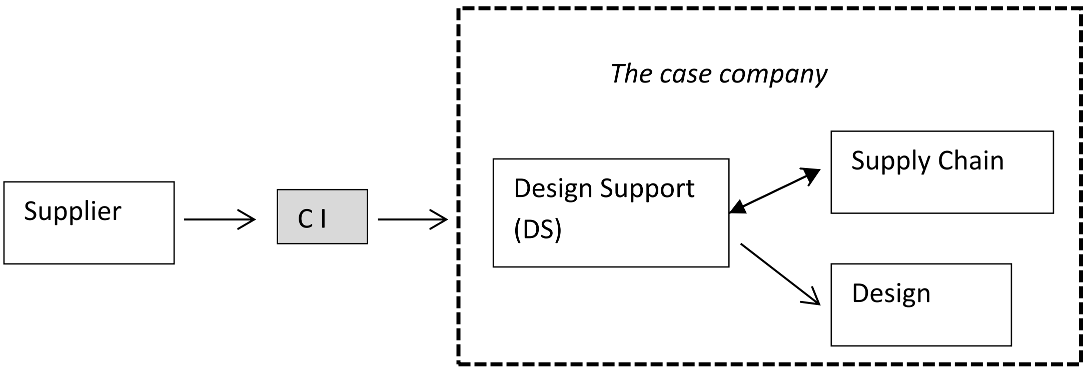

Figure 9. Organization of improvement work at the Italian product development unit

Paper 2 brings a second contribution to RQ 2 about improvement work by external manufacturing of product modules. Designers' manufacturing competence is essential not only to get a good design result, but also for designers' ability to understand improvement issues emanating from customers' and suppliers' needs. Essential knowledge becomes harder for designers to get when the distance to manufacturing processes increases. Customer and supplier relations risk being rudimentary, and the improvement issues never discussed, or awareness of them is not raised at all, due to the lack of manufacturing competence. Furthermore, in addition to courses in 'Design for Manufacturing' and 'Design for Serviceability', a fruitful contact area with manufacturers both strengthens the relations and increases designers' manufacturing competence. Working together with testing and simulation, partly at the company's test rigs, partly in suppliers' plants, seems to work out well at both design units.

4.3 Paper 3: Coordinating external manufacturing of product modules

This paper is also built on study 1 and 2 in the multinational company relying heavily on external suppliers, but with a different purpose. The different facilitators used for coordination described in paper 1 were analyzed and matched with the company's four platforms' characteristics. Key coordination mechanisms linked to complexity and time-in-market are pinpointed in Table 4.

When a company relies on external suppliers, SCM is needed to coordinate the suppliers' contribution, and in the long run the supply chain function could become the main contact area between the company and the suppliers. First, the main finding in this paper, contributing both to RQ 1 and 2, is that a resulting low activity in the DM interface risks complicating the design function's contacts with external manufacturers, and possibly hindering the sharing of knowledge and improvement issues. One way of compensating for this is to link designers with feasible suppliers, both for developing new solutions and for testing of prototypes, e.g., by a small team of engineering generalists as the Italian design support (DS) group. Such a team, empowered to work cross-functionally, could also support the supply chain function with necessary technical skills.

Second, contributing to RQ 1, when managing external manufacturing, it is more relevant to open up for different coordinating mechanisms than to try to optimize the integration level. Given a strategic common ground with a supplier, the level of collaboration could vary according to situational dynamics, and a tool set of coordination mechanisms could be used.

Table 4. Key coordination mechanisms for the platforms.

Platform	A	B	C	D
Type	Medium complexity product family	Medium complexity product family	High complexity product family	Complementary distribution systems
Design location	Sweden	Italy	Sweden	Sweden and Italy
Suppliers location	In China	Mainly in Italy	Mainly in Austria and Sweden	Mainly in Sweden and USA
Age	More than ten years old	More than ten years old	One to two years old	Different ages
Prioritized coordination mechanisms	*Own local production personnel in China supports suppliers. *Supply function simplifies the DM communication.	*Design Support group sets up expert teams, working intense both at own plant and at supplier plant.	*Suppliers join early in the concept phase of product development. *Supply chain function has a leading role	*Strategic supplier collaboration mainly grounded on "trust".

Since this paper presents an in-depth analysis of qualitative data in order to find out how different coordination mechanisms may be used to match different situations, the analysis was guided by the framework suggested by Miles and Huberman (1994), including reduction and visualization of data.

4.4 Paper 4: Combining internal and external manufacturing of product modules

The two studies in the main case company recognizes a weakness in the contact area between designers and suppliers when all manufacturing is external, and it becomes natural to question whether maintaining some of one's own manufacturing could be a way to compensate for this weakness Does the updating and customization process become better, and could it be beneficial for designers to communicate technical issues with one's own manufacturing, if suppliers are not used for all manufacturing? A complementary case study, study 3, at another Swedish engineering company with both their own and external manufacturing, aims to investigate how the company's interface between their own design and own manufacturing differentiates, and the results are compared with when all manufacturing is external.

Thus, through product modularization, both smaller and larger product improvements are supported as long as they are mainly defined to a specific module, otherwise coordination efforts are needed. Concerning process improvements, such are best enhanced by the closeness that one's own manufacturing of product modules brings. Therefore, some improvement issues become more difficult to communicate when the manufacturing unit is located far away from the design unit. On the other hand, the same manufacturing unit could be located close to important customers, which brings other opportunities. The global markets of today make location and sourcing issues fundamental. The embedded coordination, that product modularization brings, opens up for differentiated solutions on how to combine internal and external manufacturing. Study 3 contributes to RQ 1 and 2 with two findings which are useful to reflect upon when a company considers the level of external manufacturing.

First, with one's own manufacturing located nearby product development brings preconditions for close collaboration regarding both product and process improvements through scheduled meetings and accrued cooperation channels. The extended contact area such a nearby location could bring also opens up for such spin-off effects as dissemination of manufacturing knowledge to designers and informal decision-making.

Second, the informal way to handle problem situations emanating from a close relation between own product development and own manufacturing risks eliminating the common process framework needed for production preparation, and the grounds for long-term improvement work.

To sum up, the external manufacturing of product modules can bring knowledge problems and difficulties to improve products and processes, because the distance between design and manufacturing may lead to the product development engineers having less direct contact with the product modules. Even if this could be balanced by dedicated persons emanating from the design function who work cross functionally, an alternative is to keep some manufacturing internally. Additionally, that alternative also enhances the work with product and process improvement.

5. Analysis

This chapter analyses the results of this thesis with regard to the two research questions. First, the four papers contribution to each of the two questions is presented; then research question 1 about how to coordinate design and manufacturing of product modules are dealt with in section 5.2. Finally, section 5.3 answers research question 2 about how product realization is affected by external manufacturing of product modules.

5.1 Papers contribution to the answering of the research questions

Table 5 summarizes the papers connection to the research questions and how they contribute to them.

Table 5. Contribution from research papers to the two research questions.

Paper	RQ 1- Coordination mechanisms	RQ 2- Improvement of product realization
Paper 1: Managing customization by product modularization	Structuring coordination mechanisms	Identifying shortcomings in customization
Paper 2: Managing continuous improvements by product modularization	-	Changing character of improvement work
Paper 3: Coordinating external manufacturing of product modules	Analyzing character of coordination mechanisms	Long-term effects from external manufacturing
Paper 4: Combining internal and external manufacturing of product modules	Identifying type of coordination by internal manufacturing	Identifying and analyzing differences in the improvement work

Regarding RQ 1, in paper 1 and 4, used coordination mechanisms are identified and structured, while in paper 3 their different characteristics are analyzed, as well as how the mechanisms could be used to match different situations.

All four papers contribute to the answering of RQ 2; paper 1 by focusing on the upgrading of product modules according to customers' needs , paper 2 and 3 by characterizing improvement work by external manufacturing of product modularization, and finally, paper 4 by comparing improvement work in different contexts.

5.2 Coordination of design and manufacturing of product modules

The first research question focuses the need to manage the interactions between design and manufacturing by different means of coordination:

RQ1: How can design and manufacturing of product modules be coordinated?

This thesis is based on three case studies conducted in two companies, one "main case company", Company A that relies totally on external suppliers, and another "complementary case company", Company B, having a mix of internal and external manufacturing. Although the needed coordination is reduced by the embedded coordination product modularization brings, further coordination is always more or less required (Persson & Åhlström, 2013). Especially external manufacturing needs coordination mechanisms, since less proximity affects the level of close collaboration (Howard and Squire, 2007). A large number of mechanisms related to the two companies' situation are identified and analyzed in this thesis, though without the ambition of embracing every existent coordination mechanism in this particular research area.

Coordination by external manufacturing of product modules

Company A has almost entirely engaged external manufacturers, since the beginning more than fifty years ago, then the suppliers were small and located nearby, but through the company's global expansion, the supplier base also became global. As a consequence, SCM has gradually become more important not only for purchasing issues but also in handling the relationships with different types of suppliers. Today, this SCM-focus also affects how the management of the DM interface could be characterized, more mentioned below.

Therefore, in order to manage and coordinate the relationships between their own product design and different suppliers, Company A mainly combines a strategic, structured framework with a more contingency based use of intermediaries. The company has developed a structured product development framework with rules and templates which regulates the design process, characterized as "standardization" and "coordination by plan" according to March and Simon (1958). This framework is well implemented in the organization and also disseminated to external manufacturers so that they work according to the company's intentions. The structured framework is one of the company's strengths, which also contribute to the improvement work by its well-defined procedures. This is well in line with what literature states, that product modularization requires such a ground of collaboration with suppliers as that of a common framework. (Howard and Squire, 2007). These authors claim that such a framework must be combined with other activities, e.g., cross-functional teams, to strengthen the relation, being able to meet new, unexpected situations. Figure 10 illustrates how the company today combines a strategic framework (a thin DM arrow) with different coordination activities. Since all manufacturing has been external for a long time, the supply chain function has gradually become more important, both for strategic management reasons and to coordinate the suppliers. A growing part of the supplier contacts has gradually passed through this supply chain function. Finally, ending up in the situation of today, the supply chain function has become the main contact area between the company and the suppliers, resulting in decreased communication between designers and suppliers. The DM distance has become an issue to deal with, and the company could do this with different coordination activities, marked in Figure 10.

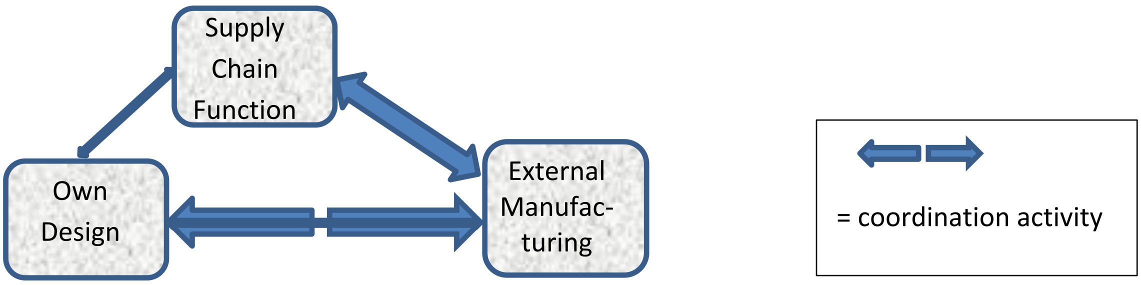

Figure 10: The relation between own design and external manufacturing is not fully developed, and needs to be strengthened by coordination efforts.

The company uses a tool box of coordination mechanisms to bridge the distance between product development/design and manufacturers, described at length in appended Paper 1 and 3 and some key coordination mechanisms are summarized here below in Table 6.

Table 6. Key coordination mechanisms for Company A's platforms.

Platform	A	B	C	D
Type	Medium complexity product family	Medium complexity product family	High complexity product family	Complementary distribution systems
Prioritized coordination mechanisms	*Own local production personnel in China link suppliers to design function. *Supply function simplifies the DM communication.	*Design Support (DS) group sets up expert teams, working intense both at own plant and at supplier plant.	*Suppliers join early in the concept phase of product development. *Supply Chain function has a leading role	*Strategic supplier collaboration mainly grounded on "trust".

A characteristic for the case company is to use their own different intermediary actors to narrow the DM gap, which is similar to 'liaison persons' mentioned in the literature (e.g., Twigg, 2002). This coordination mechanism seems to rely to a great extent on the skills and personality that the acting persons possess in handling the different emerging situations. One product group could use a single 'super user' whereas another uses a team to work cross-functionally. The manufacturing of platform A in China is coordinated by both the supply chain function and by their own local production unit, to help suppliers fulfill the requirements. Such use of contingency related intermediaries is well in line with that which Terjesen et al. (2012) suggest, mentioned in section 2.2.3 about matching product modularization and supplier integration. Company A has a clear sourcing strategy connected to product modularization. The supply chain function is strongly positioned in the product development process, and has power to decide both which suppliers to utilize and when to replace a supplier. According to Terjesen et al. (2012), in such a situation the combination of a high level of modularization and a high supplier integration level raises performance, though after a certain point further integration will be costly and will not result in better performance. The authors suggest a contingency perspective since the performance peak is difficult to identify. Company A's use of intermediary persons and teams brings such flexible means to both coordinate the DM relation, and to be able to change the supplier integration level according to circumstances.

Although, the company's sourcing strategy also affects the possibility of building long lasting relations with suppliers. For instance can a manufacturer engaged during the prototype phase be replaced by another when it comes to commercialization, and another example is that the case company is now implementing 'dual sourcing' to reduce their dependency on one single supplier. This means that the company's coordination backbone, the structured framework, must be implemented by new suppliers. During such periods the suppliers' integration level risks decreasing so much that it becomes difficult to manage. Howard and Squire (2007) warn for this and mean that external manufacturing of product modules must be based on long lasting collaboration with strategic suppliers. Company A does not seem to be totally aware of the consequences of such a replacement of suppliers, in spite of their suppliers being labeled as strategic.

Internal manufacturing of product modules

The complementary case company Company B has product development units in Sweden and the US, together with manufacturing plants and manufacturing suppliers spread globally, mostly in Europe and the US. Further, in this thesis, the relationship between the Swedish product development unit and their own engine plant situated at about one hour's distance by car, is stressed.

Also, this company builds the DM relationship on an ICT based structured framework, although narrowed by different types of coordination mechanisms, compared with Company A. There are mainly three coordination efforts that shape the DM relation:

1. Regular meetings once or twice a month, concerning operative quality issues, mostly at the engine plant. The number of meetings varies according to weighed up needs and both designers and the manufacturing staff seem to have an informal approach and try to find solutions together when a quality issue is raised. This is in line with "coordination by informal communication" and "team work" according to Twigg (2002). Even if this is mainly seen as positive, the informal decisions made sometimes risk shortcutting the formal framework needed to prepare the production processes.
2. Different development projects are driven by the designers, and the contact area mentioned above is used to test constructions in practice, i.e., operators are often involved in a more or less formal way. It happens rather often that a designer works some hours in the production line in order to learn more about a certain issue.
3. Sometimes when all the test rigs are occupied at the product development unit, engines could be long-term tested at rigs at the manufacturing plant. This extra contact area brings further communication which enriches the network in the DM interface. Designers and manufacturing personnel learn to know each other better, which is useful when they collaborate around development projects and improvement issues.

This relationship does not need intermediaries to bridge the DM distance, instead designers and manufacturing personnel communicate directly via ICT based tools and by face-to-face meetings. The DM collaboration is mainly moderated by the physical distance 'one hour by car' creates; it is a close distance, but not too close. The functional integration between design and manufacturing seems high, perhaps sometimes too high since the informal manners risk narrowing the awareness of needed system thinking and contextual factors influencing the DM relation. "Too friendly" relations or too much integration could cause important information for the situation being overlooked (Souder, 1988; Fernandez et al., 2010) or could hinder product innovation (Koufteros, Vonderembse and Jayaram, 2005). If, for any reason, it becomes necessary to diminish the integration level, the natural coordination mechanism seems to be to strengthen up and formalize the common work according to the structured framework.

5.3 Influence from external manufacturing on improvement of product realization

The second research question focuses on how external manufacturing is related to different types of improvements.

RQ 2: 'How does external manufacturing of product modules affect improvement of product realization?'

As mentioned in the introduction, this thesis addresses three parts of the 'product realization' concept (Bellgran and Säfsten, 2010); the development of a new product, the upgrading of an existent product and the improvement of manufacturing processes.

As already stated, the main case company relays totally on external manufacturers. In the case studies at Company A was found that the distance between design and manufacturing affects the continuous improvement work on different products and modules, which will be described more below. Several of the respondents stated that if the manufacturing was located in-house or nearby the design unit, it would have been easier to communicate face-to- face and thereby make changes and improvements together. Meetings could be held more often and informally, without time consuming transports. Such a situation would also bring the means of keeping the design function updated with the current manufacturing knowledge through frequent communication in the design/manufacturing (DM) interface.

Before investigating how external manufacturing affects the improvement work, it can be useful to describe how the improvement work at Company B is managed, to compare it with the stated, somewhat idealized version above, and with the actual version at Company A.

An example of improvement work by internal manufacturing of product modules

As described in the section 5.2 above, Company B combines a structured framework with quite informal face-to-face communication to coordinate the internal DM interface. Concerning improvement work, during recent years the responsible product designer has made efforts to build up a good relation with the manufacturing personnel, and to handle operative quality issues in a structured way. Both product and process improvements are discussed at the monthly meetings and ways to handle them are initiated, e.g., through a cross functional improvement group. This usually works out well, though some recurrent problem issues are almost neglected, and the manufacturing unit has to live with their 'homemade' solutions, since otherwise the designers prioritize. The relationship has an informal approach, though development projects are driven by the designers in a formal way.

To sum up, the internal improvement work between design and manufacturing works out reasonably well and leads to good product quality on delivered modules, in line with the potential for improvement of product and processes by internal manufacturing (Chapman and Corso, 2005). One advantage is the informal and friendly atmosphere that provides dissemination of knowledge to each other, especially designers who gain manufacturing skills, useful and necessary in many other situations (von Haartman, 2013).

