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ANTON KAIVOLA

DECREASING PRODUCT VARIETY-DRIVEN COSTS: THE VIEW POINT FROM COMPLEXITY MANAGEMENT AND COMPONENT COMMONALITY IN BATCH-PROCESS CONTEXT

Master of Science Thesis

Examiner: Assistant Professor Teemu Laine.
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ABSTRACT

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Keywords: complexity management, component commonality, product design, product variety, cost management, complexity costs, batch-process industry, vertical integration.

The case company suspected it had too many products variants for its inner customers in contrast to the inflexible batch process production. Literature recognizes the negative effect of product variety on economic and operational performance in batch process industry. Component commonality is a way to decrease variety and recognized as a cost reducing method, although lacking ways to find potential targets. In contrast, complexity management is useful for reasoning what is causing product driven complexity, but too abstract for cost analysis. The objective of this study is to analyze the cost effect of product driven complexity by recognizing potential targets and ways to decrease these complexity costs. This can be achieved by combining complementary theories about complexity management and component commonality, in order to calculate the cost effect of decreasing complexity.

The thesis is an interventionist case study analyzing the cost effect of component commonality. The research was an iterative process reflecting between theory and case context, in order to investigate the effect of product variety on the case company performance and consequently a potential cost effect of decreasing the variety i.e. product-driven complexity costs. Paper mill conducted research in addition provided qualitative and quantitative data about the subject throughout the process as well as other units of the company.

As a result, the thesis recognized the most potential product attribute to decrease excess complexity that was not driven by customer. The decreased complexity turned into costs in following fields; longer production runs, lower inventory level and positive effect on cost driver use. More speculative cost effects supported by theory could supplement these direct cost effects. Results support the literature view on effect of increasing product variety and opposite effect of component commonality. Contribution to literature based on combining component commonality and complexity management itself and bringing these theories into a context of batch process industry and two-stage value chain. These two theories resulted not only better understanding about the cost effect, but also how complexity can be managed better in value chain. This means eliminating excess internal complexity, balancing between internal and external complexity and pushing the point of differentiation late as possible. In the end, the product design decisions are linked to the competitive advantage of the case company.

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Avainsanat: kompleksisuuden hallinta, komponenttien samankaltaisuus, tuotesuunnittelu, tuotevariaatiot, kustannusten hallinta, kompleksisuuskustannukset, prosessiteollisuus.

Kohdeyritys koki, että se tarjosi tarpeettoman monta tuotetta sisäisille asiakkailleen suhteessa jäykkään tuotantomuotoon. Kirjallisuus tunnistaa tuotevariaatioiden negatiivisen vaikutuksen taloudelliseen ja tuotannolliseen suorituskykyyn prosessiteollisuudessa. Komponenttien samankaltaisuus on keino vähentää variaatioiden määrä ja alentaa kustannuksia, mutta se ei tunnista potentiaalisia kohteita. Kun taas kompleksisuuden hallinta soveltuu rationalisoimaan mikä aiheuttaa tuotteiden aikaansaaman kompleksisuuden, mutta liian abstrakti kustannusanalyysin toteuttamiseen. Työn tavoitteena on analysoida tuotteiden aiheuttamia kompleksisuuskustannuksia tunnistamalla potentiaaliset kohteet ja keinot alentaa niitä. Tämä on saavutettavissa yhdistämällä toisiaan tukevat teoriat kompleksisuuden hallinnasta ja komponenttien samankaltaisuudesta, jonka avulla analysoimme laskevan kompleksisuuden kustannusvaikutuksen.

Diplomityö on konstruktiivinen tapaustutkimus, joka analysoi komponenttien samankaltaisuuden kustannusvaikutusta. Tutkimus oli iteratiivinen prosessi reflektoiden teorian ja käytännön välillä, jonka kautta tutkimme variaatioiden vaikutusta kohdeyrityksen suorituskykyyn, sekä toisinpäin pohtien mikä on kustannusvaikutus kompleksisuuden laskiessa. Tutkimus toteutettiin paperitehtaalle, joka toimitti kvalitatiivista ja kvantitatiivista tietoa koko tutkimusprojektin ajan. Myös muilta yksiköiltä yrityksen sisältä saatiin tukea.

Diplomityön tuloksina tunnistimme potentiaalisen tuoteominaisuuden, jonka kompleksisuutta voidaan alentaa eikä ollut asiakkaan aiheuttama. Alentunut kompleksisuus pystyttiin kääntämään kustannusvaikututuksesi seuraavilla alueilla: pidemmät ajot, alemmat varastot ja positiivinen vaikutus kustannusajuriin. Suorien kustannusvaikutusten tueksi syntyi myös spekulatiivisia kustannusvaikutuksia teorian tukemana. Tulokset tukevat kirjallisuuden näkemyksiä tuotevariaatioiden vaikutuksista ja komponenttien samankaltaisuuden päinvastaisesta vaikutuksesta. Kontribuutio kirjallisuudelle perustuu yhdistämällä kompleksisuuden hallinnan ja komponenttien samankaltaisuuden teoriat yhteen, sekä pohtimalla näiden vaikutusta prosessiteollisuuden ja kaksivaiheisen arvoketjun konteksteissa. Edellä mainitut teoriat johtivat parempaan ymmärrykseen kustannusten syntymisestä, sekä toivat käsityksen kuinka kompleksisuutta voidaan hallita paremmin arvoketjussa. Tämä tarkoittaa turhan kompleksisuuden poistamista, tasapainoilemista ulkoisen ja sisäisen kompleksisuuden välillä sekä lykätä tuotteen kustomointi mahdollisimman myöhäiseksi. Lisäksi tuotesuunnittelun valinnat ovat yhteydessä kohdeyrityksen kilpailutekijöihin, joka korostaa kompleksisuuden hallinnan tärkeyttä

PREFACE

Finding new markets and solutions to products can be challenging, however turning these products into more suitable for a company to produce is where the fun part begins. I hope that I get a chance in a future tackle more this subject. The journey to this point has been great and there are a few people I would like to show gratitude to get this point.

I would like to thank Assistant Professor Teemu Laine for insightful comments and valuable guidance throughout the whole project. It has been great to have your support for making this thesis. Moreover, I would like to show gratitude to the company for giving this chance to make this thesis and deepen myself into the topic. I want to thank for my supervisor Juha for inspiring and supportive discussions. Additionally, I am grateful to Jukka, Jussi and the rest of people working in the mill. You made me feel welcomed and I want to thank you for contributing to this research. Special thank belongs also to Pejk for giving me soft landing to the company and to the industry. Lastly, I want to thank everyone working in Helsinki.

My dearest friends have been great support in order to get this point and finish the thesis in a great spirit. Finally, I owe my deepest thanks to my dear family for support through my journey. Finally yet importantly, I warmly thank my girlfriend Kaisa for understanding and encouraging through the process.

Tampere 20th February

Anton Kaivola

CONTENTS

1. INTRODUCTION 1
1.1 Background of the thesis 2
1.2 Research problem 4
1.3 Structure of the report 4
2. COMPLEXITY MANAGEMENT 7
2.1 What is complexity? 7
2.2 Managing complexity 9
3. ALLIGNMENT OF PRODUCT AND PROCESS STRATEGIES 14
3.1 Product-Process-Matrix 14
3.2 The impact of product variety on production performance 19
3.3 How to correct imbalance in Product-Process-Matrix 23
4. MANAGING COMPLEXITY COSTS 25
4.1 The cost effect of component commonality 30
4.2 Cost reducing mechanism of component commonality 31
4.3 Frameworks for analyzing cost effect of commonality 35
5. RESEARCH METHODOLOGY 38
5.1 Research process 38
5.2 The case company background 43
6. THE COST EFFECT OF COMPONENT COMMANLITY IN THE CASE COMPANY 45
6.1 Complexity inside the case company value chain 45
6.2 Component commonality in the case company 48
6.3 The cost effect of component commonality for product attribute 52
6.3.1 The effects on cost driver use 53
6.3.2 Longer production runs 54
6.3.3 Changes in supply chain 57
6.4 Overall cost effects of component commonality 62
7. DISCUSSION AND CONCLUSION 66
REFERENCES 74

APPENDIX A: CHANGES IN SUPPLY CHAIN

APPENDIX B: CHANGES IN SET-UPS AS BATCH SIZE INREASES

1. INTRODUCTION

Case company sensed that it had too many products for a dozens of inner customers and wanted to conduct a research about how to improve product management. From there began an iterative process between theory and case context to investigate the effect of product variety on case company performance and consequently a potential cost effect of decreasing the variety. The amount of product variants is considerable in contrast to mature and inflexible paper mill capabilities to produce different products. Closer look between inner customers revealed that 92% products were completely unique and therefore very little commonality. Even the consultants of a major ERP-project were wondering about the sheer amount of unique products. The purpose of this thesis is to answer a question: "so what if we have that many product variants, what is the effect?"

Literature recognizes the negative effect of product variety on economic and operational performance in batch process industry. Increasing variety leads to higher inventory levels, increasing lead-time, adding set-ups and therefore lower productivity (Da Silveira 1998; Fisher & Ittner 1999; Berry & Cooper 1999; Randall & Ulrich 2001; Er & MacCarthy 2006; Nowak & Chromniak 2006; Wan et al. 2012). Other field of literature contributing to research is complexity management. Product complexity refers to sheer quantity of product variety and not the complexity of producing a product itself. Complexity in product management context can be divided into external and internal complexity. External complexity describes the heterogeneous needs of customers. Internal complexity describes product variety offered by a company in order to satisfy customers, therefore increasing costs. The link is product design decisions and way to success is finding the right balance. The internal complexity itself is not bad, but having excess complexity or not managing it, might lead to excess complexity costs and bad performance.(Perona & Miragliotta 2004; Blecker & Abdelkafi 2006; Marti 2007; Schaffer & Schleich 2008; Lindemann et al. 2009; Weiser et al. 2016a) In batch process industries relevant ways to decrease product-driven complexity costs are component commonality and pushing the point of differentiation late as possible in a method of a mass customization.