When this engine module is delivered to a system builder to fit with other modules into a vehicle, many problem issues are reported. The quality of the total product system seems to be rather low; at least lots of adjustments are needed. Yet, it is not possible to analyze if the close internal DM relation could impact this result, i.e., by a narrow focus which may lead to a suboptimation of the improvement efforts.

On the whole, this resembles quite well the idealized version stated above, though the informal manners risk undermining the work according to the common framework and thereby indisposing the preparation of the production processes. Additionally, the design unit could get used to the manufacturing plant ‘fixing’ issues that ought to be handled in a more professional and long-term manner.

In the next sections, the improvement work at Company A will partly be related to this example taken from Company B.

5.3.1 Development of a new modularized product

Thus, in the literature it is stated that high interfunctional integration is positive when developing a new modularized product (Danese and Filippini, 2010). This means that representatives from different units, e.g., design, manufacturing, marketing, finance ought to form a cross-functional team in order to consider how functional aspects affect the modular design early in the development process. This could otherwise be costly, with iterative redesign of module interfaces being enforced through not considering the consequences.

Company A’s Platform C is an example of a newly launched modularized product, and has only been in the market for rather more than a year. As already mentioned, since the level of complexity is higher compared with the other platforms, collaboration with strategic suppliers has been crucial when developing this new platform. Frontloading with early supplier involvement in the concept phase together with extensive cross-functional teamwork characterizes how the new platform has been developed, just as suggested in literature (ibid.). The supply chain function has been in a leading coordinating position in this development work. However, giving the supply chain such empowerment has been questioned by some designers, and using a group similar to DS at the Italian plant, could have made the linking of different groups easier. This small team originates from the design function, but is empowered to work cross-functionally to connect designers, suppliers and supply chain representatives when needed. DS’s role is also to deploy manufacturing competence, both to designers and to the supply chain function. Such a team could bring required dynamics into the organization in the important modularization phase, given that the right people with necessary skills come together and manage to collaborate. When launching a new product family such a team may have a regulated role until a common working ground for different functions is established.

The launch of platform C has taken longer than expected, and several reconstructions, more than expected, have taken place. According to literature, both high interfunctional integration and close supplier collaboration (Howard and Squire, 2007) are essential for the development of a new complicated modularized product, in foreseeing upcoming interface issues. Here it seems that the needed DM integration levels have not been fully reached, leading to delays and reconstructions. One reason for this is probably that the supply chain function has become the main contact area between the company and the suppliers, resulting in decreased direct communication between designers and suppliers. Though the company uses different coordination activities to strengthen this DM integration; frontloading, cross functional teams, courses in ‘Design for Manufacturing’, extended drawing reviews; the indicated conclusion is that the supply chain function seems to need to legitimize their leading position through more design skills.

5.3.2 Improvement and upgrading of the product modules

Suggestions from suppliers or customers for more innovative changes to a single product module could preferably be developed together with the design function if they are affecting other modules to a lesser degree (Hsuan, 1998). Other improvement suggestions ought to be examined before an improvement project could start, since changes to several modules must be managed and coordinated (Persson and Åhlström, 2013). The coordinating persons require developed manufacturing competence to conduct the improvement process.

Company A uses a reporting system into which improvement suggestions from suppliers are logged and filtered before decision is made as to whether or not an improvement project should be started. Just in line with what literature proposes and the likely focus are more project oriented product improvements, since it is easier for companies to collaborate around innovative product issues (Chapman and Corso, 2005).

This is managed differently at the two studied locations. Therefore, in Italy, an improvement suggestion coming from an external supplier is first reviewed by the DS group, mentioned above. This group considers the economic aspects together with the supply chain function. After passing this filter, relevant persons become involved in a pilot project, aiming at upgrading the product design, illustrated in Figure 11.

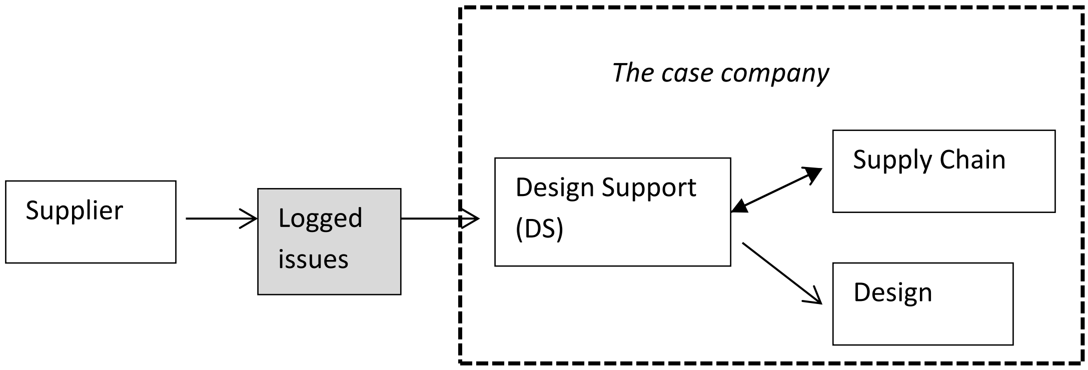

Figure 11. Organization of product improvement work at one product development unit

An initiated improvement project is also conducted by the DS group in collaboration with the supply chain function and designers. The DS group helps linking to proper prototyping supplier, educates designers in manufacturing issues and helps the supply chain function with cost estimations. This group is built up of what Ettlie (1988) characterizes as ’engineering generalists’ and is rather dependent on group members’ individual skills.

The solution used at the other location is different and not so straightforward. Instead of using a team, different persons are involved one by one. Although, the logged suggested product improvements are handled more slowly with poor feedback and no distinct appointed and responsible person.

5.3.3 Improvement of the manufacturing processes

Concerning process improvements, such are best enhanced by one's own manufacturing of product modules (Chapman and Corso, 2005), since such improvements need close collaboration. Process oriented methods need a higher integration level with the supplier than that which external manufacturing of modules naturally brings. Therefore, due to the external manufacturing, improvements of the manufacturing processes could be done by the suppliers as long as they do not affect the module interfaces. Most often the case company Company A, does not stipulate how the manufacturing should be done as long as the product design is not affected. If the design is only affected to a lesser degree, the responsible designer could confirm directly, otherwise the improvement suggestion must pass through the logging system mentioned above. It seems that small-step improvement suggestions from suppliers stays in the system, and after a while the suppliers give up logging such suggestions. Here, Howard and Squire's (2007) call for long lasting supplier collaboration by product modularization, which probably would have made a difference in the work with improvement of manufacturing processes. Instead, the supplier integration level is limited by the case company's sourcing strategy, aiming at reducing the dependence of single suppliers.

The difference compared with Company B is striking. As mentioned above, regular monthly DM meetings raise both product and process improvement suggestions and ways of handling them are initiated, e.g., improvement groups. The close, informal relationship opens up for discussions about manufacturing improvements, especially since designers also sometimes work hours in the production line to learn more about a certain issue.

Beyond the obvious need for designers in an outsourcing company to obtain necessary manufacturing skills for design purposes, it is crucial in a more indirect way. The designers need to have relevant manufacturing knowledge (von Haartman, 2013), in order to be able to understand improvement issues from suppliers and customers. If not, customer and supplier relations risk being rudimentary and improvement issues will never be discussed, or awareness of them will not be raised at all. Company A's courses in Design for Manufacturing is one attempt to bring such skills, but a fruitful contact area with manufacturers to strengthen the DM relationship, and increase designers' manufacturing competence is needed. Working together with testing and simulation, partly at the company's test rigs, partly in suppliers' plants, is one such contact area, seems to work out rather well, but with an unexplored potential.

6. Concluding discussion

Conclusions in this chapter are drawn according to the purpose of investigating the DM interface, with respect to where the answers of the research question ended up. The contribution of these answers is stated, leading to implications for practice. Further research directions are outlined, before the chapter ends up with a learning perspective on product modularization.

6.1 Main conclusions

The purpose of this thesis has been to investigate the interface between product development/design and manufacturing when product modularization is used, with the emphasis on external manufacturing. Different characteristics for product modularization lead in somewhat contradictional directions which require an increase of awareness to be fully managed. This thesis presents several findings which add to the existing knowledge about product modularization.

6.1.1 The relationship between design and manufacturing

Several conclusions can be drawn from the analysis of the DM interface. First, intense cross functional teamwork is needed in the initial phase when the modules are designed to foresee upcoming module interface interdependencies (Danese and Filippini, 2010) in order to get the most out of the product modularization. This extensive work could then be used to build a lasting relationship between design and manufacturing, which could be coordinated to match different situations, e.g., product and manufacturing improvement work. Though, somewhat contradictory, since product modules' embedded coordination reduces the need of further coordination, external manufacturing is enhanced and instead of lasting DM relations, there will often be new unproven suppliers hired with whom to collaborate. Then, how to coordinate the different interactions in the DM interface becomes an issue to manage, and has not been stressed before in product modularization literature Second, when managing external manufacturing of product modules, it is more relevant to open up for different coordinating mechanisms than to try to optimize the integration level. This is in line with Terjesen et al. (2012) who claim that a high integration level with external product module manufacturers is beneficial to a certain degree, before further integration becomes costly and non-efficient. A well-developed ICT based corporate framework, common with strategic suppliers, lays the ground for such a high integration level. Thus, depending on contingency factors, further integration is needed, more or less to obtain best performance. The toolset of coordination mechanisms which is identified in this thesis ought to be handled with care, and adapted to the situational dynamics different modularized products' properties bring. Given a strategic common ground with a supplier, the level of collaboration has to be managed according to, among other things, the product's complexity and the supplier's skills.

Third, the external manufacturing of product modules can in the long-term perspective cause a competence problem. If the SCM influence grows, it could result in lower activity in the DM interface and product development engineers may lose relevant knowledge about manufacturing methods and techniques. Even if this effect is generally identified by outsourced manufacturing (e.g., Olausson and Magnusson, 2011), it is accentuated when product modularization is used as a sourcing tool. This aspect ought to be considered early when implementing a sourcing strategy, and may be balanced by dedicated persons, who emanate from the design function and work cross functionally to link designers, suppliers, and the supply chain function around certain problem issues. Therefore, finding a fruitful contact area with manufacturers, e.g., working together with testing and simulation, both strengthen the relations and increases designers' manufacturing competence.

6.1.2 Improvement of product modules and manufacturing processes

Another part of the purpose of this thesis is to investigate how the improvement work is influenced when a product is modularized and the manufacturing of the modules is done by external suppliers. First, based on the analysis of the case studies, it can be concluded that whether or not the suppliers are located close to the design unit, it affects the improvement work's character. The need for coordination increases through greater distance, and the focus of the improvement work tends to shift from small-steps improvement to redesign issues according to claims from customers and suppliers (Chapman and Corso, 2005). The geographical distance does make a difference, but could be handled by different means, especially if a professional DM relation built on good personal contacts is available.

Second, to have one's own manufacturing unit close to the design unit not only enables an effective improvement work in that specific DM relation, especially concerning small-steps improvement of manufacturing processes. The closeness also brings the means of developing the designers' manufacturing competence in a natural way. Such competence is essential both for a good design result, but also for the ability to understand improvement issues emanating from customers' and suppliers' needs. An alternative, if a company chose only to hire external manufacturers could be to develop close, lasting supplier relations (Howard and Squire, 2007) or to use dual sourcing, so the company could have such close collaboration with some nearby located suppliers, while others remain more distant.

Third, if all manufacturing is external and distant and the company use product modularization as a sourcing tool, the improvement work's character changes and becomes more of a log report system. Findings in this thesis indicate that to function well, such a system needs to be managed by someone who coordinates the improvement issues together with designers, suppliers and customers. Therefore, giving feedback on all logged suggestions, also rejected, seems crucial. A cross-functional group emanating from the design unit with a coordinating role, and working closely together with the supply chain function, seems to balance the necessary trade-off between lasting relations with suppliers and an active supplier sourcing strategy.

6.2 Contributions

Product modularization has long since been used for several reasons in different fields (e.g., Baldwin and Clark, 1997; Flynn et al., 2010) and lots of studies of the concept have been conducted (Gershenson et al., 2003; Pasche, 2011). Although, the concept's organizational potential is not fully developed, this research study contributes with new findings in two areas. First, connected to the ongoing globalization, product modularization is gradually becoming a sourcing tool since product modules enhance outsourcing of manufacturing to suppliers. What then happens in the long run has not been studied before this thesis, where a sourcing company with reliance on external manufacturers for more than fifty years is studied. This makes the company an exemplary case (Yin, 2009) and useful for companies in an earlier phase of the sourcing process. Second, since studied organizational benefits product modularization give their contribution somewhere in between the Operations Management and the SCM area, the full potential has neither been recognized by product modularization researchers, nor by SCM researchers. Sanders, Zacharia, and Fugate (2013) pinpoint that the growing importance for SCM has not yet been fully valuated and still lacks a comprehensive view and functional suboptimizations needs to be resolved by a more holistic view. This research relates to existent literature and brings a theoretical contribution to how product modularization could be used for managing purposes. Synthesizing what literature says concerning product modularization and DM integration, it is stated that better performance (lead time reduction) is supported by product modularization if high functional integration is obtained in the module design phase (Danese and Filippini, 2010). This could lead to a lasting DM relationship with a rather high integration level (Howard and Squire, 2007), which could be adapted to changing situations by means of coordination. To get the best possible performance, coordination flexibility is more important than to reach optimal integration level (Terjesen et al., 2012).

Additionally, connected to what is mentioned just above about integration level, the 'integration' concept needs to be updated and this thesis has started that process. Instead of an often preconceived view of 'the more integration the better' (Turkulainen and Ketokivi, 2012), the level of integration ought to be adapted to match different situations (Rubera et al., 2012). As found in this thesis, it is more relevant to stress 'coordination mechanisms' than 'optimal integration' (Terjesen et al., 2012), since situational prerequisites are changing so rapidly today.

6.3 Implications for practioners

This thesis brings two managerial implications to outsourcing companies who could be in an earlier phase than the main case company, which has been relying on external manufacturers for a long time. First, external manufacturing of product modules can bring knowledge problems and difficulties in improving products and processes, because the distance between design and manufacturing may cause the product development engineers having less direct contact with the product modules. Even if this could be balanced by dedicated persons emanating from the design function who work cross functionally, an alternative is to keep some manufacturing internally. Both alternatives provide benefits and challenges. It is important not to lose required long-term manufacturing skills and therefore consideration must be taken about such aspects early on when implementing a sourcing strategy.

Second, high functional integration is needed initially when product modularization is implemented (Danese and Filippini, 2010) and then when the modules are manufactured, lasting supplier collaboration enhances the improvement work (Howard and Squire, 2007). This is important to bear in mind when implementing a sourcing strategy since, for instance, the replacement of one prototyping supplier with another by commercialization may be more risky than seen at first glance.

6.4 Further research

The main contribution of this thesis is the investigation and analysis of how the exemplary main case company manages their sourcing strategy connected to product modularization. Future research could put more focus on the level of modularity, and how it affects appropriate integration level. Similarly, how the 'age' of the supplier-relation and suppliers' skills are related to structural elements and coordination mechanisms seems to be crucial to understand in a sourcing situation. Therefore, it is important to get a fuller picture, including the perspective from the supplier base. This could then be the basis for finding a correlation between mechanisms, e.g., through a quantitative study. Another feasible comparative study object could be a company similar to the main case company, with the supply chain function in an even more leading role. Will there emerge new interfaces to design, market, and purchasing for the supply chain function to handle?

Product modularization's organizational potential is not fully recognized. Improvement of product modules is often related to sustainable upgrading, aiming at reducing waste. One upcoming field to study is how product modularization could become a real enabler of meeting future requirements in a cycle economy (Seliger and Zettl, 2008). Such aspects could quite easily be more focused in the sustainable concept product modularization already stands for.

6.5 A learning perspective

Additional to the characteristics of product modularization already mentioned throughout the thesis, the concept also has the potential of being used as a learning means in different technical education. Yet, not so many have recognized how the modularization concept could be seen as a many-headed tool to illustrate different applications, not only in product development.

6.5.1 Modularization as a learning tool

Being both a researcher and a high school teacher in product design, it seems natural to transfer these research findings into the educational arena. I propose four directions, into which modularization could be a "Swiss Army knife" to form technical knowledge in a coherent manner, step by step as:

- An introducer to LEAN thinking
- A bridge to practice
- A green paint container
- A means for open innovation

An introducer to LEAN thinking

One leading principle of modularization is to structure something quite complicated into manageable units (Gershenson et al., 2003). Thus, learning how to differentiate a complicated situation and sort out the essential components, becomes more and more useful in an even more technical and interlinked future. Soon after a person has started to structure an issue, the need of reduction comes into mind. This can then be the starting point for introducing the LEAN thinking concept (Womack and Jones, 1996) where reduction of waste is central.

A bridge to practice

To learn from real practice seems to be the ultimate way of active learning (e.g., Itin, 1999). Therefore, helping local SME's structure and standardize the use of frequent components could be done by quite young students after some training in the modular concept. Once getting into a company it seems natural that the collaboration with the student continues. Both high school and college students have the potential of collaborating with smaller companies which in the long run could lead to a mutual relationship between academia and local SME's.

A green paint container

Today's students are conscious about the need to find solutions to meet future challenges, and modularization offers a business potential also considering such sustainable aspects as recycling and reuse. When a product is modularized, a component could be replaced by another quite easily compared with an integrated product. If the replaced component is worn out it could either be repaired or recycled in an environment friendly way. In addition, by continuous improvement, the replacing component could be friendlier to the environment. It could be lighter, using less energy or made of a more homogeneous material than the older component. Brunø et al (2013) evaluates more thoroughly how different driving forces for modularization are related to the ten ECO-design rules according to Karlsson and Luttrop (2006). Their conclusion is that sustainable aspects could quite easily be included in the concept product modularization stands for.

A means for open innovation

Since the concept of open innovation was introduced more than a decade ago (Chesbrough, 2003), several companies use open innovation to broaden their creativity base. A concept similar to modularization, product platforming, involves the developing and introducing of a partially completed product where non-expert persons, e. g., students, can extend the platform product's functionality while increasing the overall value of the product for everyone involved. By dividing a complex product, or a complex system, into smaller pieces it becomes easier to understand and manage. As long as the developed modules conform to the standardized module interfaces, the design of different modules can be loosely coupled and independent groups can suggest an unlimited amount of design solutions. This leaves room for creativity, crucial not only for younger people's motivation.