Complexity management is good for reasoning potential targets and ways to decrease complexity; however, it is too abstract for calculating the cost effect. On the other hand, component commonality is missing ways to recognize potential targets for commonality, but has good discussion about cost effects. Purpose of this research is to combine these theories, in order to recognize potential product attribute to decrease product driven complexity i.e. decrease variety by standardizing. This is followed by calculating direct and speculative cost effects of component commonality in the case company for the most potential product attribute.

The product is at the central point of the case company but not managed from the value chain perspective. Current product design choices are more or less based with rather independent units that have led to the situation of partial optimization. The point is to recognize the potential of better product management inside the value chain by calculating the cost effect of eliminating excess variety (i.e. not customer driven) or pushing differentiation late as possible (i.e. a way to mass customize). Understanding the cost effect is required in order to challenge the product requirements of inner customers and build commonality among them. Lastly, the research has rather strategic aspects as component commonality is connected to case company's core competence like responsiveness, delivery reliability, quality and cost competitiveness.

1.1 Background of the thesis

Manufacturers and service providers justify product variety based on satisfying customer needs. It is often neglected that excessive variety may actually make manufacturing uneconomical. There is a point at which responding to external complexity (i.e. fragmented customer needs) with internal complexity (i.e. the diversity of the product offered to customers) turns into excessive internal business complexity (a driver of cost, quality, and time inefficiencies within a business). This is the point at which product variety stops being a strategic advantage. It may create additional value for a few customer segments by ensuring a full product range, but it is a drag on the business. It is costly, time consuming, and corrodes quality. Most important, it leads to unnecessary complexity, much of which is not even visible to managers. Thus, cutting it out and making sure it stays out, requires systematic effort and willingness to sustain it.

External complexity cannot be effected; therefore managing the internal complexity should be emphasized. In this thesis, we focus on how to manage the internal complexity and deduct the challenging question what is the right balance between internal and external complexity. Managing complexity is about turning low internal complexity into high external complexity, which is a form of mass customization. Link between external and internal complexity is product design and the point of differentiation in the value chain. The objective of this study is to estimate the cost effect of component commonality of most potential product attribute, which is a first step towards less internal complexity. In order to facilitate component commonality, it requires actions and investments to product commonality among stage 2 manufacturers. Understanding the cost effects is a key to facilitate conversation and increase potential to build commonality between internal customers. The value chain is represented below in the Figure 1. It can be separated into two different stages.