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Paper 1

Managing customization by product modularization

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Managing product customization by modularization

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Abstract
The purpose of this paper is to investigate how to organize external manufacturing of product modules. Modularization can be used to facilitate the use of external suppliers. However, the ability to work with continuous manufacturing improvements and customization becomes more difficult due to the increasing distance between design and manufacturing. This is also confirmed by the case study done for this paper at a manufacturing company relying heavily on external suppliers.

In the case study we could also identify how the company handles this situation by using different solutions (facilitators), that are strategically based or influenced by the contextual situation.

Keywords: Customization, Product modularization, Design-manufacturing relationship

Introduction
The need for more customized, individualized, products is constantly increasing (Jiao and Tseng, 1999; Simpson, 2004). Hence, the ability to be able to offer customized products, in other words product variants that meet customers' different needs, has the potential to give companies a competitive advantage. But, increased number of product

variants also adds more and more complexity to the operations of a company, e.g. more different components to manage in manufacturing. Therefore, many companies have adopted a product platform and/or modularization strategy as a way to deal with this growing product variety (Sanchez, 1995; Simpson, 2004). It is well-known that product modularization can be used in order to give benefits in product development, such as reduced lead-time and cost (Baldwin and Clark, 1997; Pasche, 2011).

But, it is also possible to use product modularization for managing the sourcing process. It is quite common that companies outsource manufacturing activities to suppliers, but keep the R&D activities in-house (Berggren and Bengtsson, 2004). One of the risks of this is that the daily face-to-face contact between product development and manufacturing personnel disappears, and this distance makes it difficult to coordinate the manufacturing. In the present literature it is argued that modularizing a product is a way to manage this distance between Design and Manufacturing. By standardizing the interfaces between the different modules, outsourcing of modules to external suppliers is made easier (Brusoni and Prencipe, 2001; Gadde and Jellbo, 2002). Further, the standardized interfaces bring 'embedded coordination' into the modularized subsystems (Baldwin and Clark, 1997; Hong and Hartley, 2011), and hence the need for coordination is reduced. This means that modularization creates a high degree of independence or 'loose coupling' between the modules due to the standardized interfaces (Sanchez and Mahoney, 1996). As long as the developed modules conform to the defined interfaces the design of different modules can be loosely coupled (Sanchez and Mahoney, 1996).

The more technical aspects of product modularization are rather well-researched. For example there are a number of matrix based methods (e.g. Erixon, 1998; Huang and Kusiak, 1998) that can be used to group certain components into different modules, and to define interfaces between the modules. But, research concerning organizational implications is more limited. There are some research (e.g. Sanchez and Mahoney, 1996; Brusoni and Prencipe, 2001; Pasche and Persson, 2012; Persson and Åhlström, 2013) focusing on organization aspects of modularization, however this is an area that is not yet fully explored.

Persson and Åhlström (2013) concluded that the development of product modules can not be completed without coordination between organizational units developing the different modules. In other words, coordination can not take place only through standardized interface specifications. The study by Persson and Åhlström (2013) was focusing on different product development units in one single company. But, since the literature suggests (e.g. Brusoni and Prencipe, 2001; Gadde and Jellbo, 2002) that product modularization could facilitate outsourcing of product modules to external suppliers, it would be interesting to investigate if this brings any challenges to the company. Therefore, the purpose of this paper is **"to investigate how to organize external manufacturing of product modules"**, illustrated in Figure 1.

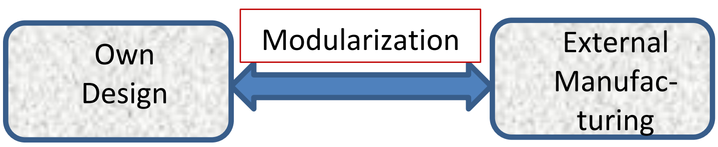

Figure 1: Modularization and the relation between own design and external manufacturing are in focus of the study

The paper is organized as follows. First the literature on product modularization and external manufacturing/outsourcing is reviewed. Next the employed methodology is described. The empirical findings are then presented and discussed. Finally, conclusions are drawn regarding how to organize external manufacturing of product modules.

Literature review

Product modularization is, shortly described, to divide a product or a system into a number of parts/modules, each of these modules consisting of a number of components (Gershenson et al., 2003). By dividing a complex product, or a complex system, into smaller pieces it becomes easier to understand and manage. Product modularization is also about the definition and development of interfaces between the different modules (Baldwin and Clark, 1997). The interface specifications describe how the different modules work together with each other (Baldwin and Clark, 1997). The ultimate goal is to achieve a product in which the different modules are decoupled from each other so that changes can be made in one module without affecting the other modules (Mikkola, 2003). The module interface makes it possible to have a large variety within a module, but without causing disruptions in other modules (Sanchez and Mahoney, 1996).

A product modularization strategy can give the company several benefits, such as reduced development lead-time and cost (Baldwin and Clark, 1997), which for example is achieved by using common components across different products (Ulrich and Tung, 1991), and standardization implying economy of scale and scope (Muffatto and Roveda, 2002; Jacobs et al., 2007). Product modularization can also contribute to improved sustainability, this because the module interfaces facilitate product maintenance and remanufacturing (Seliger and Zettl, 2008). A product having distinct detachable modules improves the recycling possibilities and the re-use of long-lasting modules (Gu et al., 1997). Modularized products also give strategic flexibility, which means that companies can react quickly to changes in demands (Sanchez, 1995). Another benefit from product modularization is the increased possibility for decoupling of tasks. This decoupling makes it possible to accomplish different development as well as manufacturing activities in parallel (Ulrich and Tung, 1991; Baldwin and Clark, 1997). The decoupling can for example help to speed up the product development process, to shorten the development lead-time. It will also be easier to upgrade products throughout their life cycle because changes can be done in different modules that are independent to each other (Brusoni and Prencipe, 2001).

A major part of previous research in the product modularization areas has focused the more technical aspects, for example how to divide a product into modules, each of these modules consisting of a number of components. This with the purpose to define interfaces between the modules in a way so that they become decoupled from each other (McClelland and Rumelhart, 1995). In the literature it is possible to find a number of structured methods (e.g. Erixon, 1998; Huang and Kusiak, 1998), most of them are matrix based, having the purpose to help to divide a product into a number of modules. But, the modularization ideas have also been extended to the design of product development organizations (Brusoni and Prencipe, 2001). The standardization of module interfaces allows processes for developing component designs to become loosely coupled (von Hippel, 1990; Sanchez and Mahoney, 1996). The development processes can then be effectively coordinated simply by requiring that all developed components conform to the standardized component interface specifications. Coordination can thus be achieved with a minimum of managerial effort.

The interface standardization can also facilitate the outsourcing of modules to different suppliers (Brusoni and Prencipe, 2001; Gadde and Jellbo, 2002). However, if the manufacturing of the modules has been outsourced to different suppliers, sometimes located in different parts of the world, the ability to continuously work with manufacturing improvements become difficult (e.g. Greasley, 2009). In the same way, adaptions to customers' needs become more difficult to communicate when the manufacturing unit is located far away from the design unit.

Olausson and Magnusson's study (2009) strengthens that there is a need for internal manufacturing competence at a contracting or outsourcing firm, a statement which has been identified in several previous studies (Prencipe, 1997; von Haartman and Bengtsson, 2009). Olausson and Magnusson's cases show that firms are capable of improving their manufacturing competence even when all manufacturing activities have been outsourced. To compensate for the lack of own manufacturing, the suppliers ought to be engaged in an early stage of the NPD project, visits to suppliers are taking place frequently and formalized standards and checklists are used to enhance both the formal and informal communication process with the suppliers. Applying such an early involvement of suppliers to modularized products, the initial extensive work, which forms the product modules, will create a relationship between the design and manufacturing units. Such a relation could then be adapted to match different customizing issues. High integration in the relation could match situations with high uncertainty NPD projects; low integration could be more efficient in other situations, for instance minor refinements of design or certain phases of a product development project (Rubera et al., 2012). The embedded coordination, that product modularization brings (Baldwin and Clark, 1997), opens up for such a differentiation of the level of integration with external manufacturers.

Methodology

The organizational aspects of product modularization, and what challenges it brings when it comes to organizing external manufacturing of modules, is an area that is not very well researched. There is only a limited number of studies, which was also described in the literature review, that has had this focus. Therefore, we have chosen a case study approach for the purpose of this paper. There are two reasons for choosing this methodology, the current state of knowledge and the nature of the problem (Pettigrew, 1990). First, case studies are well suited for questions that are not thoroughly researched (McCutcheon and Meredith, 1993). Second, this methodology was chosen since our focus is on 'how' and 'why' questions (Yin, 2009). To investigate how a company organizes its external manufacturing of product modules also calls for an in-depth insight in a company that a case study can give. In addition, a case study is suitable since both the physical and human aspects in this relationship are concerned (Voss, 2009). It would have been difficult to formulate survey questions which could bring more than just superficial understanding of the studied aspects.

A single case study gives limited possibilities to generalize the findings, but as our goal is to enrich the theory of product modularization, such a case study could be the first step in theory building that could be followed by further studies in other companies.

The case company

The empirical data for this paper originate from a multinational Swedish manufacturing company. In 2011 the turnover was about 10 billion euros, and the number of employees about 20,000. The company has operations located in many different countries in different parts of the world, but the main center for product development is located in Sweden. This company develops and produces large industry machines in rather small series; it is thus not a large volume producing company.

This company has a clear product modularization strategy, as a way to deal with product customization, being able to meet customers' different needs. The company relays on external suppliers for almost all of its manufacturing. The extensive use of external suppliers, together with the modularization strategy, makes this company a suitable study object for the purpose of this paper.

Data collection

The data for this paper was collected through 11 semi-structured interviews that were accomplished during winter 2013. The interviewees were chosen in collaboration with an R&D Manager in the case company. Nine of the respondents were working in the main product development unit in Sweden, which has around 250 employees. Most of these interviewees are Module Managers, i.e. responsible for a module or a sub-module. But also a purchaser and a production technician from the Supply chain organization were interviewed. The interviews lasted between 60 and 90 minutes. All interviews were recorded with a Dictaphone and both interviewers (two of the authors) took notes.

The interviews followed a semi-structured approach, but were systematically asked in the following areas, with the focus on how the collaboration between own product development and the external manufacturing suppliers is organized:

- The product development work
- The modularization work
- Design for Manufacturing, DfM
- How changes in the product are implemented
- Collaboration with suppliers

The respondents also were asked to rate some interview related statements according to a nine-degree scale. This were not for statistical usage but to clarify the interview responses . In addition to the interviews, informal discussions were held with other people involved in the product development process.

In addition to these nine interviews with people in the main product development unit, also one of the external suppliers was interviewed. Almost the same questions (see above), only with minor adjustments, were used in this interview. The purpose of this interview was to investigate how the collaboration with the case company is perceived by a supplier, not to get the full supplier picture. Finally, a sales engineer at a marketing company belonging to the case company was interviewed regarding customization issues. For this interview the same semi-structured questions were used, slightly modified.

The collected data were grouped based on the five areas in the interview guide, discussed and analyzed with the aim to find patterns and relationships. These eleven interviews give a reasonable level of saturation (Yin, 2009) according to the focus of the study, though it would have been interesting to interview further suppliers.

Empirical findings

The study focuses on the company's three main platforms with somewhat different characteristics. In the case company, a platform is a product group constructed with a common set of modules, which could be modified to individualized products. Platform A is an older product group than B, which also is more expensive. Platform C is used for supplemental equipment to the two other product groups, e.g. different types of distribution components linked together. Table 1 gives a platform overview.

Table 1. Characteristics for the three studied platforms.

Platform	A	B	C
Type	Older product group	Newer product group	Newer / older distribution systems
Suppliers location	In China	Mainly in Austria and Sweden	Mainly in Sweden and USA
Design location	Sweden	Sweden	Sweden

Several respondents stated that if the manufacturing was located in-house or at a supplier quite close to the case company, it would have been easy to communicate face to face and thereby making changes and decisions together. Meetings could be held often and informally, without time consuming transports. Such a situation would also bring the means to hold the design function updated with the current manufacturing knowledge through frequent communication in the design/manufacturing (DM) interface.

Since the suppliers are located abroad or not so close to design in Sweden, the DM distance makes it difficult to have such "over day" face-to-face meetings. It becomes more problematic for the designers to obtain latest manufacturing competence in a natural way, since they seldom physically get in contact with the manufacturing process. Then, both the lack of sufficient manufacturing know-how as well as the DM distance becomes an issue to handle and the case company does this in different ways. Some of the solutions are used strategically while others are more context based. If such solutions, here called facilitators, are a result of a strategic direction in the company, as structuring of the project processes and close collaboration with suppliers, it could be classified as "strategically". On the other hand, if the facilitator more or less is the result of an opportunity raised from the context, it is relevant to classify it as "context based". Access to persons with useful skills is an example of the latter, provided that the skills are not a result of the company's education plan, which instead makes them strategically based. In Table 2 at next page there is a presentation of such solutions, results from the interviews. The italic concepts primarily are used to raise the readability of the table by grouping similar facilitators together. The numbers in brackets in the table are used when certain aspects are pinpointed below the table.

Table 2 Facilitators used by the case company to handle the Design/Manufacturing distance

Facilitator	**Description**	**Main effect on the three platforms A, B and C**	**Result**
Mainly strategically based solutions			
Structured process working			
Corporate standards and organized corporate framework. (1)	Product development work is structured and follows standards and plans, and is communicated to suppliers	The newer project, the more of this process method.	Suppliers join the same framework as the case company, more or less.
Regulated product changing process. (2)	There is a framework for how to log desired changes in products and how to handle the process.	Used by all platforms	Enhances communication with suppliers when changes are needed in the product.
Concurrent engineering			
Frontloading- suppliers join the design process early. (3)	Suppliers join early in the concept phase of product development.	Important by new product development, as for B now.	Concurrent product development enhances manufacturability.
Education in "Design for manufacturing" increases the designers' manufacturing competence. (4)	Courses are given according to identified specific needs	Important for all platforms	Dissemination of know how in the organization
Supplier partnership			
A-level supplier collaboration mainly grounded on "trust".(5)	Strategic supplier choice, with different level of engagement.	Deep collaboration with some suppliers most important for C	C is developing partnership with strategic suppliers
Different strategic meetings with suppliers. (6)	Once or twice a year suppliers discuss strategic issues together with the case company supplier function.	Used by all platforms	Product development objectives are communicated to suppliers on a general level.
Organization			
Supply function simplifies the DM communication. (7)	Supply chain has an intermediate role to bridge the DM distance	Crucial for A, linking Chinese suppliers with own design function.	An intermediary helps to form the DM relation
		Important for B, acts as a communicator in the DM interface	An intermediary helps to form the DM relation
		Helpful for C	Helps to coordinate supplier contact for C
More or less context based solutions			
Drawing reviews			
The own supply function's production technician is a drawing reviewer and communicator. (8)	A dedicated person who prepare for manufacturing by communicating design results to suppliers	Crucial for B to prepare design for manufacturing	The DM distance is narrowed by this person's manufacturing competence
"Super user" as drawing reviewer and communicator. (9)	Each platform dedicate some persons to handle manufacturing issues	Important for all platforms	The DM distance is narrowed by these persons' manufacturing competence
Supplier gives feedback by drawing review. (10)	Manufacturing issues are supplier reviewed at an early stage.	Important by new product development, as for B now.	Improved supplier involvement and manufacturability.

Test process			
Established test equipment in supplier plant brings deeper collaboration. (11)	The case company and the supplier together develop the testing process at supplier plant.	Important when developing new products, as for B now.	Forms a closer collaboration with suppliers.
Own test equipment brings basic data, suitable to form supplier knowledge(12)	The case company assembles and tests all modules together before delivery.	Test results are communicated to suppliers, especially at the B platform.	The continuous work with improvements is enhanced by the test logs.
Others			
Case company's local production unit in China facilitates communication. (13)	Own local production personnel link suppliers to design function.	Important for A	An complementary intermediary to handle the DM distance
Set-up expert groups with suppliers. (14)	Design function forms an expert group together with key suppliers.	Yet not used for these three platforms but for an external platform.	Close collaboration disseminate manu-facturing know how

During last years the case company has made their process work more structured and uses corporate standards and frameworks for decisions, responsibility, and project management, (1). This is communicated to the suppliers and gives a strategic common ground in the relations with them. Another strategic means is to involve suppliers as early as possible in the development process, i. e. frontloading, (3). This process has recently started so in many cases the suppliers still do not join the process until they give feedback by the drawing review, (10). Sometimes even the case company's own production technicians and "super users" do most of the reviewing before handing over the drawings to the supplier for further review, (8) and (9). This part of the process seems to be context based according to the involved persons' relationships and competence, as well as the distance to the supplier.

To strengthen the designers' manufacturing competence, appropriate education in "Design for Manufacturing and "Design for Serviceability" are held when there is an identified need for it, (4). This is an ongoing long term project of strategic character, though it follows upcoming issues depending of the context.

The supply function has a somewhat unusual extended strategic role in the product development process. Strategic meetings with supplier groups are held yearly, (6), but on top of this, the supply function is an intermediary in the interface between the design function and the manufacturing supplier, (7). This has a bridging effect on the DM relation, but the supplier could on the other hand mix-up who is the responsible party. This solution is rather unproven and the organization is not fully used to it yet.

Though there is a regulated process for how to handle customization and needed changes to products, (2), it does not work out very well, both according to the interviewed supplier and the sales engineer. Reported problems are logged into the system, but the given feedback is both rare and slow. The degree of customization is lower today than some years ago according to the sales engineer. One positive reason is a more structured way to work, e. g. without any improvised shortcuts between the market company and suppliers. On the other hand, both customer demands and wishes tend to be logged by the market company but seldom reach the point where decisions about appropriate changes ought to be taken. Problems to communicate through the DM distance seems to play a role also here.

Concluding discussion

The present literature (e.g. Brusoni and Prencipe, 2001) suggests that contracted modules should be possible to manufacture without any coordination except the embedded. But, the findings in this paper showed that for the case company there was a need for further coordination.

If all manufacturing of product modules is left to suppliers there is a risk to loose manufacturing competence. Prencipe (1997) and von Haartman & Bengtsson (2009), claim that there is still a need for internal manufacturing competence to be able to develop new products. The case study in this paper strenghtens these research findings.

Both the need for further coordination and more manufacturing competence are connected to the gap that emerges because of the distance between own design and external manufacturing. The findings in this paper adds to the existing literature by showing how the case company is dealing with these two issues in different ways (facilitators), summarized in Table 2. Examples of strategically based facilitators are structured product development work, early involvement of strategic suppliers in the development process and a bridging role for an own supply function.

Some of the context based facilitators could be developed. For instance, the testing process, both in-house, (12) and at suppliers, (11), could be used as a means to bring the case company closer to suppliers by collaborative work. This could also be a starting point to enhance the manufacturing know-how and to work continuously with improvements, even though the distance between design and manufacturing (Greasly, 2009). Customers' demands concerning lower energy and material waste will also benefit from such improvement work.

Future research could study how the, in this case study identfied, facilitators could be used appropriately to manage different type of NPD projects as well as the continous improvement work.

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Paper 2

Managing continuous improvement by product modularization

Eklind, M.J. and Persson, M.

Paper presented at the CINet 14th annual conference, Nijmegen, 8-11 September 2013.

MANAGING CONTINUOUS IMPROVEMENT BY PRODUCT MODULARIZATION

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ABSTRACT

The purpose of this paper is to investigate how a company's ability for continuous improvement is affected by product modularization. Modularization facilitates product improvements defined to a specific module. However, the ability to work with manufacturing improvements becomes more difficult if the modules are manufactured by external suppliers. The improvement work must be transformed and focused on more innovative rather than incremental changes. This is also confirmed by the case study done for this paper at a multinational company relying heavily on external suppliers.

In the case study we could also identify how the company handles this situation by using different intermediaries, for instance a design support group, that coordinate designers and suppliers when improvement issues are raised. Designers' manufacturing competence is essential not only to get a good design result, but also for designers' ability to understand improvement issues emanating from customers' and suppliers' needs. By dual sourcing the company could differentiate the level of collaboration and get closeness with some suppliers, providing the designers updated manufacturing skills.

Keywords: Product modularization, improvement work, co-creation, case study

1. INTRODUCTION

This paper is about continuous improvements (CI), and how a company's ability to work with CI is affected by product modularization. To work with continuous improvement is often described as crucial for almost all companies (e.g. Greasley, 2009; Krajewski et al., 2010). The term 'CI' has its origins back in the Japanese concept kaizen, a 'continuous change for the better' (Imai, 1986) to offer customer best product and process quality. It is also possible for a company to get a competitive advantage by being able to offer customized and individualized products on the market (Jiao and Tseng, 1999). Many companies have adopted a product modularization strategy to increase their ability of customizing products (Sanchez, 1995; Simpson, 2004). A modularized product is also easier to change and upgrade, since the different modules are decoupled from each other and changes can be made to one module without affecting the other surrounding modules (Ericsson and Erixon, 1999; Hsuan, 1998). So, modularization is a way to facilitate product renewals, in other words continuous product improvements. According to Lindberg and Berger (1997) the improvement work should be organized in different ways in different situations regarding to structure, responsibilities, processes and resources.

Both continuous improvement and mass customization are included in the framework consisting of four business models (see Figure 1) for a product's life time, which Pine (1993) suggests. An invention brings new products and processes, and these will be adapted according to the present business situation. The business model which focuses continuous improvement is considered to be at a higher level, number three of four. CI-work needs an advanced horizontal process focus with information sharing, contrasting to the static hierarchical and bureaucratic structure connected to mass production. To reach the highest level; mass customization, many companies modularize their products. To take the step upwards to mass customization, the organization must transform itself even further and "the tightly coupled processes created through continuous improvement should also be broken apart and modularized" (Pine, 1993, p.24). The improvement work then, in the same way, needs to be reorganized and transformed to support modularized products.

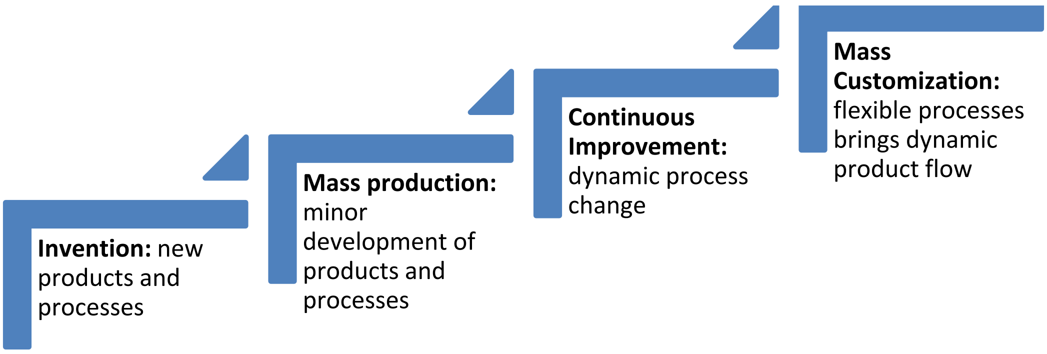

Figure 1. Four different business models (developed from Pine, 1993)

The ability for a company to improve its performance is crucial for its competiveness not only in phase three (see Figure 1) but also in the mass customization phase. But, the influence of product modularization on CI is not very well researched, and the product modularization's organizational aspects have to be considered to make the CI work better fitted to mass customization. A major part of previous research in the product modularization field has focused on the more technical aspects, such as how to divide the product into a number of modules and defining the interfaces between the modules in a way so that the different modules become decoupled from each other functionally (McClelland and Rumelhart, 1995; Benassi, 1998). This paper focuses especially on what the decoupling of product modules means for continuous improvement, and how the distance between the design and manufacturing units affects CI when external manufactures are used.

The purpose of this paper is **to investigate how a company's ability for continuous improvement is affected by product modularization.** The focus is on manufacturing improvements affecting the product design, and the modules in the product.

The paper is organized as follows. First, the literature on product modularization and continuous improvement is reviewed. Next the employed methodology is described. The empirical findings are then presented and analysed. Finally, conclusions are drawn regarding how to organize external manufacturing of product modules for maintaining the ability to work with improvements.

2. LITERATURE REVIEW

Product modularization is a strategy used by many companies as a way to deal with product customization, and by that the growing product variety to manage (Sanchez, 1995; Ulrich and Tung, 1991). Product modularization is the grouping of components into modules and the definition of interfaces between modules (Baldwin and Clark, 1997). The aim is to develop a product in which the different modules are decoupled from each other, which makes it possible to make changes/improvements in one module without affecting the other surrounding modules (Mikkola, 2003). Modules can also be used across different products to achieve economies of scale and scope (Muffatto and Roveda, 2002). Product development lead-time and cost can also be reduced by product modularization (Baldwin and Clark, 1997; Ulrich and Eppinger, 1995). In addition, modularized products make it possible for companies to react quickly to changes in demands (Sanchez, 1995).

A concept closely related to product modularization is mass customization. Mass customization helps companies to combine product differentiation and cost efficiency (Blecker and Abdelkafi, 2006). “The term mass customization denotes an offering that meets the demands of each individual customer, but that can still be produced with mass production efficiency” (Piller, 2007, p. 631). Mass production focuses on achieving scale effects (Pasche, 2011), but mass customization tries to combine the benefits of standardization and individualized products to achieve economies of scope (Blecker and Abdelkafi, 2006). Mass customization is enabled by having responsive and flexible processes in the company (Piller, 2007), and by modular product structures (Åhlström and Westbrook, 1999). Previous research has indicated that to be successful in implementing mass customization, to go from step 3 to step 4 in Figure 1 (from Continuous Improvement to Mass Customization), also the organizational aspects have to be taken into account. For example, it calls for a tight integration between product development, manufacturing and market (Tseng et al., 1996; Åhlström and Westbrook, 1999).

Another applicable field for modularization is the management of the sourcing process. The need to coordinate external manufacturing could be reduced by using product modules, since you bring ‘embedded coordination’ into the modularized subsystems (Baldwin and Clark, 1997; Hong and Hartley, 2011). If the manufacturing of the modules have been outsourced to different suppliers in different parts of the world the ability to continuously work with manufacturing improvements is probably made more difficult. Thus, the CI process could be affected by the larger distance such outsourcing brings. There could also be CI suggestions coming from one of the module suppliers that not only affect the modules that this specific supplier is manufacturing, which makes it more complicated, when such changes must be coordinated to several suppliers. So, on one hand, product modularization supports smaller or larger improvements as long as they are mainly defined to a specific module, otherwise coordination efforts are needed.

On the other hand, small-step improvements are not enhanced generally when companies have to collaborate around them; on the contrary more innovative issues are more likely to be successful (Chapman and Corso, 2005). The authors claim: “But while inter-company collaboration in radical innovation is a reality, collaboration in small-step innovation (or continuous improvement) of products and processes is considerably less common. Although apparently simpler, continuous innovation within a network of companies requires a much deeper integration between companies along the supply chain and a change in culture that not only involves selected teams, but is extended to the key business processes within the participating organizations" (Chapman and Corso, 2005, p.339). Product modularization decouples the processes and the companies could work quite independently with their modules. The integration level diminishes and thereby the natural ground for the CI work is eliminated.

Instead of 'Continuous Improvement', other terms are more suitable when product modules are manufactured by external suppliers. Just 'Improvement work' or 'Continuous Innovation' are concepts more likely to catch the characteristics of such a work. Besides, enhancing the modularized product's function renewal (Ericsson and Erixon, 1999) is much more in focus, than to improve the manufacturing processes.

The designers' manufacturing skills are crucial not only to improve the design quality. Indirectly, a lack of manufacturing knowledge affects the relationships towards suppliers and customers. Von Haartman's (2013) study strengthen that the need for designers to have manufacturing skills is not only related to the innovation process. To be able to understand customers' demands and to handle minor or major improvement issues, the designers' manufacturing knowhow plays an important role as it helps the customer integration. Thus, to have relevant manufacturing competence is not only for exploiting internal performance metrics, but furthermore to enrich the relations to external sources as customers and suppliers, which enhances the improvement work.

Many researchers have stressed this importance of manufacturing knowhow in the product development process (e.g. Hill, 2000). Olausson and Magnusson's study (2011) strengthens that there is a need for internal manufacturing competence at a contracting or outsourcing firm, a statement which has been identified in several previous studies (e.g. Prencipe, 1997; von Haartman and Bengtsson, 2009). Olausson and Magnusson's cases show that firms are capable of improving their manufacturing competence even when all manufacturing activities have been outsourced. To compensate for the lack of own manufacturing, the suppliers ought to be engaged in an early stage of the NPD project, visits to suppliers are taking place frequently and formalized standards and checklists are used to enhance both the formal and informal communication process with the suppliers.

To summarize, the improvement activities related to external manufacturing of product modules are quite narrowed.

- 'Continuous Improvement' of manufacturing processes could be done independently by suppliers as long as they only lead to minor design changes.
- Suggestions from suppliers or customers for more innovative changes to a product module could preferably be developed together with the design function if they are affecting other modules to a minor degree.
- Other improvement suggestions ought to be examined before an improvement project could start, since changes to several modules must be managed and coordinated. The coordinating persons need developed manufacturing competence to conduct the improvement process.

3. METHODOLOGY

How to organize continuous improvement of externally manufactured product modules is an area that is not very well researched. In the literature review it was found that there are only a limited number of studies which have had this focus. Therefore, we have chosen a case study approach for the purpose of this paper. We investigate a contemporary phenomenon in-depth with 'how' and 'why' questions (Yin, 2009, p.9), i.e. product modularization as an organizational means, with no clear boundaries to the context (Yin, 2009, p.18), for example the organization context influence the degree of modularization. Case studies are well suited for questions that are not thoroughly researched (McCutcheon and Meredith, 1993). To investigate how a company organizes its external manufacturing of product modules also calls for an in-depth insight in a company that a case study can give. In addition, a case study is suitable since both the physical and human aspects in this relationship are concerned (Voss, 2009). It would have been difficult to formulate survey questions which could bring more than just superficial understanding of this type of issue.

This is a single case study with two embedded units of analysis; two different design units belonging to the same company are studied. Single case studies together with survey-based quantitative studies are the foremost used methods in this research field about the design/manufacturing interface (Dekkers et al., 2013). These authors' literature review of what has been written in the latest two decades shows the relevance of conducting single case studies. On the other hand, as a single case study gives limited possibilities to generalize the findings, the authors call for more multi-case based research and this study is planned to be followed by a study in another company.

3.1 THE CASE COMPANY

The empirical data for this paper originate from a multinational Swedish manufacturing company. In 2011 the turnover was about 10 billion euros, and the number of employees about 20,000. The company has operations located in many different countries in different parts of the world, but the main centres for product development are located in Sweden and Italy. This company develops and produces large industry machines in rather small series; it is thus not a large volume producing company.

This company has a clear product modularization strategy, as a way to deal with product customization, being able to meet customers' different needs. The company relays on external suppliers for almost all of its manufacturing. The extensive use of external suppliers, together with the modularization strategy, makes this company a suitable study object for the purpose of this paper.

3.2 DATA COLLECTION

The data for this paper was collected through 17 semi-structured interviews that were accomplished February to May 2013. The interviewees were chosen in collaboration with an R&D Manager in the case company. Nine of the respondents were working in the product development unit in Sweden. Most of these interviewees are Module Managers, i.e. responsible for a module or a sub-module. But also a purchaser and a production technician from the Supply chain organization were interviewed. The interviews lasted between 60 and 90 minutes. All interviews were recorded with a Dictaphone and both interviewers (the authors) took notes. Another similar six respondents, Module Managers and Supply chain representatives, were interviewed at the company's product development unit in Italy.

The interviews followed a semi-structured approach, but were systematically asked in the following areas, with the focus on how the collaboration between own product development and the external manufacturing suppliers are organized:

- The product development work
- The modularization work
- Design for Manufacturing, DfM
- How changes in the products are implemented
- Collaboration with suppliers

The respondents were also asked to rate some interview related statements according to a nine-degree scale. This was not for statistical usage but to clarify the interview responses. In addition to the interviews, informal discussions were held with other people involved in the product development process.

In addition to these fifteen interviews with people in the product development units, also one of the external suppliers was interviewed. Almost the same questions (see above), only with minor adjustments, were used in this interview. The purpose of this interview was to investigate how the collaboration with the case company is perceived by a supplier, not to get the full supplier view. Therefore this supplier interview could be seen as complementary, not as another unit of analysis. In the same way, a complementary interview regarding customization issues was done with a sales engineer at a marketing company belonging to the case company. For this interview the same semi-structured questions were used, slightly modified.

The collected data were grouped based on the five areas in the interview guide, discussed and analyzed with the aim to find patterns and relationships. These seventeen interviews give a reasonable level of saturation according to the focus of the study, though it would have been interesting to interview further suppliers. If there will be a third embedded unit in this single-case study, it will focus the suppliers.

4. EMPIRICAL FINDINGS AND ANALYSIS

The focus of this paper is on how a company's ability for continuous improvement (CI) is affected by product modularization. In this case study this CI work has been investigated for four different platforms in the company. A platform for this company is a group of products constructed with a common set of modules, which could be modified to individualized/customized products. This definition of platform is very much in line with a product family, which is defined as a collection of products sharing the same assets (Halman et al., 2003).

Platform	A	B	C	D
Type	Older product family	Newer product family	Newly launched product family	Newer / older distribution systems
Suppliers location	In China	Mainly in Italy	Mainly in Austria and Sweden	Mainly in Sweden and USA
Design location	Sweden	Italy	Sweden	Sweden and Italy

Table 1. Characteristics for the four studied platforms

Platform A is an older product family than B, which also is more expensive. Platform C was launched just about a year ago and there are not so many commercialized products yet. Platform D is used for supplemental equipment to the three other platforms, e.g. different types of distribution components linked together. Table 1 gives an overview of the studied platforms.

As already stated, the case company relays totally on external manufacturers, almost no manufacturing is done in-house. In the case study it was found that this distance between Design and Manufacturing affects the continuous improvement work on different products and modules. Several of the respondents stated that if the manufacturing was located in-house, it would have been easier to communicate face-to- face and thereby make changes and improvements together. Meetings could be held more often and informally, without time consuming transports. Such a situation would also bring the means to keep the design function updated with the current manufacturing knowledge through frequent communication in the design/manufacturing (DM) interface. Since the suppliers are located at different distances to design, it becomes more or less difficult to have a 'natural' updated knowledge about the manufacturing process, and this will impact the improvement work. To bridge this DM-gap and to bring sufficient manufacturing know-how to designers, the case company uses different solutions, as focusing of manufacturing aspects and close collaboration with suppliers early in the design project processes.

4.1 DIFFERENT FOCUS IN THE IMPROVEMENT WORK

The organization of the product improvement work could be divided into improvement work done during the product design, respectively improvement work that is done after the design phase. There are differences between the two studied design units (Sweden and Italy) as well between the two phases, featured in Table 2. During the design phase there are for example several direct contact means between the designers and the external manufacturers, which are reduced when the product is commercialized.

	Italian design location	Swedish design location
Design phase	A design support group (DS) connects designers and suppliers. Joint testing and simulation are the main means for improvement of product design.	Drawing reviews done by suppliers, or own production technicians, is the main means for improvements, together with reviews of test results.
Commercialized product	Logged improvement suggestions are directed, and filtered, by the design support group monthly. Then the decided improvement projects are conducted by the design support group in collaboration with the supply chain function and designers.	Logged improvement suggestions are directed and filtered by the supply chain function's technical group. Decided improvement projects are conducted by the supply chain function together with designers.