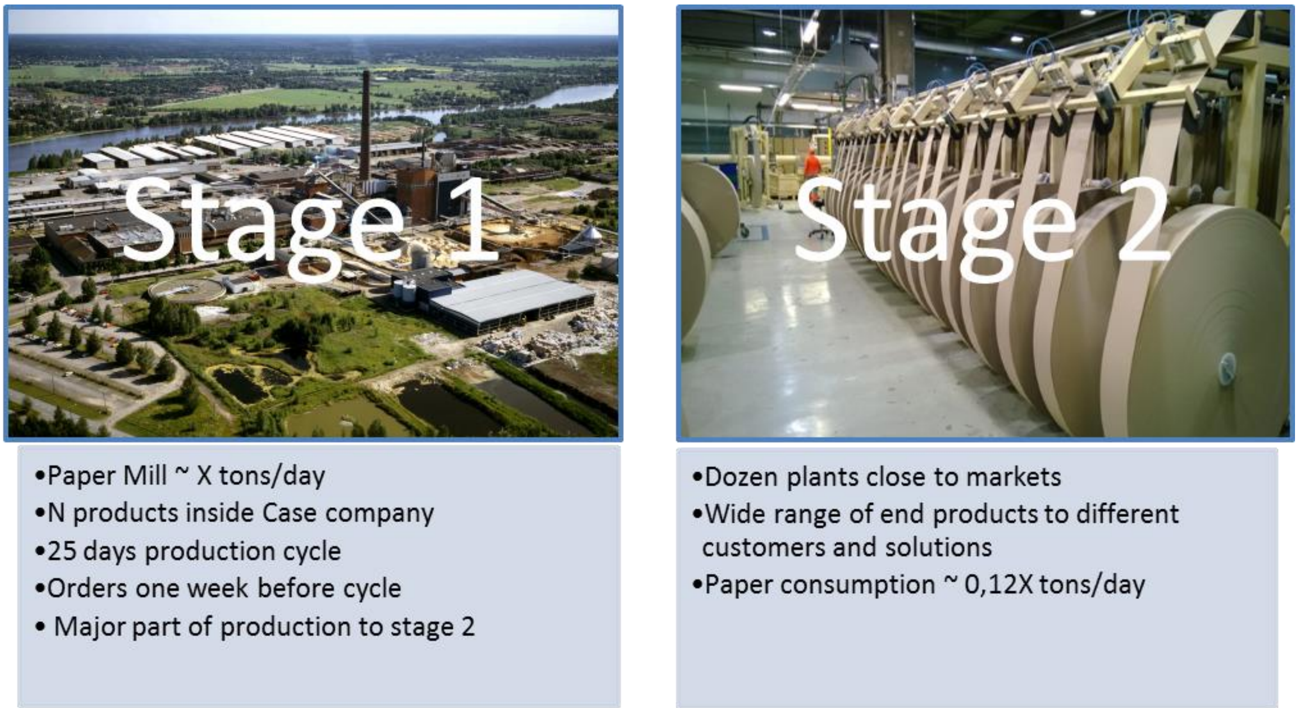

Figure 1: Illustration of the value chain. Stage 1 is the case company and stage 2 represents the inner customers of the case company

Stage 1 is large a scale paper factory, which paper is further processed and used as a main raw material in the stage 2. Case company in this study is repetitive of one of the stage 1 mills. Value chain in this study is understood from case company to inner customers of stage 2. Customers of stage 2 are understood as end customers that are the source of external complexity. Managing the internal complexity that is not driven by customers is focal point of this study. Complexity itself is not harmful but having excessive and not managing it may result in bad performance.

Ever increasing external complexity and customized products for stage 2 had led to feeling in the case company that there are too many products for inner customers. Slow evolution of increasing products makes the effect of product variety hard to detect. Complexity in stage 2 has dribbled down to the case company, which production is more sensitive to increasing variety that is multiplied by having several stage 2 inner customers to be served. Every time a new product or its variety is introduced, it increases complexity and has complexity cost factor effecting on different functions of the company. Detecting the cost of effect of complexity cost is rather abstract. Therefore, the thesis focus on one product attribute and its complexity costs by calculating direct and more speculative cost effects of component commonality for the selected product attribute.

1.2 Research problem

Case company problem is having too many products that effects negatively to the performance of the company. Turning this into research problem results into objective to analyze cost effect of product driven complexity costs and how to recognize and prioritize potential ways to decrease these costs. Research questions are the following; (1) what does the complexity costs mean in the case context; (2) what costs are resulted from the complexity to a product attribute; (3) what are the ways to decrease following cost by first recognizing and then eliminating?

Product driven complexity has unique features in the case context that is based on batch process industry. Product variety influences to overall performance in the case company as the manufacturing method is inflexible compared to other forms of manufacturing. Consequently, theory has recognized how product variety (i.e. product driven complexity) effects in batch process industry, which enables a foundation for discussion in the case context. In result, we emphasize the cost effect of product attribute that is defined in a more flexible cutting process, which has the biggest impact on sheer amount of different variants. This observation leads us to better picture about the cost effects of internal complexity that is not driven by external complexity, although the biggest impact might be considering product attributes defined in more inflexible paper machine. Lastly, we enlighten a way out of product driven complexity by first recognizing potential targets to lower excess product driven complexity and other potential methods to manage complexity in the value chain. Considering these questions and views it is possible support decision making in order to improve the whole value chain and competitive advantage. Eventually these questions turn into rather strategic as the potential of internal complexity is understood and furthermore how it can be managed better. Product design decisions have been neglected from the whole value chain point of view and resulted a situation of partial optimization. Firstly, thesis brings insights to get rid of excess complexity, lastly enlighten ways for better management of complexity and turn it into core competence in the industry.

1.3 Structure of the report

The approach into the research problem is comparable into a funnel as presented in Figure 2. Interventionist research approach was iterative as demonstrated later in research methodology. Each chapter goes more deeply into the subject by first getting understanding what the reasons behind product driven complexity are and what the cost effect of decreasing excess complexity is in the case company. After conceptualizing the complexity, it is possible to find potential targets to decrease the complexity. This means calculation of complexity costs that is supported by literature about cost effect component commonality. The report is divided into 7 different chapters, where chapters 2-4 are about supporting theory, chapter 5 about methodology, chapter 6 are results from the case company, lastly discussion and conclusion. In the beginning of chapters, have supplementary quotes from “Toyota Way” by Liker (2004). These are added to delight reader about complexity management from lean management perspective as well as it is relevant to the case company (Marti 2007).