Table 2. Improvement work focus at different locations during and after the design phase

After the design phase, when there is a commercialized product, the improvement work in Italy are done differently compared to how it is organized in Sweden, see Table 2. For three of the platforms (A, C and D) for which most of the design is done in Sweden, improvement suggestions from suppliers are logged into a reporting system (see Figure 2), where they are filtered before decided if an improvement project should be started or not.

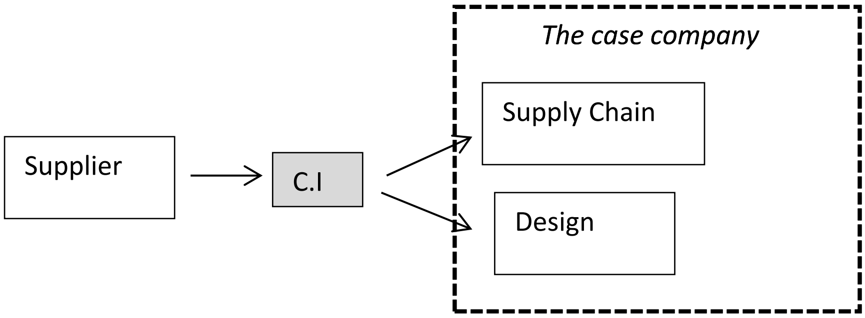

Figure 2. Organization of improvement work at the Swedish product development unit

For the fourth platform (B), which has its design location in Italy, the improvement suggestions are managed in a different way. The improvement suggestions coming from the external suppliers are first reviewed by a Design Support group (see Figure 3), who together with the Supply Chain function consider the economic aspects. After passing this filter, relevant persons become involved in a pilot project, aiming at upgrading the product design.

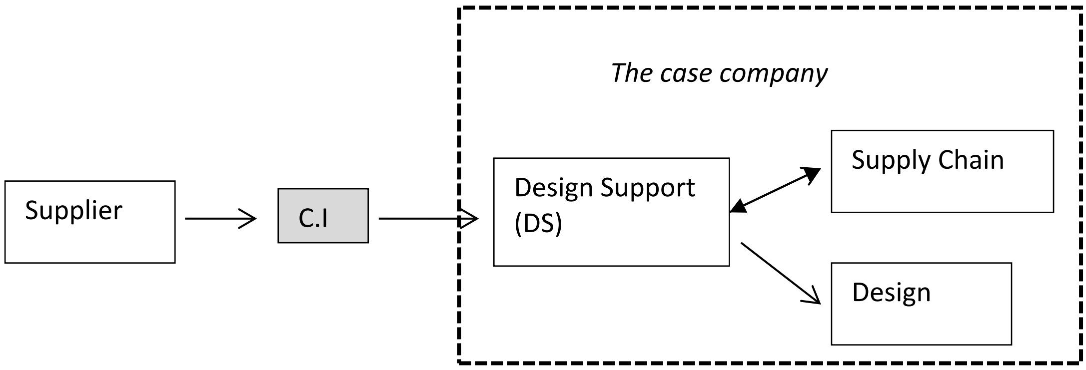

Figure 3. Organization of improvement work at the Italian product development unit

This Design Support group (DS) is central at the Italian design location; as already described there is no corresponding unit at the Swedish location. DS's role is mainly to bridge designers to external suppliers when it is needed and to deploy manufacturing competence, both to designers and to the supply chain function. The interviews done with people in the DS unit showed that DS takes care of claims and logged improvement suggestions from suppliers. Further, this work has been successful, for example by that the amount of claims has been reduced from yearly 11 000 to 3 500 in a couple of years. Contrary, the solution used at the

Swedish location has not been such successful. Both the interviewed supplier and sales engineer stated that the logged issues; suggested product improvements, are handled slowly with poor feedback and no distinct appointed and responsible person.

4.2 *Product improvements related to manufacturing improvements*

Since the case company's products are modularized, and manufactured only by external suppliers, the company focuses improvement of the product's functions more than continuous improvement of the production processes. Process oriented methods need a higher integration level with the supplier than what external manufacturing of modules naturally brings (Chapman and Corso, 2005). Instead of prioritizing methods as Continuous Improvement, the company (both in Italy and Sweden) focuses 'Design for Manufacturing', DfM, and 'Design for Serviceability', DfS. The lack of own in-house manufacturing makes it natural to strengthen the designers' competence through courses and supporting expert knowledge. This is done in similar ways in both countries by dedicated experts, but also DS plays a vital and connecting role at the Italian design unit.

Due to the external manufacturing, continuous improvements of the manufacturing processes could be done by the suppliers as long as they follow the 'black-box design', where the functional specification is set by the buyer. In this case the detailed engineering responsibility is completely in the hands of the supplier (Hsuan, 1998). The case company do not stipulate how the manufacturing should be done as long as the product design is not affected. If the design only is affected to a minor degree, the responsible designer could confirm directly, otherwise the improvement suggestion must pass through the logging system mentioned above. Thus, since the CI work mainly is work done to the suppliers processes, the case company uses other improvement terms rather than the CI term, even if it is similar.

4.3 *COMBINING STRUCTURED FRAMEWORK WITH INDEPENDENT INITIATIVES*

The company has developed a structured product development framework with rules and templates which regulates the design process. This framework is well implemented in the organization and also disseminated to external manufacturers so they work according to the company's intentions. Both the interviewed supplier and several designers claim that this structured framework is one of the company's strengths, which also contribute to the improvement work by its well-defined procedures. At the same time they pinpoint the risk for a too formalized and rigid organization, and they call for other means to use for innovative and creative solutions for more radical improvements. The established Italian design support group, DS, is one possible thread to follow in such a direction. As mentioned above, this group (DS) has an active role for coordinating manufacturing issues in the design organization in a cross-functional way. When a designer is searching for a new solution, DS could support and link resources.

One example of such an innovative improvement is the renewal of an inaccurate distribution product unit. The responsible design team changed their work and formed a more independently working group. Instead of using outside consultants, handpicked 'doers' were hired to accelerate the redesign process, where DS had this vital supporting role. The project became a success, resulted in several new patents and a clearly expressed customer satisfaction. The work was characterized by several designer visits to customer plants, robust prototype testing together with a local manufacturer and innovative solutions matching the company's standardized framework. The fact that the distribution module is 'in the end of the line' with clear interfaces to other modules facilitates the independent teamwork.

4.4 SUPPLY CHAIN FUNCTION'S ROLE FOR THE IMPROVEMENT WORK

The case company's Supply Chain function (SC) has a strong influence in the organization, both during the design process and afterwards when there is a commercialized product. SC coordinates the module purchasing with different suppliers during the design process, this according to the technical specifications given in the drawings. As being the connection point with the suppliers, SC actively connects the suppliers to the design process at an early stage to make so called front-loaded design possible. By this, manufacturing issues should be considered already from the beginning through the involvement of manufacturing suppliers. The level of front-loading varies between different platforms, and the interviewed supplier still finds it difficult to know which person to contact for different issues, if it should be the designer or the one representing SC. This problem could be even more accentuated since another SC function takes over when the product is commercialized after a year or so.

The case company's product modularization strategy is by SC considered as a means to form flexible relations with suppliers. A modularized product contains 'embedded coordination', and it is therefore possible to have a mix of different types of suppliers. There are different examples of how the manufacturing is moved between those:

- A manufacturer engaged during the prototype phase could be replaced by another when it comes to commercialization.
- Since one supplier was stroked by the earthquake in Italy 2012, the case company is now implementing 'dual sourcing' to reduce their dependence of one single supplier.
- Even if the supplier base is located in Europe, the company considers relocation to manufacturers closer to the growing markets in Asia and South America. Platform A has already its supplier base in China, though the design still is located in Sweden.
- Also the labeling of the suppliers could change. If a product becomes more established, a system supplier could lose its 'strategic supplier' A-rating and become a B, 'preferred supplier', or a C, 'regular supplier'. Therefore the case company demands that the suppliers are innovative and improve their performance to be able to keep up their rating and challenge the other suppliers.

The interviewed (A-rated) supplier calls for a mutual relationship with the case company, supporting creative and innovative solutions, instead of the one-sided cost reduction focus of today. Designers call for stability in the supplier relations since it take quite a long time before a new person fully understands and can work according to the case company's framework.

5. CONCLUSIONS

Product modularization enables continuous upgrading and renewal of a product module as long as the functions outside the module are not affected. Since product modularization also facilitates external manufacturing, much of the work with continuous improvement (CI) related to manufacturing processes is left to the suppliers. Therefore, the type of improvements tend to be incremental or even left out if the distance between design and manufacturing is not bridged. The case company shows some characteristics that impact the improvement work:

- A cross-functional design support group (DS) plays an active role to coordinate issues in the design/manufacturing interface. If there is no such clear bridging role, improvement issues seem to get lost in the logging system.
- Since all manufacturing is external there is a risk for designers to lose manufacturing skills which impacts the quality of designed products. Both education in 'Design for Manufacturing' (DfM) and early involvement of suppliers in the design process help to consider manufacturing issues already from design start.
- To be able to understand improvement issues from suppliers and customers, the designers need to have relevant manufacturing knowledge (von Haartman, 2013). If not, customer and supplier relations risk to be rudimentary and the improvement issues will never be discussed, or awareness of them is not raised at all. In addition to courses in DfM, a fruitful contact area with manufacturers both strengthen the relations and increases designers' manufacturing competence. Working together with testing and simulation, partly at the company's test rigs, partly in suppliers' plants, seems to work out well.
- The case company's well-structured design framework, which also includes suppliers, lays the common ground for the design process. To avoid the risk for rigidity in the system, and to encourage innovative improvements some persons or groups ought to have a more independent and cross-functional role in the organization. The members in the team, who made successful improvements to a distribution issue, seem to have both willingness and competence to apply their work to challenge other problem fields.
- Since the supply chain function (SC) has a strong intermediary role to connect designers and manufacturing suppliers, their sourcing strategy affects the improvement work a lot. A close, mutual design/manufacturing relation supports CI of manufacturing processes. By less mutuality and a more distant relation, the improvement work's character changes and becomes more a log report system. To function well, such a system needs to be managed by someone who coordinates the improvement issues together with designers, suppliers and customers. To give feedback on all logged suggestions, also rejected, seems crucial. The DS group has this coordinating role and together with SC they are forming a model which could be used worldwide in the case company.

To summarize, the purpose of this paper was to investigate how the improvement work is influenced when a product is modularized and the manufacturing of the modules is done by external suppliers. Based on the analysis of the case study it can be concluded that if the suppliers are located close to the design unit or not, affects the improvement work's character. By longer distance, the need for coordination increases and the focus of the improvement work tends to shift from continuous improvement to redesign issues according to claims from customers and suppliers.

To have a supplier close to the design unit not only enables an effective continuous improvement work in that specific design/manufacturing relation, the closeness also brings the means to develop the designers' manufacturing competence in a natural way. Such competence is essential both for a good design result, and for the ability to understand improvement issues emanating from customers' and suppliers' needs. By dual sourcing the company could have close collaboration with some suppliers, while others remain more distant.

6. FUTURE RESEARCH

This paper has showed that the work with continuous improvement must change when a product is modularized for customization reasons, according to the model presented in Figure 1, based on the argumentation Pine stated 1993. Since this case company relays totally on external manufacturers, it would be interesting to study a company with own manufacturing, in-house or located in own plants away from where their product development is located.

To get the perspectives from the case company's suppliers, this single-case study could be complemented with the supplier base as a third embedded unit.

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Paper 3

Coordinating external manufacturing of product modules

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Coordinating External Manufacturing of Product Modules

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ABSTRACT

Globalization opens up increasing possibilities in reaching new customers and suppliers. Therefore, in order to do this, many companies have adopted a product modularization strategy. First, modularized products facilitate customization, i.e., the fulfilment of customers' different needs. Second, product modularization also brings 'embedded coordination' by the standardized module interfaces that facilitates the use of external suppliers. However, heavy reliance on suppliers increases the distance between design and manufacturing. Therefore, there will be a need for coordination between design and manufacturing in order to be able to work with product improvements and customization. Thus, the purpose of this paper is to investigate how such coordination of external manufacturing of product modules takes place.

This paper is based on two case studies done at a manufacturing company that relies heavily on external suppliers. These studies identify different means of handling the increased distance between design and manufacturing. Besides organizational solutions, different intermediaries between design and manufacturing play an important role in bridging the distance, with the supply chain function in a leading position. When the supply chain management's influence grows, it could result in lower activity in the design/manufacturing interface. This ought to be balanced by dedicated persons who work cross-functionally linking designers, suppliers and the supply function in solving problem issues.

We could identify a number of coordination mechanisms used for external manufacturing of product modules. We recommend the use of different coordination mechanisms, adapted to the actual situation rather than trying to optimize the integration level with the different suppliers.

INTRODUCTION

Today's globalization opens up increasing possibilities in reaching new customers through product diversification and collaboration with new suppliers (Hitt, Hoskisson, & Kim, 1997; Flynn, Huo, & Zhao, 2010). Therefore, in order to meet new customers' individual needs, the product offer needs to be more customized and varied (Jiao & Tseng, 1999; Simpson, 2004).

Furthermore, in the same way, todays accentuated endeavor for sustanaible solutions makes it crucial to offer upgradable products (Seliger & Zettl, 2008). Hence, the ability to meet customers' different needs has the potential of giving companies a competitive advantage. However, an increased number of product variants also adds more complexity to the operations of a company, e.g., more differentiated components to manage in manufacturing. Therefore, many companies have adopted a product platform and/or modularization strategy as a way of dealing with this growing product variety (Sanchez, 1995; Simpson, 2004). A modularized product gives the possibility of having independent modules that are manufactured and tested separately (Ulrich & Tung, 1991). The modules can also be pre-assembled instead of assembled in sequence on an assembly line, yielding shorter assembly time (Erixon, 1998). Additionally, product modularization can be used in order to give benefits in product development, such as reduced lead-time and cost (Baldwin & Clark, 1997; Pasche, 2011). Thus, a modularized product facilitates the need for customization.

Moreover, it is also possible to use product modularization for managing the sourcing process, and it is common, in the globalized world, that the most suitable manufacturing process is found far away from where the product is developed. It is quite common that companies outsource manufacturing activities to suppliers, but keep the R&D activities in-house (Berggren & Bengtsson, 2004). The present literature argues that modularizing a product is a way of managing this distance between design and manufacturing. Furthermore, by standardizing the interfaces between the different modules, outsourcing of modules to external suppliers is facilitated (Brusoni & Prencipe, 2001; Gadde & Jellbo, 2002). Further, the standardized interfaces bring 'embedded coordination' into the modularized subsystems (Baldwin & Clark, 1997; Hong & Hartley, 2011), and hence the need for coordination is reduced. This means that modularization creates a high degree of independence or 'loose coupling' between the modules due to the standardized interfaces. As long as the developed modules conform to the defined interfaces, the design of different modules can be loosely coupled (Sanchez & Mahoney, 1996). The 'embedded coordination' in the modules can also make it easier to replace an existing supplier.

However, if a company relies heavily on external suppliers for manufacturing, the importance of supply chain management (SCM) increases. Mentzer, DeWitt, Keebler, Min, Nix, Smith, and Zacharia (2001, p.18) define SCM as *"the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long term performance of the individual companies and the supply chain as a whole"*. Therefore, the main objetive of SCM is to manage the flows of products, services, finances, or information from a source to a customer, and SCM traditionally does not focus on the coordination of product modules. Moreover, from a SCM perspective, product modularization would rather be seen as a facilitator building up a firm's sourcing strategy. Furthermore, some recent studies (eg. Pasche & Persson, 2012; Persson & Åhlström, 2013) have pointed out that coordination can not take place only through strandardized interface specifications. There is sometimes still a need for coordination by management involvement in making decisions in order to solve conflicts between different organizational units. An increased use of external suppliers in different parts of the world also makes it more difficult to work with manufacturing improvements (Greasley, 2009), and when several companies are involved even small improvement issues need coordination (Chapman & Corso, 2005). Therefore, the purpose of this paper is **"to investigate how coordination of external manufacturing of product modules takes place".**

The paper is organized as follows. First literature on product modularization, coordination mechanisms, and external manufacturing/outsourcing is reviewed. Next, the employed methods are described. The case findings are then presented and analyzed. Finally, conclusions are drawn regarding coordination of external manufacturing of product modules.

THEORETICAL EXPOSITION

This chapter starts with a literature review on product modularization and its relation to supply chain management. Then the chapter continues with a brief literature review on coordination mechanisms, and finally on longterm effects from external manufacturing of product modules.

Product modularization

Product modularization is about dividing a product or a system into a number of modules, each of these modules consisting of a number of components (Gershenson, Prasad, & Zhang, 2003). Baldwin and Clark (2000, p.63) define a module as *"a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements on other units. Clearly there are degrees of connection, thus there are graduations of modularity"*. Important in product modularization is the definition and development of interfaces between the different modules (Baldwin & Clark, 1997). The interface specifications describe how the different modules work together (Baldwin & Clark, 1997). Thus, by dividing a complex product, or system, into smaller pieces it becomes easier to overview and manage. The ultimate goal is to achieve a product in which the different modules are decoupled from each other, so that changes can be made in one module without affecting the other modules (Brusoni & Prencipe, 2001; Mikkola, 2003).

A product modularization strategy can give several benefits, such as reduced development lead-time and cost (Baldwin & Clark, 1997), which is achieved by using common components across different products (Ulrich & Tung, 1991), and standardization implying economy of scale and scope (Muffatto & Roveda, 2002; Jacobs, Vickery, & Droge, 2007). Standardized modules interfaces also make it possible to recombine different modules into alternative products (Sanchez, 1996; Pasche, 2011). Hence, modularization allows firms to offer a broader product variety. Product modularization can also contribute to improved sustainability, in terms of recycling possibilities (Gu, Hashemian, Sosale, & Rivin, 1997), since the module interfaces facilitate product maintenance and remanufacturing (Seliger & Zettl, 2008). Modularized products also provide strategic flexibility, which means that companies can react quickly to changes in demands (Sanchez, 1995). This also means that modular products can more easily be upgraded throughout the product life cycle (Sanchez, 1996). Another benefit is the increased possibility for decoupling of tasks. This decoupling makes it possible to accomplish different development, as well as manufacturing, activities in parallel (Ulrich & Tung, 1991; Baldwin & Clark, 1997). The decoupling can, for example, help to speed up the product development process in order to shorten the development lead-time.