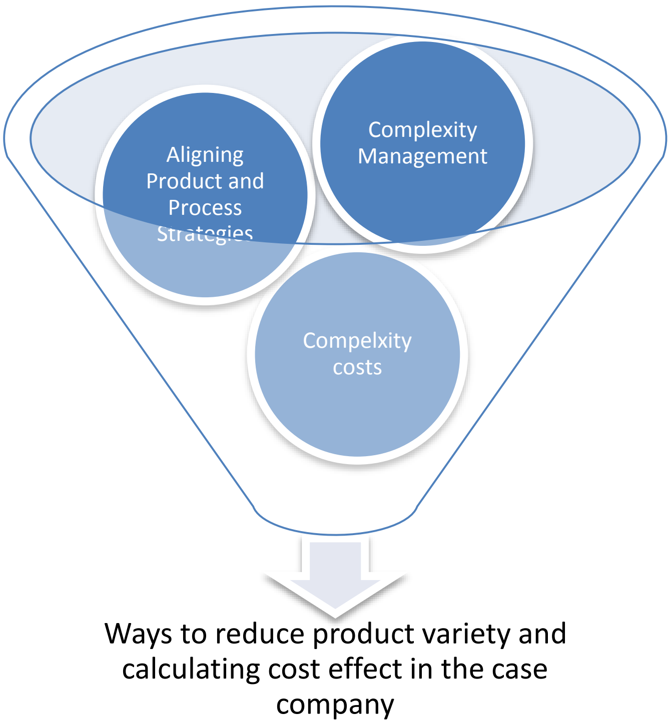

Figure 2: Structure of the report described as a funnel towards the research problem

The content and objective of each chapter is following:

Chapter 2 introduces what complexity means in product management context. Its origin is in the German literature to describe how external complexity is effecting on internal complexity of a company. After conceptualizing product driven complexity, ways to manage the complexity is represented with product design decisions and how to push product differentiation late as possible.

Chapter 3 discusses the impact of product variety in batch process industry and how companies should find the right balance between product and production strategies. Additionally, ways to find a better balance between strategies are introduced and supported by a fundamental production management concept called Product-Process-Matrix.

Chapter 4 introduces the cost effect of component commonality derived from literature about complexity costs and the cost effect of increasing product variety. Component commonality is seen as a cost reducing mechanism and therefore manages complexity. Frameworks to analyze cost effect of commonality are also introduced.

Chapter 5 enlightens how the iterative process of interventionist research. The overview of research process is presented and described how empirical data was collected. The point is to build an overall picture what was done in the research project to build understanding about research problem.

Chapter 6 is built on similar chronology as the theory by first reasoning the complexity behind current product variety. The cost effect of component commonality was calculated for the potential product attribute by selecting 3 different targets that had major cost impact. Cost effects are calculated first with more direct cost effects and moving into more speculative costs

Chapter 7 responds to the research problem by summarizing results and opens up potential ways to extend the observation in the case company. It highlights the limitations and critique of the research. Reflects and complements current theory. Finally, the potential implications and more strategic questions are considered.

2. COMPLEXITY MANAGEMENT

Observation, in the case company led to understanding that the effects of product variety can be discovered throughout the whole value chain. To capture the effect in the whole value chain, the literature introduced the concept of complexity managements and its monetary value called complexity cost (Weiser et al. 2016a). Complexity management conceptualizes the source of complexity and how it can be managed. The literature has its roots among German product management studies, where researchers have used the analogy about complexity and brought it in the field of product management (Weber 2005). Complexity management does not offer completely new methods; rather it combines known concepts in literature in order to help companies to understand what is behind the complexity in the whole value chain. In this thesis, we focus on product complexity that is driven by external complexity. Guided by complexity management it is easier to understand what is behind the product complexity and how it can be managed. To calculate complexity costs the methodology was simply too abstract, therefore component commonality and its cost effect is introduced in the last section. The complexity cost is more like a managerial concept of understand the cost effect of product variety and other product design choices.

In order to reduce Complexity cost, companies must either reduce excess complexity or manage it better. Also the task is to balance between external and internal complexity. Companies should also bear in mind that complexity itself is not an evil. The downside is to have excess complexity i.e. offering lavishly product variety or not managing the complexity.

Discussion about complexity so far has been somewhat conceptual. With the help of complexity management, the point is to recognize potential targets and ways to reduce product complexity and finally calculate the cost effect of component commonality. Component commonality is lacking ways to find potential targets for commonality (Lyly-Yrjänäinen 2008), whereas complexity management is a pretty abstract in order to calculate cost effect. Combining these two methodologies has been vital to understand fundamental reasons behind the product complexity and entering into the cost effect.

2.1 What is complexity?

“You can have any color as long as it's black”.

- *Presumably said by Henry Ford about Model-T (1909)*

In this chapter, we open up how the term “complexity”, which turns into the context of product management. Furthermore, we discuss what is causing the complexity and what is the source of complexity? Additionally, we examine the dimensions of complexity and build boundaries for discussion in this thesis.

The complexity is characterized by the following parameters: the quantity of variables, connectivity and transparency. In most cases, the aim is to reduce the complexity of objects. (Ehrlenspiel et al. 2007) To manage the complexity, we have to understand it better. Weber (2006) has elaborated the discussion about complexity from other fields of science into product management and more narrowly on product design, where managing complexity has always been important in scientific and practical level. Complexity implies various aspects, such as a number of components and variants in system, as well how these are connected together (Weiser et al. 2016a)

In recent decades, the product variety has increased in most industries. In packaged-goods industry, for example the number of new products introduced doubled from 12,000 in 1988 to 24,000 in 1996 (Thonemann & Bradley 2002). The increase of product variants is associated companies a task to designing appropriate output clusters to fit with the heterogeneous market requirement in the best possible way (Marti 2007) s.18. Additionally, increase of product variants is associated with the decrease of product life cycle time (Lindemann et al. 2009). Offering product variety to consumers is essential for success in business environment. However, the question is how much should be offered? Benefits of product variety must be assessed relative to the cost of product variety. (Thonemann & Bradley 2002). Product variety results as manufacturing complexity (Schaffer & Schleich 2008).