A major part of previous research in the product modularization areas has focused on the more technical aspects, for example, how to divide a product into modules, each of these modules consisting of a number of parts. This with the purpose of defining the interfaces between the modules in such a way that they become decoupled from each other (McClelland & Rumelhart, 1995). It is possible to find a number of structured methods in the literature (e.g., Erixon, 1998; Huang & Kusiak, 1998), most of which are matrix based, having the purpose of helping to divide a product into a number of modules. However, the modularization ideas have also been extended to the design of product development organizations (Brusoni & Prencipe, 2001). The standardization of module interfaces allows processes for developing component designs to become loosely coupled (von Hippel, 1990; Sanchez & Mahoney, 1996). The development processes can then be effectively coordinated simply by requiring that all developed components conform to the standardized component interface specifications. Sanchez and Mahoney (1996) argue that the standardized module interfaces bring ‘embedded coordination’, so coordination can thus be achieved with a minimum of managerial effort.

Coordination mechanisms

Furthermore, in order to achieve different goals, many activities are carried out in an organization, and as several of these are interrelated, as well as there are constraints as to how they should be done, there is a need for coordination (Crowston, 1997). Malone and Crowston (1994) define coordination as “managing dependencies between activities”. Some of these dependencies cause coordination problems that force actors to carry out additional activities, which are often called coordination mechanisms (Crowston, 1997). One example is that if a software engineer plans to change one module in a computer system he/she must first check if the changes will affect other modules, and then arrange for the necessary changes to the affected modules; two engineers working on the same module must each be careful not to overwrite each other’s changes (Persson & Åhlström, 2013).

March and Simon (1958) are central in the field of coordination mechanisms. They stated that organizational coordination can be done by standardization, coordination by plan, or coordination by mutual adjustment. These are described as (March & Simon, 1958):

- *Standardization* involves the establishment of routines or rules that constrain the action of each unit into paths consistent with those taken by others in the interdependent relationship.
- *Coordination by plan* involves the establishment of schedules for the interdependent units, by which their actions may be governed.
- *Coordination by mutual adjustment* involves the transmission of new information during the process of action. It refers to informal communication, implying that coordination rests in the hands of the doers.

The theory on coordination mechanisms has, since the work by March and Simon (1958), been further developed, e.g., by Mintzberg (1979), who describes the following five coordination mechanisms:

- *Standardization of work processes*, achieving coordination by specifying the contents of the work.
- *Standardization of output*, achieving coordination by specifying the dimensions of the product or the performance, but leaving the decision on work process to the worker.
- *Standardization of skills*, achieving coordination by specifying the kind of training required to perform the work itself.

- *Mutual adjustment*, achieving coordination of work by informal communication. Control rests in the hands of the doers.
- *Direct supervision*, achieving coordination by having one individual take responsibility for the work of others, issuing instructions to them and monitoring their activities.

Adler (1995) suggested that it is possible to identify a number of different coordination mechanisms in the internal interface between design and manufacturing. He distinguishes between five modes of interaction: non-coordination, standards (or rules), schedules and plans, mutual adoption and teams. There are a number of different teams that can function as coordination mechanisms. It can, for example, be supplier development teams (Adler, 1995; Twigg, 2002) that are helping suppliers to improve their operations performance. Another example is joint product/process design teams (Adler, 1995; Twigg, 2002), teams that at an early stage offer informal advice to designers concerning producibility aspects of the product design.

A comparison of the different coordination mechanisms suggested by these authors shows a lot of similarities, see Table 1. This is probably not so surprising since these three publications are very much based on each other. First, in 1958, March and Simon described three different coordination mechanisms. These were then, 20 years later, developed by Mintzberg. Mintzberg (1979) divided the mechanism standardization into three different types; work processes, output and skills. He also added direct supervision as a coordination mechanism. Also Adler (1995) suggests coordination mechanisms that are in line with the previous ones. But, he added team work as an additional coordination mechanism.

Table 1: Overview of mechanisms for coordination suggested in literature.

Mechanism: Author:	Standardization	Planning and scheduling	Mutual adjustment	Direct supervision	Team work
March and Simon (1958)	Standardization	Coordination by plan	Coord. by informal communication		
Mintzberg (1979)	Standardization of work output skills		Coord. by informal communication	Direct supervision	
Adler (1995)	Standards	Schedules and plans	Coord. by informal communication		Teams

External manufacturing

Terjesen, Patel, and Sanders (2012) have studied how modularization, combined with supply chain integration (SCI), affects the operational performance for a company with external manufacturing. Relating to the well studied concept of “differentiation-integration”, introduced by Lawrence and Lorsch back in 1967, the authors connect “differentiation” with modularization, and “integration” with integration activities in the supply chain. Lawrence and Lorsch (1967) argue that high differentiation and integration in tandem brings the best operational performance. Thus, in the same way, Terjesen et al., (2012) show that the combination of a high level of modularization and high SCI level increases performance in all their investigated cases. Also, according to what Lawrence and Lorsch (1967) suggested, the result is contingency based on firm-specific and environmental factors. The relationship between SCI and operational performance form a reversed U-shape and therefore after a certain point, further integration will be costly and will not result in better performance. A reversed U-shape, ∩, means that the performance peaks at the inflection point at the top. Since this inflection point is difficult to identify the authors suggest a contingency perspective since they also show that fit between differentiation and integration is critical, especially when the uncertainty is high in the environment.

Product modularization is also likely to enhance an active sourcing strategy since the embedded coordination makes it possible not only to outsource modules, but also to change suppliers during different production phases. The “black box” concept (Brusoni & Prencipe, 2001) related to product modularization opens up for “module sourcing” (Miltenburg, 2003) with low dependence of several suppliers at arm’s-length distance. Furthermore, such a sourcing strategy increases the possibilities of using the supply chain management proactively, i.e., a prototyping supplier could be substituted by another when it comes to commercialization, despite the difficulties this could bring to the designers in communicating with a new inexpert manufacturer. Howard and Squire (2007) show in their study that modularized components require collaborative sourcing practices in order to co-develop products and reduce interface constraints. They examine this relationship “co-development/partnership” vs “arm’s-length/black box” and their results support the idea of modularization as being closely tied to collaboration and information exchange during all phases of the design-to-delivery process. They mean that the prospect of switching to an alternative source of supply is complex, costly, and high risk. However, an optimal level of integration, and thereby a suitable module sourcing, could not be predicted and instead the authors suggest further research to reveal other mediating factors, such as process complexity, product variety, and proximity.

Product modularization and SCM have been well studied during recent decades, but how they could harmonize is not very well researched. Sanders, Zacharia, and Fugate (2013) pinpoint that the growing importance for SCM has not yet been fully valuated and still lacks a comprehensive view. Each person in design, market, and purchasing has their own opinion of what SCM stands for, and functional suboptimizations needs to be resolved by a more holistic view. One mediating factor, mentioned by Howard and Squire (2007), is proximity. ‘Proximity’ to a manufacturer is, for example, more important for a designer than it most often is for a purchaser. If the manufacturing of the modules has been outsourced to different suppliers, sometimes located in different parts of the world, the work with manufacturing improvements is affected (e.g., Greasley, 2009) due to the distance. Designers risk loosing manufacturing skills (Kotabe & Murray, 2004) and improvement issues thereby becoming more difficult to communicate, and in a similar way, adaptions to customers’ needs could become more difficult to communicate when the manufacturing unit is located far away from the design unit. The ability to continuosly upgrade product modules according to customers and manufacturers suggestions is essential for the product modularization concept (e.g., Erixon, G.,1998; Gu et al., 1997). Olausson and Magnusson’s study (2011) strengthens the fact that there is a need for internal manufacturing competence at a contracting or outsourcing firm, a statement which has been identified in several previous studies (Prencipe, 1997; Bengtsson & von Haartman, 2009). Olausson and Magnusson’s cases show that firms are capable of improving their manufacturing competence also when all manufacturing activities have been outsourced. Furthermore, in order to compensate for the lack of their own manufacturing, the suppliers ought to be engaged at an early stage of the new product development (NPD) projects, visits to suppliers should take place frequently, formalized standards and checklists should be used to enhance both the formal and informal communication process with the suppliers. Applying such an early involvement of suppliers to modularized products in the initial extensive work, which forms the product modules, could also create a strong relationship between the design and manufacturing units. Such a relation can then be adapted to match different customizing issues. High integration in the relation could match situations with high uncertainty NPD projects; low integration could be more efficient in other situations, i.e., minor refinements of design or certain phases of a product development project (Rubera, Ordanini, & Calantone, 2012). A strong relationship together with the embedded coordination, that product modularization brings (Baldwin & Clark, 1997), opens up for a dynamic differentiation of the level of integration with external manufacturers.

METHODS USED

The organizational aspects of product modularization, and the challenges it brings when it comes to coordinating external manufacturing of modules, is an area that is not very well researched. There are only a few studies, which are also described in the literature review that has had this focus. Therefore, a case study approach was choosen in order to fulfill the purpose of this paper. There are two reasons for choosing this methodology, the current state of knowledge and the nature of the problem (Pettigrew, 1990). First, case studies are well suited for questions that are not thoroughly researched (McCutcheon & Meredith, 1993) and have an explorative character. Second, this methodology was chosen since the focus is on ‘how’ and ‘why’ questions (Yin, 2009). Furthermore, investigating how a company coordinates its external manufacturing of product modules calls for an in-depth insight in a company that case studies can give. Therefore, case studies are suitable since both the physical and human aspects in this relationship are concerned (Voss, 2009) and the phenomena cannot be explained in isolation due to their complexity in reality (Flick, 2009). These studies enabled us to collect rich data about how coordination is done. The generation of theoretical categories would have been difficult to do by using survey questions.

Two case studies in one company

The empirical data for this paper originates from two case studies in a multinational Swedish manufacturing company. The turnover of this company in 2011 was about 10 billion euros, and the number of employees about 20,000. The company has operations located in many countries in different parts of the world, but the two main centers for product development are located in Sweden and Italy, where the two case studies were conducted. This company develops and produces large industrial machines in rather small series; it is thus not a large volume producing company.

The company has a clear product modularization strategy, as a way of dealing with product customization, thereby being able to meet customers’ different needs. The company has already since the beginning of the fifties relied on external suppliers for almost all of its manufacturing. The extensive use of external suppliers, together with the modularization strategy, makes this company an exemplary case (Yin, 2009), suitable to study about what happens in the longterm when external manufacturers are used.

The company has a clear sourcing strategy connected to product modularization. The supply chain function is strongly positioned in the product development process and has power to decide both which suppliers to utilize and when to replace a supplier. After an earthquake in Italy 2012, the company initiated a programme for dual sourcing for the whole company to reduce the vulnerability of being dependent on a single supplier. The supply net is growing worldwide, though the base is still in Europe.

The two conducted studies focus on the company's four main platforms with somewhat different characteristics. A platform for this company is a group of products designed with a common set of modules, which could be modified to customized products. This definition of platform is very much in line with a product family, which is defined as a collection of products sharing the same assets (Halman, Hofer, & van Vuuren, 2003). Table 2 presents some facts about these four platforms.

Table 2: Characteristics for the four studied platforms.

Platform	A	B	C	D
Type	Medium complexity product family	Medium complexity product family	High complexity product family	Complementary distribution systems
Design location	Sweden	Italy	Sweden	Sweden and Italy
Suppliers location	In China	Mainly in Italy	Mainly in Austria and Sweden	Mainly in Sweden and USA
Age	More than ten years old	More than ten years old	One to two years old	Different ages

Moreover, as mentioned in the literature review, there are graduations of modularity (Baldwin & Clark, 2000). Halman et al. (2003) state that modular product architecture is characterized by a high degree of independence between modules, in other words the coupling between the different modules is low, but not zero. Since it is impossible to make a product's architecture completely modular, modularization becomes a matter of degree (Persson & Åhlström, 2006). Although there are differences in level of modularity between these four platforms they are not significant enough to motivate a differentiation, and instead all could be characterized with 'medium modularity'.

Since the main part of product development and design is made by the case company for strategic trademark reasons, the concept "modular sourcing" is less relevant to consider. Modular sourcing means that the manufacturing supplier also does the design of the modules (Miltenburg, 2003).

Complexity is a term that is not very easy to define and when reviewing literature it is possible to find many different definitions of complexity. Therefore, in this paper the principle interest is in comparing the different platforms in relation to each other when it comes to complexity. Therefore, we say that the greater differentiation of technologies present in a product, the more complex it is (Ulrich & Eppinger, 2000). The complexity also depends on the number of parts in a product (Pugh, 1991; Pahl & Beitz, 1996), the same when it comes to the number of different product variants (Ishii, Juengel, & Eubanks, 1995).

Complexity and level of establishment differ between the platforms and will later on be used to identify prioritized coordination mechanisms to different situations. Table 3 gives an overview of how well established the platforms are together with their complexity.

Table 3: Time-in-market and complexity vary between platforms.

		Time in market	
		New	Established
Complexity	High	Platform C	
	Medium		Platform A Platform B Platform D

Data collection

The data for this paper was collected through 17 semi-structured interviews that were accomplished February to May 2013 in Sweden (study 1) and in Italy (study 2). The interviewees were chosen in collaboration with an R&D Manager with a comprehensive role at the case company in order to get a broad picture of how the company handles product modularization and external manufacturing issues. Nine of the respondents were working at the product development unit in Sweden. Most of these interviewees are Module Managers, i.e., responsible for design of a module or a sub-module. However, since SCM is highly involved in the design process, also key persons from the Supply Chain organization were interviewed. The interviews lasted between 60 and 90 minutes. All interviews were recorded with a Dictaphone and two 2 interviewers (two of the authors) took notes. Another similar six respondents, Module Managers and Supply Chain representatives, were interviewed at the company's product development unit in Italy. Table 4 below presents the interviewees. The interviews followed a semi-structured approach, but were systematically asked about the following areas, with the focus on how the collaboration between own product development and the external manufacturing suppliers is organized:

- The general product development process and organization
- The product modularization strategy
- Design for Manufacturing (DfM)
- The coordination between design and manufacturing, e.g., coordination mechanisms used.

The respondents were also asked to rate some interview-related statements using a nine-degree Likert scale. This was not for statistical purpose but to validate the interview responses to see if they conform with a given rating of the statements. Also, process documents were gone through and informal discussions were held with other people involved in the product development process.

Moreover, in addition to these fifteen interviews with people at the product development units, one of the external suppliers was also interviewed. Almost the same questions (see above), only with minor adjustments, were used in this interview. The purpose of this interview was to investigate how the collaboration with the case company is perceived by a supplier working with both the Swedish and the Italian design units, although not primarily to get the full supplier view. Therefore, this supplier interview could be seen as complementary, not as another unit of analysis. Also, in the same way, a complementary interview regarding customization issues was done with a sales engineer at a Swedish marketing company belonging to the case company. However, for this interview the same semi-structured questions used were slightly modified. Furthermore, on a direct question from this sales engineer in a mail conversation about how honest he could be, the sampling R&D Manager recommended "full transperancy for the company's best" and, as several respondents phrased critical standpoints, it seems reasonable to presume that transperancy is achieved throughout the interviews.

Table 4: Number of interviewed persons with different roles.

Role	Study 1 in Sweden	Study 2 in Italy
Product development and design: module managers and designers	5	4
Supply chain representatives: purchasing, supply strategy, production technician	4	1
Design support group	-	1
Own market company representative	1	0
Long-term strategic supplier	1	

These 17 interviews give a reasonable level of data saturation according to the focus of the study, since the interview guides were systematically followed, and the last completed interviews brought no new information contradictional to the previously originated data (Guest, Bunce, & Johnson, 2006).

Methods of analysis

The collected data were grouped based on the four areas in the interview guide in order to ensure trustworthiness of the findings. The recordings were also thoroughly re-listened, discussed, and analyzed by the two interviewers with the aim of finding patterns and relationships (Miles & Huberman, 1994). The analysis done was guided by the steps described by these authors. The initial step of data reduction; focusing, simplifying and abstracting data (Miles & Huberman, 1994), was done by displaying tables and causal networks on sticky notes and whiteboards. These visualized data were analysed by the three authors and the conclusions drawn were validated by agreement both from respondents and top management of the company when the results were presented. This agreement, together with the triangulation by using multiple sources of evidence such as interviews, documents and informal discussions (Yin, 2009), strengthen the studies construct validity.

Langley (1999) suggests seven different templates for process data analysis in order to make both analysis and presentation of a studied process clear. The author opens up for combinations of templates and underlines the importance of leaving room for creativity in the sensemaking process. We used such an open-minded approach in this study in order to combine the "narrative" template in a linear-analytic structure (Yin, 2009) with important elements of the "visualing mapping" template to analyze and present the results. The emergence of the studied process in the case company, the design/manufacturing (DM) interface, is described both in words and figures, and the analysis of the two design units is guided by the visualization different tables may bring.

The generalizability of results from qualitative case studies is limited (Yin, 2009) compared with quantitative studies. Nevertheless, the case studies findings could be generalized in an analytical manner instead of a statistical one (Miles and Huberman, 1994;

Yin, 2009). This means that theory developed in case studies could be generalized to defined areas in line with the scope of the theory emerged in the case studies (Yin, 2009). Thus, from this research study, the findings could be useful for companies with any of the two following characteristics: first, companies that use product modularization for rather complicated products in limited series, with a **medium or high share** of external manufacturers; second, companies with a clear sourcing strategy with supply chain management well positioned in the company, not necessarily using product modularization.

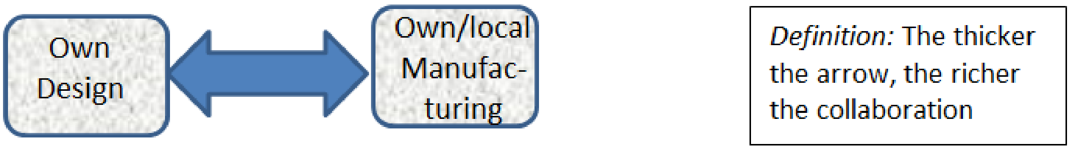
CASE FINDINGS

Before presenting the findings from the two case studies, the background to the contextual situation of today is briefly sketched together with Figures 1-4. Then findings regarding the company's different coordination mechanisms are described and analyzed, with the purpose of identifying key coordination related to each platform's characteristics.