A company can react to increasing external market complexity (i.e. homogeneous market) by the increasing internal complexity of its product portfolio (i.e. increasing the variety of its products) (Lindemann et al. 2009). The concept of complexity gives us a better understanding; what the source of the complexity is and how the company has to balance in this challenge from increasing company's internal complexity. Link between these two is a product. The next figure illustrates the sources of complexity and dividing it between internal and external sources. In Figure 3 below can be seen four fields of complexity and associated sources of them (Lindemann et al. 2009). The market complexity is external and sources behind the complexity might be norms, standards, customer diversity or competitors. In the case company, complexity is associated to standards set by industry or customers to meet quality requirements, which can be changed based on industry or geographical reasons. Customers are the major source of complexity as they each have their unique setting even though the product itself is simple. This sets difficulties in sales in order to challenge customer requirements to serve a product that meets customer needs and still be economical to produce.

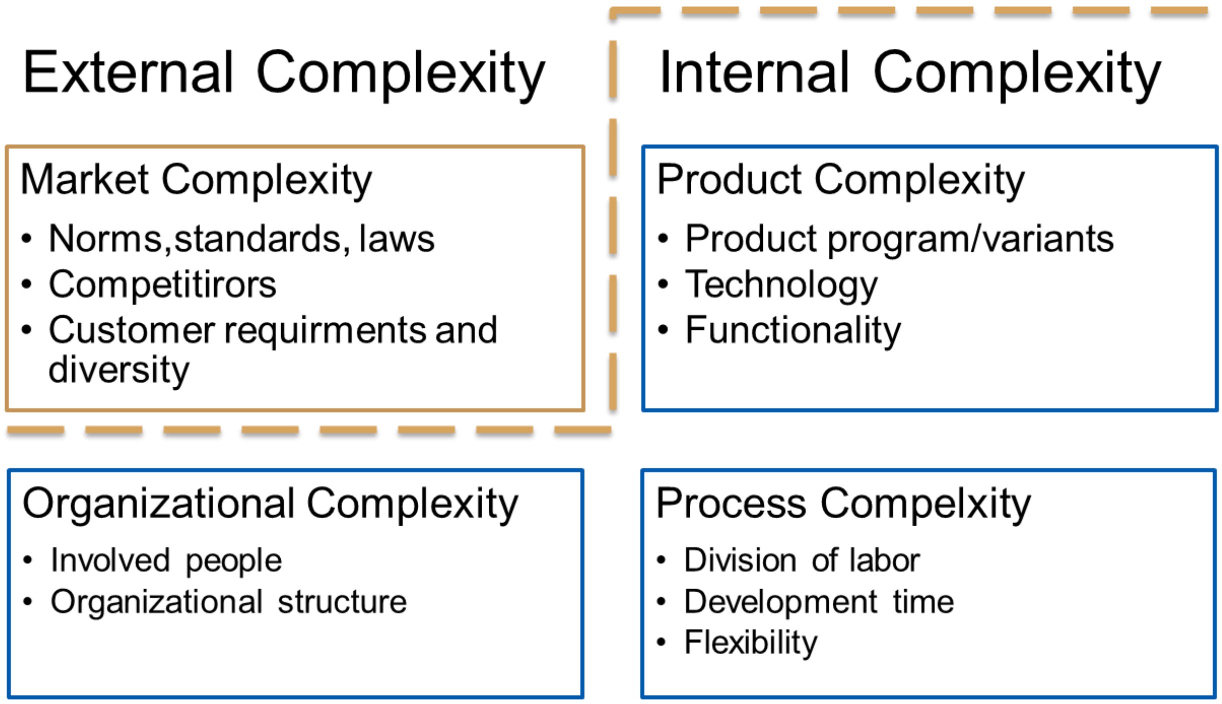

Figure 3: Four field of complexity and associated sources; source Lindemann et al. (2009)

Lindemann et al. (2009) have divided forms of internal complexity into a product, process and organizational complexity. This presents how extensive effect external complexity has. In this study, we focus on the key link between internal and external complexity that is product complexity. The thesis opens the decisions and choices in product design that can minimize the effects of external complexity. Discussion about a process and organizational complexity is done from the perspective of product design and what this means from the cost perspective in the following fields.

External complexity is an origin of the internal complexity. Responding to external complexity increases internal costs, which decreases competitiveness. Companies can react on this by increasing even more product variants in order to serve yet more niche markets and the circle is closed. (Lindemann et al. 2009) Alternatively, companies can reduce internal complexity, which typically requires compromising the customization of products. On the contrary, this complicates the task of differentiating from competitors. (Marti 2007) External and internal complexity dimensions pose a challenge for companies because they require different and sometimes conflicting actions. Literature has recognized several ways to fight back on complexity or in other words manage it.