The emergence of the situation of today

Several respondents stated that if manufacturing was located in-house or at a supplier quite close to the case company, it would have been easier to communicate face to face, and thereby being able to make changes and decisions together. Meetings could be held often and informally, without time consuming transports. Such a situation would also bring the means of keeping the design function updated with the current manufacturing knowledge through frequent communication in the DM interface. Figure 1 illustrates such an ideal relation with a broad arrow.

Figure 1: Ideal relation between own design and own/local manufacturing is characterized by frequent communication and close collaboration.

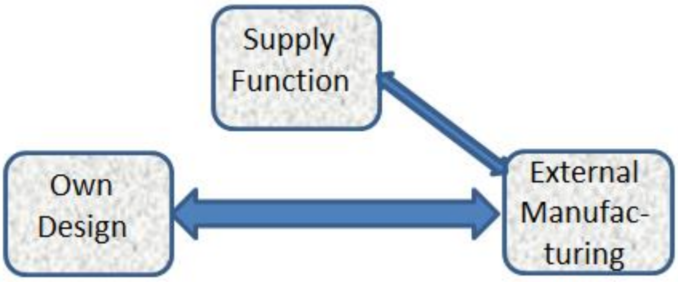


When the suppliers are located abroad, or at least not close to design, the increased DM distance makes it difficult to have "over day" face-to-face meetings. It could become more problematic for designers to get the latest manufacturing competence, since they seldom physically come in contact with the manufacturing process. The communication channels become ICT (Information and Communications Technology) based and the less rich collaboration is illustrated in Figure 2 with a thinner arrow.

Figure 2: The relation between own design and external manufacturing becomes less rich when the DM distance increases.

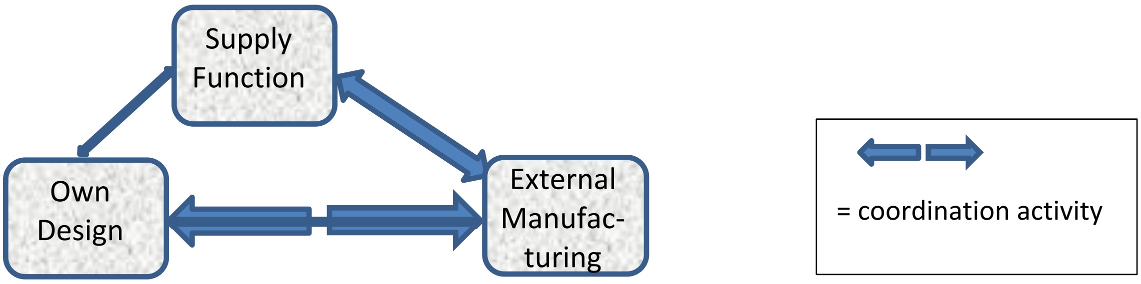
Since all manufacturing in the case company is external, after a while the supply function becomes more important, both for strategic supply chain management and to coordinate the suppliers. A growing part of the supplier contacts goes through the supply function, illustrated in Figure 3.

Figure 3: The relation between own supply function and external manufacturing becomes richer when the DM distance needs further coordination.



Finally, ending in the situation of today (sketched in Figure 4), the supply function becomes the main contact between the company and the suppliers, and there is a risk for decreasing communication between designers and suppliers, which impacts the transmission of relevant manufacturing know-how. The DM distance becomes an issue to handle and the case company does this in different ways. Some of the solutions are built in the organizational framework, while others are based more on coordination of the relation between design and manufacturing.

Figure 4: The relation between own design and external manufacturing is not fully developed, and needs to be strengthened by coordination efforts.



These solutions, used by the case company to coordinate between design and manufacturing, are in line with what in previous literature is called coordination mechanisms (e.g March & Simon (1958) , Mintzberg (1979) and Adler (1995)). The identifed coordinaton mechanisms differ in character. Table 5 presents such solutions identified in the interviews.

The italic concepts are primarily used to improve the readability of the table by grouping similar mechanisms together. The numbers in brackets in the table are used when certain aspects are pinpointed below the table.

Table 5: Coordination mechanisms used by the case company to handle the design/manufacturing (DM) distance.

Coordination mechanisms ⟺	Description	Main effect
Structured process working		
Corporate standards and organized corporate framework. (1)	Product development work is structured and follows standards and plans, and is communicated to suppliers	Suppliers join the same framework as the case company, more or less.
Regulated product changing process. (2)	There is a framework for how to log desired changes in products and how to handle the process.	Enhances communication with suppliers when changes are needed in the product.
Concurrent engineering		
Frontloading- suppliers join the design process early. (3)	Suppliers join early in the concept phase of product development.	Concurrent product development enhances manufacturability.
Education in "Design for manufacturing" and "Design for serviceability" increases the designers' manufacturing competence. (4)	Courses are given according to identified specific needs	Dissemination of know how in the organization.
Supply Chain Management		
Supply function has a leading role (5)	Supply function not only coordinate supply chain, but has decision power in the product develop process	Supply function is main contact area with suppliers, even if designers also communicate directly with suppliers.
A-level supplier collaboration mainly grounded on "trust".(6)	Strategic supplier choice, with different level of engagement.	The company is frequently developing partnership with strategic suppliers
Different strategic meetings with suppliers. (7)	Once or twice a year suppliers discuss strategic issues together with the case company supplier function.	Product development objectives are communicated to suppliers on a general level.
Supply function simplifies the DM communication. (8)	Supply chain has an intermediate role to bridge the DM distance	A strong intermediary helps to form the DM relation
Mutual DM work		
Supplier gives feedback by drawing review. (9)	Manufacturing issues are supplier reviewed at an early stage.	Improved supplier involvement and manufacturability.

Established test equipment in supplier plant brings deeper collaboration. (10)	The case company and the supplier together develop the testing process at supplier plant.	Forms a closer collaboration with suppliers.
Own test equipment brings basic data, suitable to form supplier knowledge(11)	The case company assembles and tests all modules together before delivery.	The continuous work with improvements is enhanced by the test logs.
Temporary close DM collaboration including simulation and prototyping (12)	Design Support group sets up expert teams, working intense both at own plant and at supplier plant.	Problem issues are focused by handpicked persons
Coordination by intermediaries		
Case company's local production unit in China facilitates communication. (13)	Own local production personnel link suppliers to design function.	An complementary intermediary to handle the both geographical and cultural DM distance
The own supply function's production technician is a drawing reviewer and communicator. (14)	A dedicated person who prepare for manufacturing, by communicating design results to suppliers	The DM distance is narrowed by this person, belonging to the supply function.
"Super user" as drawing reviewer and communicator. (15)	Each platform dedicate some persons to handle manufacturing issues	The DM distance is narrowed by these persons, belonging to the design function.
Design Support group as drawing reviewer and DM coordinator (16)	Designers, suppliers and the supply function are linked together by Design Support group.	Innovative solutions could be found by cross-functional collaboration. The group belongs to the design function but is also supporting the supply function with supplier validation.

During recent years the case company has made their process work more structured and use corporate standards and frameworks for decisions, responsibility, and project management, (1). This is an example of coordination mechanisms that are, according to Mintzberg (1979) and Adler (1995), called standards and standardization. The framework is communicated to the suppliers and gives a strategic common ground in the relations with them. Another strategic means is to involve suppliers as early as possible in the development process, i.e., frontloading, (3). However, the distant DM interface in combination with a sourcing strategy with interchangable suppliers brings problems in communicating through this DM distance. Both the interviewed supplier and the sales engineer stated that the logged issues in (2); "suggested product improvements", are handled slowly with poor (or no) feedback and seldom reach the point where decisions about appropriate changes ought to be taken. The supply function with its leading role of coordinating the DM interface, produces means to strengthen the situation, as well as the design function, which are described below.

Working closer with suppliers through drawing reviews (9), mutual testing (10) +(11), and simulations (12) is practised both at the Swedish and the Italian design units. These are examples of mutual adjustment coordination mechanisms, which are by March and Simon (1958) defined as “the transmission of new information during the process of action”.

The use of intermediaires, individuals or teams, to coordinate further, (13) - (16), is quite often practized in the case company. It is possible to recognize an important difference between the two design units, leading to different performance. There is a “Design Support group” (DS) at the Italian location, dedicated to handling issues in the DM interface. When problems arise, DS link designers to relevant suppliers for close collaboration and manufacturing education. The DS (16) is a coordination mechanism of the team type (Adler, 1995). DS also handles the logged product improvement suggestions from suppliers and customers (2), by ranking the issues’ priority and giving clear feedback on what is going on. As the amount of claims has been reduced from yearly 11 000 to 3 500 in a couple of years it indicates a more efficient solution than the one used at the Swedish location, where suggested product improvements are reported to be handled with poor feedback and no specifically appointed responsible person.

The supply function has a leading role at both locations in coordinating the product development process. When a company chooses to rely on external manufacturers it seems natural in the long run that the supply function becomes involved in handling strategic sourcing issues (Kotabe & Murray, 2004), e.g., could a manufacturer, engaged during the prototype phase, be replaced by another when it comes to commercialization. Such solutions make designers call for more stability in supplier relations, since it takes quite a long time before a new person fully understands and can work according to the case company’s framework. Furthermore, giving the supply function’s enough technical skills to make correct decisions in such a sourcing situation seems crucial, and DS is sometimes used for supporting not only designers but also the supply function.

These findings are mostly in line with Terjesen et al., (2012), who claim tandem solutions of differentiation and integration. Here, high differentiation through product modularization is combined with high supplier integration around certain issues in order to achieve good performance. If the suppliers are familiar with what is expected from them, DS and other intermediaries can link together and integrate the right persons in order to make the operational performance rise. Therefore, if they are not so familiar with the company’s framework or if the linking of people is unsuccessful, the performance will not be as good since the integration level will not rise sufficiently.

Key coordination for platforms

Throughout the platforms, a common structured process framework with corporate standards is used to coordinate their own design work with the external suppliers manufacturing. Other coordination mechanisms are more specific to each platform’s needs and situations. Even if most of the mechanisms have strategic grounded relevance, there are some others that are more contingency based. Different actors narrow the distance between product development/design and manufacturers, and it seems to rely to a great extent on the skills and personality that the person possesses as well as who could be responsible. Apart from this it is possible to identify a matching of preferred coordination mechanisms according to each platform’s characteristics, which is summarized in Table 6.

Platform A: Since this platform was established a long time ago, and produces products mainly used in low cost countries it seems reasonable to also manufacture the platform there, in this case in China. The geographical distance to the design unit in Sweden, and especially the cultural differences are difficult to manage. The case company has established a local production unit in China to help suppliers fulfill the upgrading requirements which occur. Even if the complexity is moderate compared with the other platforms, several suppliers have not enough competence to meet that challenge without help from the case company's intermediaries.

Platform B: This product family (platform) has been sold all over the world for a long time, and may be characterized as a cash cow for the company. Although established, the platform is continuously upgraded with respect to different needs, e.g., new software, which helps customers reduce waste. The Design Support group (DS) is crucial for the Italian plant where the platform is designed and links designers with feasible suppliers, both for developing new solutions and for testing of prototypes. DS also handles the reported claims and initiates improvement projects according to listed problem issues, and DS also has tight connections to the Supply Chain function.

"These days we are working hard to validate different suppliers since the company has decided to follow a dual sourcing strategy to be less vulnerable if something happens to a strategic supplier. We bring both technical competence and cost estimate to help the Supply Chain function make good decisions."

Member of the Design Support group

This small team originates from the design function, but is empowered to work cross-functionally to connect designers, suppliers and supply chain representatives when needed. Such a team could bring dynamics into the organization, given that the right people with necessary skills come together and manage to collaborate. DS also works with the Italian part of platform D and since both platform B and D are well-established, this team could help bring dynamics into the quite structured framework.

Platform C: This product family is newly launched, and has only been in the market for rather more than a year. Since the level of complexity is higher compared with the other platforms, collaboration with strategic suppliers has been crucial when developing the platform. Frontloading with early supplier involvement in the concept phase with the supply chain function in a leading coordinating position characterizes how the new platform has been developed. However, giving the supply chain such empowerment has been questioned by some designers and using a group similar to DS at the Italian plant, could have made the linking of different groups easier. Although, when launching a new product family then such a team may have a more regulated role until a common working ground for different functions is established.

Platform D: This product family consists of different equipment used to handle the distribution of the other three platforms' products, e.g., conveyers. Since customers want increased distribution speed, upgrading and new solutions are continuously required. Even if several suppliers are involved, more or less strategic, the partnership with a US based supplier is crucial.

"The geographical distance is no problem to handle since they do a really good job and try hard to understand our needs. Sometimes we go there, sometimes they come to us. I dare say this relation works out better than with other suppliers nearby, for instance in Scandinavia."

Module manager at platform D

Compared with other platforms, this partner is allowed to do more of the product development since this product family is not directly connected with the case company's trade mark. A professional relation built on good personal contacts seems to be the basis for a long-term strategic partnership.

Table 6: Key coordination mechanisms for the platforms.

Platform	A	B	C	D
Type	Medium complexity product family	Medium complexity product family	High complexity product family	Complementary distribution systems
Design location	Sweden	Italy	Sweden	Sweden and Italy
Prioritized coordination mechanisms	Own local production personnel in China link suppliers to design function. (13) Supply function simplifies the DM communication. (8)	Design Support group sets up expert teams, working intense both at own plant and at supplier plant. (12),(16)	Suppliers join early in the concept phase of product development. (3) Supply function has a leading role (5)	Strategic supplier collaboration mainly grounded on “trust”.(6)

CONCLUDING DISCUSSION

The purpose of this paper has been to investigate how coordination of external manufacturing of product modules takes place. From the analysis of the case study presented in the paper two conclusions can be drawn. First, when managing external manufacturing of product modules, it is more relevant to open up for different coordinating mechanisms than to try to optimize the integration level. This is in line with Terjesen et al., (2012) who claim that a high integration level with external product module manufacturers is beneficial to a certain degree, before further integration becomes costly and non-efficient. A well developed IT based corporate framework, common with strategic suppliers, lays the ground for such a high integration level. Thus, depending on contingency factors, further integration is needed, more or less to obtain best performance, i.e., as too much supplier integration could hinder product innovation (Koufteros, Vonderembse, & Jayaram, 2005) and feasible SCI mechanisms ought to be handled with care and adaption to the actual situation and at that point in time. In the case study we could identify a rich tool set of coordination mechanisms, which could be adapted to the situational dynamics different modularized platform properties brings. Given a strategic common ground with a supplier, the level of collaboration has to be managed, e.g., according to the product platform’s complexity or the supplier’s skills.

Second, the external manufacturing of product modules can in the longterm perspective cause a competence problem. If the SCM influence grows, it could result in lower activity in the DM interface and product development engineers may lose relevant knowledge about manufacturing methods and techniques. Such aspects ought to be considered early when implementing a sourcing strategy and may be balanced by dedicated persons, who emanate from the design function and work crossfunctionally to link designers, suppliers, and the supply function around certain problem issues. Sanders et al., (2013) call for a more holistic view on SCM, which seems relevant to mention here, since design issues risk being left out by focusing sourcing possibilities.

Howard and Squire (2007) have called for further studies on the impact of ‘proximity’ in the DM interface. This case study has indicated that geographical distance does make a difference, but could be handled by different means, especially if a professional DM relation built on good personal contacts is available.

LIMITATIONS AND FUTURE RESEARCH

Since this case company has a clear product modularization strategy, as a way of dealing with product customization, and has already since the beginning of the fifties relied on external suppliers for almost all of its manufacturing, makes this an exemplary case (Yin, 2009). But, the findings can be useful also for companies that are about to increase their external manufacturing, especially for those with a sourcing strategy built on product modularization. Future research could study aspects as ‘level of modularity’, ‘supplier skills’ in similar companies to compare structural elements and/or to find other mechanisms useful in coordinating the integration level. This could then be the basis for finding a correlation between mechanisms, e.g., through a quantitative study. As this case company relies totally on external manufacturers, it would also be interesting to study a company with their own manufacturing of product modules, in-house or located in their own plants away from where their product development is located. Will the differentation level then diminish and, if so, how ought the integration tasks differ?

Another feasible comparative study object could be a company similar to the case company, with the supply function in an even more leading role. Will there emerge new interfaces to design, market, and purchasing for the supply function to handle?

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Paper 4

Combining internal and external manufacturing of product modules

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Combining internal and external manufacturing of product modules

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Abstract

This paper considers different ways to manufacture product modules. When all product modules are manufactured externally there is a risk for diminished activity in the design/manufacturing interface, which could result in lower capacity to upgrade products according to customers' needs. An alternative to this could be to have some own manufacturing, though there are benefits and drawbacks to consider. Own manufacturing located nearby the product design unit brings preconditions for close collaboration and spill off effects as dissemination of manufacturing knowledge to designers and informal decision-making. Though, such informal decision channels risk to eliminate the ground for long-term improvement work.

Keywords: Product modularization, Design-manufacturing relationship

Introduction

Globalization has during the last years become more and more intense for many companies. This opens up increasing possibilities to reach new potential markets through product diversification and customization (Jiao and Tseng, 1999; Simpson, 2004). Globalization also makes it more easy to collaborate with different suppliers, due to emerged worldwide communication structures (Hitt et al., 1997; Flynn et al., 2010).

A commonly used strategy among companies, exposed to globalization, is product modularization. Product modularization is briefly about to divide a product into a number of modules, each one consisting of a number of components (Gershenson et al., 2003). Starting with the market potential, to meet new customers' individual needs, the product offer needs to be more customized and varied (Jiao and Tseng, 1999; Simpson, 2004). A modularized product helps to meet new customers' needs by customization, i.e. to offer different variants according to individual needs. The standarized module interfaces make it possible to recombine different modules into alternative products (Sanchez, 1996; Pasche, 2011). Further, the standardized interfaces bring 'embedded coordination' into the modularized subsystems (Baldwin and Clark, 1997; Hong and Hartley, 2011), and hence the need for coordination is reduced. This means that modularization creates a high degree of independence or 'loose coupling' between the modules due to the standardized interfaces (Sanchez and Mahoney, 1996), something that facilitates outsourcing of product modules to different suppliers (Brusoni and Prencipe, 2001; Gadde and Jellbo, 2002). Figure 1 summarizes those two potentials related to product modularization.

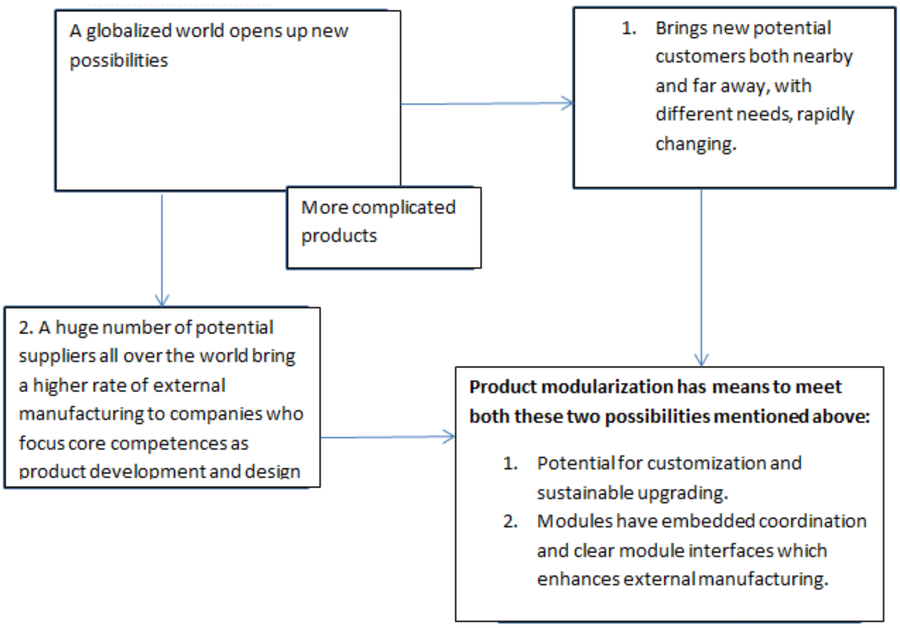

Figure 1. Product modularization has potential to get twofold benefit from globalizaton.

But, there is research, however not focusing on product modules (e.g. Jiang et al., 2006; Broedner et al., 2009), indicating that this outsourcing is not without challenges. After some years there will become a distance between design and manufacturing and the product development engineers risk to lose their knowledge about relevant manufacturing methods and techniques, which might hinder the development of good products. If a growing number of product modules are manufactured externally, the importance of an active supply chain management also increases and the supply function could become the main contact area with the suppliers. This could reduce the direct collaboration between designers and manufacturers and thereby the upgrading capability. Though, to be innovative and upgrade product properties through collaboration with suppliers is one of the main benefits of product modularization. Therefore, the purpose of this study is “**to investigate and compare internal and external manufacturing of product modules in terms of improvement work “.**

The paper is organized as follows. First, literature on product modularization and improvement work is reviewed. Next, the employed methods are described. The empirical findings are then presented and discussed. Finally, conclusions are drawn regarding how to organize manufacturing of product modules.

Literature review

Product modularization is about dividing a product into a number of modules, each of these modules consisting of a number of components (Gershenson et al., 2003). By dividing a complex product into small pieces/modules it becomes easier to develop and manage. The core of product modularization is the interface that is defined between the different modules (Baldwin and Clark, 1997). According to Baldwin and Clark (1997) these interfaces should describe how the different modules work together with each other. If the interfaces are defined so that the different modules become decoupled from each other, then changes can be made in one module without affecting the other modules (Mikkola, 2003).

A product modularization strategy has the potential to bring a company several benefits, such as reduced development lead-time and cost (Baldwin and Clark, 1997). The standardized module interfaces facilitate the sharing of common components across different products, and product variants (Ulrich and Tung, 1991). Using common components in different product variants imply economy of scale and scope (Muffatto and Roveda, 2002; Jacobs et al., 2007). These module interfaces also facilitate product maintenance and remanufacturing, which contribute to improved sustainability (Gu et al., 1997; Seliger and Zettl, 2008). In addition, the module interfaces makes it easier to react quickly to changes in demands. It is possible to redesign one module without affecting the surrounding modules (Sanchez, 1995).

By product modularization, both smaller and larger product improvements are supported as long as they are mainly defined to a specific module (Hsuan, 1998); otherwise coordination efforts are needed. Concerning process improvements, such are best enhanced by own manufacturing of product modules. Small-step improvements are not enhanced generally when companies have to collaborate around them; on the contrary more innovative issues are more likely to be successful. Since most process improvements are incremental, they require a deep integration between companies, also involving the key business processes (Chapman and Corso, 2005). The authors claim: “But while inter-company collaboration in radical innovation is a reality, collaboration in small-step innovation (or continuous improvement) of products and processes is considerably less common. Although apparently simpler, continuous innovation within a network of companies requires a much deeper integration between companies along the supply chain and a change in culture that not only involves selected teams, but is extended to the key business processes within the participating organizations” (Chapman and Corso, 2005, p.339). But product modularization decouples the processes and the companies could work quite independently with their modules. The integration level diminishes and thereby the natural ground for the CI work is eliminated.

To summarize, the improvement activities related to external manufacturing of product modules are quite narrowed.

- ‘Continuous Improvements’ of **manufacturing processes** is embarrassed and could be done by suppliers if they only lead to minor design changes to the product modules. Otherwise coordination efforts are needed.
- Suggestions from suppliers or customers for more innovative changes to a **single product module** could preferably be developed together with the design function if they are affecting other modules to a minor degree.
- Other improvement suggestions ought to be examined before an improvement project could start, since changes to **several modules** must be managed and coordinated. The coordinating persons need developed manufacturing competence to conduct the improvement process.

The designers’ manufacturing skills are crucial not only to improve the design quality. Indirectly, a lack of manufacturing knowledge affects the relationships towards suppliers and customers. Von Haartman’s (2013) study strengthens that the need for designers to have manufacturing skills is not only related to the innovation process. To be able to understand customers’ demands and to handle minor or major improvement issues, the designers’ manufacturing knowhow plays an important role as it helps the customer integration. Thus, to have relevant manufacturing competence is not only for exploiting internal performance metrics, but furthermore to enrich the relations to external sources as customers and suppliers, which enhances the improvement work.

Many researchers have stressed this importance of manufacturing knowhow in the product development process, e.g. Hill (2000). Olausson and Magnusson (2011) strengthen that there is a need for internal manufacturing competence at a contracting or outsourcing firm, a statement which has been identified in several previous studies (e.g. Prencipe, 1997; von Haartman and Bengtsson, 2009). Olausson and Magnusson’s cases show that firms are capable of improving their manufacturing competence even when all manufacturing activities have been outsourced. To compensate for the lack of own manufacturing, the suppliers ought to be engaged in an early stage of the NPD project, visits to suppliers are taking place frequently and formalized standards and checklists are used to enhance both the formal and informal communication process with the suppliers.

Methods used

To fulfill the purpose of this paper a case study approach was chosen, since the focus of the paper is about investigating a contemporary phenomenon, ‘how to organize improvement work of product modules’, with ‘how’ and ‘why’ questions (Yin, 2009, p.9), with no clear boundaries to the context (Yin, 2009, p.18), and since the organization context influence the degree of modularization. To investigate how a company organizes its external manufacturing of product modules also calls for an in-depth insight in a company that a case study can give.

The case companies

Three case studies have been done at two different companies during 2013. Two main case studies, case 1 and 2, were conducted at two different design units of Company A, located in Sweden and in Italy. Company A is an international Swedish packaging and processing manufacturer. The company sales for 2011 were about 10 billion euros and the number of employees about 20,000, all around the world. The company develops and produces large industry machines in rather small series; it is thus not a large volume producing company.

This company has a clear product modularization strategy, as a way to deal with product customization, being able to meet customers' different needs. The company has already since the beginning of the fifties relied on external suppliers for almost all of its manufacturing. Such extensive use of external suppliers, together with the modularization strategy, makes this company an exemplary case (Yin, 2009), suitable to study to see what happens in the long run when external manufacturers are used.

Since the purpose of this paper is to compare internal and external manufacturing of product modules a third case study was done at Company B. Company B is a Swedish engineering company with both own and external manufacturing This company's sales during 2012 was about 0.65 billion euros, when the number of employees was about 1,600, all around the world.

For strategic trademark reasons, most of the product development and design is done by the main case company and therefore only internal product development/design is considered in the studies.

Data collection

Semi-structured in-depth interviews have been done at the two case companies, with 22 representatives from both design and manufacturing units. 17 persons, mainly designers and supply chain managers, were interviewed during study 1 and 2 at the main case company and five persons, designers and manufacturing staff, were interviewed at the complementary case company for study 3. The purpose of study 3 was to characterize the situation for a complementary company with both internal and external manufacturing, not to investigate all aspects of the studied process.

All interviews were done together by two of the three authors, were taped, and thoroughly re-listened to clarify the notes taken during the interviews. The interviews followed a semi-structured approach, but were systematically asked with the focus on how the collaboration between own product development and the manufacturing units are organized.

Empirical findings

In this section we present the findings, based on the conducted interviews, from the two case companies. First, the findings from Company A, having all of their manufacturing of product modules externally. Then, the findings from Company B, that has a mix of internal and external manufacturing of their product modules, however the majority of the product modules being manufactured internally.

External manufacturing of product modules

The first two studies (case 1 and 2), conducted in the main case company's (Company A) DM interface, could identify both several interesting coordination mechanisms (Eklind et al., 2013) as well as problem issues in the work with product improvement and updating (Eklind and Persson, 2013), some of them being mentioned below. The company has developed a structured product development framework with rules and templates regulating the design process. This framework is well implemented in the organization and also disseminated to external manufacturers so they work according to the company's intentions. This structured framework is one of the company's strengths, which also contributes to the improvement work by its well-defined procedures. At the same time the structure may imply a risk to bring a too formalized and rigid organization.

The established Italian design support group (DS), identified in case study 2, has an active role for coordinating manufacturing issues in the design organization in a cross-functional way. When a designer is searching for a new solution, DS could support and link resources. Designers' manufacturing competence is also strengthened through appropriate education in "Design for Manufacturing and "Design for Serviceability" according to upcoming issues depending of the context.

The supply function has a somewhat unusual extended strategic role in the product development process. Strategic meetings with supplier groups are held yearly, but on top of this, the supply function is an intermediary in the interface between the design function and the manufacturing supplier. This has a bridging effect on the DM relation, but the supplier could on the other hand mix-up who is the responsible party. This solution is rather unproven and the organization is not fully used to it yet.

Though there is a regulated process for how to handle customization and necessary changes to products, it does not work out perfectly, reported problems are logged into the system, but the given feedback is both rare and slow. Problems to communicate through the DM distance seem to play a role and we conducted a case study at Company B with a mix of internal and external manufacturing to find out if such a mix makes any difference.

Internal manufacturing of product modules

Case study 3, done at Company B, focuses on investigating internal manufacturing of product modules. This company has product development units in Sweden and in the US, together with manufacturing plants and manufacturing suppliers spread globally, mostly in Europe and US. In this study, the relationship between the Swedish product development unit and an own engine plant situated at about one hour's distance (if going by car), is investigated. The relationship is built on ICT based solutions combined with regular meetings once or twice a month. Most often these meetings are held in the plant, meaning that the design representatives visit the manufacturing location, seldom vice versa. The number of meetings varies according to weighed up needs and both designers and the manufacturing staff seem to be satisfied with the way the parties collaborate. The meeting frequency also varies depending on, for example, in which phase of the development work the project is right now. It also varies depending on the magnitude of the project, a large development project calls for higher meeting frequency compared to a smaller project. There are mainly three contact areas that shape the DM relation:

1. During last years the responsible product designer has made efforts to build up a good relation with the manufacturing personnel and to handle operative quality issues in a structured way. Both product and process improvements are discussed at the monthly meetings and seem to be fruitful. The designers have an informal approach and try to find solutions together with operators and other involved persons when a quality issue is raised. Even if this mostly is seen as positive the informal decisions made sometimes risk to shortcut the formal framework needed to prepare the production processes.
2. In parallel, different development projects are driven by the designers and the same contact area is used to test constructions in practice, i.e. operators are often

involved in a more or less formal way. It rather often happens that a designer does some hours in the production line to learn more about a certain issue.

3. Sometimes, when all the test rigs are occupied at the product development unit, engines could be long-term tested at rigs at the manufacturing plant. This extra contact area brings further communication which enriches the network in the DM interface. Designers and manufacturing personnel learn to know each other better, which is useful when they collaborate around development projects and improvement issues.

From the designers' point of view, the constructive and informal way the interaction with the nearlocated plant is built on, gives them the opportunity to find rapid and smart solutions on several problem issues.

"We know that we can find solutions together even when a drawing is not perfect ready for manufacturing. Compared with our own more distant plants and with other manufacturing suppliers it is quite different, then we have to be more exact. We are thankful for this opportunity we have, hope they are aware of that."

Designer, responsible for one of the engines

From the plant manager's point of view, he is aware of the advantages the fruitful collaboration gives, but he also highlights the negative consequences the informal manners bring.

"If a designer goes directly to the operator and finds a solution or does some adjustment, he must also inform the responsible production preparer. If not, as quite often happens, our whole framework is shortcut and we have to really improve when we suddenly find such unnotified changes. In a near future our system will be totally computerized and the possibility to improvise becomes much harder, all processes must be correctly structurized."

Manager at the nearlocated engine plant

This close and friendly contact also affects the way product and process improvements are conducted. Raised quality problems are discussed at the monthly meetings and ways to handle them are initiated, e.g. through an improvement group. Mostly this works out well, though some recurrent problem issues are almost neglected and the manufacturing unit has to live with their 'homemade' solutions, if the designers prioritize otherwise.

To sum up, the internal improvement work between design and manufacturing works out reasonable well and leads to good product quality on delivered engines. According to the interviewees in the manufacturing plant, most of their improvement suggestions are listened to, and many of them become implemented. An informal and friendly atmosphere provides dissemination of knowledge to each other, especially designers get manufacturing skills, useful in many other situations.

When this engine module is delivered to a system builder to fit with other modules into a vehicle, many problem issues are reported. The quality of the total product system seems to be lower than our other case company's quality on delivered systems. Yet, it is not possible to analyze if the close DM relation could impact this result, e.g. by a narrow focus which may lead to a suboptimation of the improvement efforts.

Concluding discussion

In this paper we have studied Company A with all their manufacturing of product modules external, and Company B that has mainly internal manufacturing of product modules. In table 1 we summarize some findings from these two case companies.

Table 1. Characteristics of the case companies DM relation

Characteristics for the DM relation	
Company A, design units in Sweden and Italy. All manufacturing external.	**Company B, design unit in Sweden. Mixed manufacturing.**
The DM relations works out more or less well, sometimes the feedback from design to suppliers is poor.	Investigated DM relation works out quite well with good feedback from designers to the manufacturing unit.
The contacts in the DM relations are mainly formalized according to the common framework. The communication risks to slow down if a DM relation is poorly developed.	Informal contacts are allowed and leads to rapid solutions, though risking that necessary information to production preparer about 'smart solutions' becomes deficient or forgotten.
The formalized log system for customer claims and improvement suggestions from suppliers works out unsatisfactionary, partly depending on unclearity about who and how to handle them.	The close DM relation feeds temporary smart solutions, which could be permanented instead of initiating needed longterm improvements.

The findings in this paper indicate that if all manufacturing of product modules is left to suppliers there is a risk to lose manufacturing competence. This is in line with previous research, e.g. von Haartman and Bengtsson (2009), which claims that there is still a need for internal manufacturing competence to be able to develop new products. The contact area between designers and suppliers also risks to become weaker and in that case needs to be strengthen by coordination efforts.

Both the need for further coordination and more manufacturing competence are connected to the gap that emerges because of the distance between own design and external manufacturing. However, findings in this paper also add to existing literature by showing how the case companies are dealing with these two issues in different ways.

Since we have presented the findings from the two studies in the main case company, Company A, in our two other papers (Eklind et al., 2013; Eklind and Persson, 2013) focus here is on the study at the company with a mix of internal and external manufacturing. As some manufacturing is located nearby and belongs to the company, conditions for a close DM relation are formed. Main benefits from this relation are:

- Increased amount of manufacturing knowledge is spread to designers since they often take part of how different manufacturing processes work out.
- Scheduled, regular meetings and accrued collaboration channels in the DM interface enhances the common work around both product and process improvements.
- The extended contact area designers'testing of engines at the manufacturing plant brings, gives a spin-off effect by enrichering the DM relations.

Such a close DM relation also could bring unwanted effects as:

- Informal manners risk to undermine the work according to the common framework and thereby indisposing the preparation of the production processes.
- The design unit gets used to that the manufacturing plant 'fixes' issues that ought to be handled in a more professional and longterm manner, which is more likely if external suppliers are used.

These case studies bring a managerial implication to outsourcing companies who could be in an earlier phase than the main case company, which has been relying on external manufacturers for more than fifty years. External manufacturing of product modules can bring knowledge problems and difficulties to improve products and processes, because the distance between design and manufacturing may lead to that the product development engineers will have less direct contact with the product modules. Even if this could be balanced by dedicated persons emanating from the design function who work crossfunctionally, an alternative is to keep some manufacturing internally. Both alternatives provide benefits and challenges. To not lose required long-term manufacturing skills it is important to consider such aspects early when implementing a sourcing strategy.

The generalizability of results from qualitative case studies is limited (Yin, 2009) compared to quantitative studies. Nevertheless, case studies findings could be generalized in an analytical manner instead of a statistical (Miles and Huberman, 1994; Yin, 2009). From this research study, findings could be useful for companies with any of the two following characteristics: first, companies using product modularization for rather complicated products in limited series, with a low or high share of external manufacturers; second, companies having a clear sourcing strategy with supply chain management well positioned in the company, not necessarily using product modularization.

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