2.2 Managing complexity

"Even if the target seems so high as to be unachievable at first glance, if you explain the necessity to all the people involved and insist upon it, everyone will become enthusiastic in the spirit of challenge, will work together, and achieve it".

- *Ichiro Suzuki, chief engineer of the first Lexus*

Like presented in the previous chapter product design and its variants have impact on internal complexity. There are examples of companies that have taken actions to reduce internal complexity and order to manage it. Procter & Gamble for example reduced the number of variants in Head & Shoulders shampoo product line from 22 to 15. Ford reduced the number of variants in Taurus product line by 30% from 1988 to 1995. In both cases, the reduction did not affect adversely on sales. (Thonemann & Bradley 2002) Increased product variety offered may provide a competitive edge, however the strategic question regarding product variety concerns the appropriate level of variety. Offering product variety increases costs, but on the contrary, it provides product differentiation, hence leading to higher market share and sales volume. (Schaffer & Schleich 2008)

Lindemann (2009) states that complexity management is easily understood narrowly in the literature as variety management. The focus should be on understanding what is causing structural complexity in products and processes. Lindemann (2009) suggests that certain level of complexity can be useful, because it facilitates flexibility in process structures and therefore provide competitive advantage. This principle has similar mentality with lean philosophy, where decreasing the inventory level forces to discover the weak points of production (Liker 2004). In literature exists different strategies for complexity management. These strategies involve trade-offs between the economy of scale versus the economy of scope, or customization versus standardization. Mass customization is a hybrid version of these strategies. Therefore, managing and controlling complexity rather than reducing itself, can be seen major competitive advantage. (Lindemann et al. 2009).

Next, we will discuss mass customization, which has been recognized as a way for managing complexity at conceptual and practical levels. Mass customization systems involve product design issues as well as production and product configuration methods (Blecker & Abdelkafi 2006). In the case company, numerous product requirements connect to the fragmented production settings of inner customers. The idea of mass customization is to find an optimal combination of mass production with customized product specifications, i.e. turning low internal complexity into high external complexity (Lindemann et al. 2009). Mass customization is not about offering everything to everybody, but rather doing only and exactly each individual customer wants and needs. The earlier is a route to higher costs and latter can lower costs by eliminating waste in operations (Joseph Pine II. 2011). This approach has similarities to lean management, in order to understand what is valuable to customers and value stream mapping processes (Liker 2004). Mass customization strategy allows customizing products with a cost level close to a mass producer (Marti 2007). That is relevant strategy for the case company, which is facing simultaneously heterogeneous market and cost pressure.

Marti (2008) presented methods of implementing mass customization in different ways in the value chain. The following methods have examples in the case company environment:

- **Customize services around a standardized product -** Case company offers consulting for customers' operations to help them to get most out of the products.
- **Create customizable products and services -** Customer gets full length tubes and is responsible of cutting the length suitable for itself

- **Provide the point of delivery customization –** Last customization done inside the process of big customers in matter of minutes with an embedded system.
- **Provide a quick response throughout the value chain –** The case company has control over exceptionally long value chain, which enables better response to market needs. (Marti 2007)

Gilmore and Pine (1997) introduced strategies for mass customization. In *Collaborative customization strategy*, manufacturer is responsible for customizing the product, hence requiring close cooperation with customers and flexible operations. In *adaptive customization strategy*, the manufacturer provides a customizable product and the customer is responsible for the final customization. In third strategy, customization is automatically adapted to customer requirements (Gilmore & Pine II 1997). In one of the stage 2 manufacturer is located inside a customer's mega factory and cooperation in the customer's manufacturing process and capable customize just in time by pushing the point of differentiation late as possible. This is a great example of executing mass customization in the case company by pushing the point of differentiation late as possible and automatically customizing the product in collaboration with the customer.

Previously mentioned concepts connect with the question: "What is the point of differentiation in the value chain?" Delayed differentiation is a representative of this strategy and way to achieve mass customization also in batch process industries (Caux et al. 2006a). Delayed differentiation requires redesign for products and processes, in order to delay the point of differentiation, which gives to product unique ID. Therefore, the process would not commit the work into a particular product until a later point. (Lee & Tang 1997) Creating a variant later in the production process, results fewer variants handled upstream from the point of product differentiation (Schaffer & Schleich 2008). This approach lowers inventory costs and makes companies more responsive in forms of risk pooling and lead-time uncertainty (Caux et al. 2006a). Caux et al. (2006) found three relevant ways to implement delayed differentiation: Process restructuring, component commonality and product design. Process restructuring consists of changing operations in a process in order to delay the point of a product is customized. Component commonality discussed in next chapter because it is relevant in this case environment. Fields on the modularity or platforms of products are not discussed in this thesis (Salvador et al. 2002; Thyssen et al. 2006). Modularity is impossible to perform with simple products like paper, which is a possible reason Caux et al. (2006) has not recognized any relevant literature in this field. (Caux et al. 2006a). The benefits with the economy of scale and scope as well as goals of reusability and differentiation can be achieved simultaneously, with component/process commonality and modularity. These design principles may help reduce internal process variety, which improves flexibility, responsiveness and quality as well as reducing costs (Sievänen 2008) and from this chapter's point of view reducing internal complexity. Blecker and Abdelkafi (2006) recognize seven logical sequences for the implementation of complexity variety management for mass customization as seen in Figure 4.

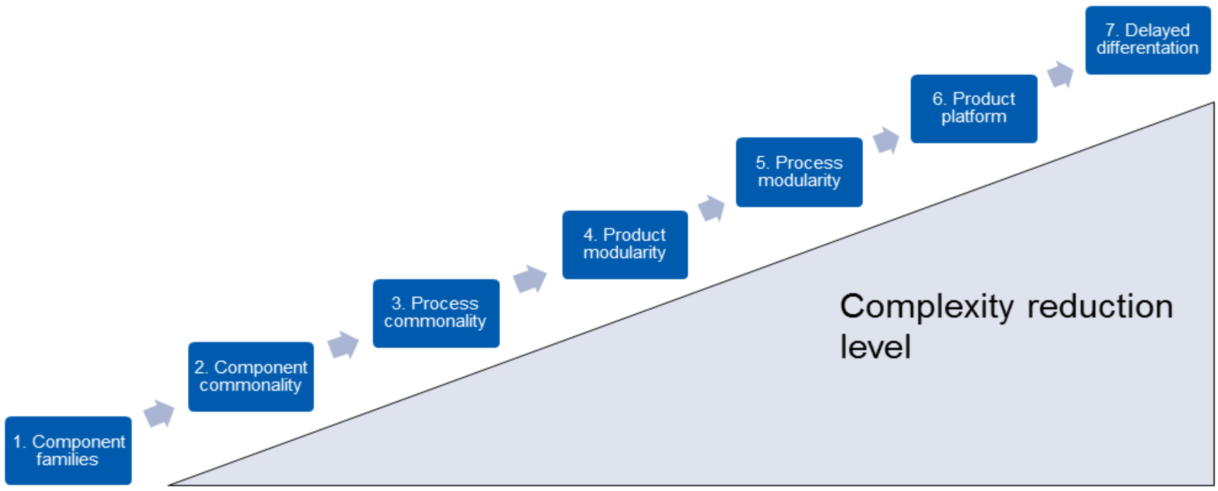

Figure 4: The logical sequence for implementing a complexity-based variety management for mass customization (Blecker and Abdelkafi 2006)

The seventh step is delayed differentiation as discussed; it is a powerful way to reduce complexity. However, in order to implement delayed differentiation previous steps must be achieved. In the case context product platforms and modularity is not achievable, therefore commonality is only relevant. Blecker and Abdelkafi (2006) define component families as a way to bring similarities to a product feature and processes, hence decreases setup times. In the case company, this is achieved with different product families. Between products, component commonality reduces the number of internal parts needed to create large product variety. Component commonality, therefore leads to increased process commonality. Additionally, variety management strategies can be separated into product and process level. In this thesis, we focus on component commonality (Chapter 3.3) which is product level strategy excluding product modularity and platforms. At the process level, the case environment is connected to component families, process commonality and delayed differentiation. (Blecker & Abdelkafi 2006)

In complexity management context, product architecture plays a vital role in manufacturing systems to create variety. Child et al. states (1991) 80% in costs, 50% in quality, the 50 % of time and about 80% business complexity, can be influenced through product and process design, both which are related to product architecture (Child et al. 1991). Product architecture decisions have profound implications for the entire company, ranging from product performance, product change, product variety, component standardization, manufacturability and product development management (Marti 2007). Companies have minimum effort regarding complexity when they are introducing new product, but try to reduce the complexity of products and processes afterwards, which can be challenging (Child et al. 1991). This has been challenge for case company because with a flexible cutting process it has been minor step to accept new product dimensions. In a long term, this has led to situation with highly customized products.

Companies have recognized the problem of having too many products and acted in different ways. Multiple ways vary from lean management to mass customization and a tool like product modularization, variety reduction program, the design for variety or product platforms (Marti 2007). All of these involve configuration product and production processes. Additionally, considering the point of differentiation becomes important question and how far it can be pushed. In the case company context, the logical steps are building process commonality in stage 2. Therefore, enable component commonality in stage 1 that leads to process commonality. After these steps, it is possible to perceive towards delayed differentiation.

Complexity itself is not harmful, but having excessive or not managing it may result in bad performance. Communicating about the excess product complexity can be difficult as presented in the research by Wihinen (2012), where batch-process production managers had difficulties argument for marketing team the effect of introducing new products. The key here was a better costing system, which based on using contribution per hour as a way to measure profitability instead of normal contribution margin. Even the contribution per unit was misleading because in some of product cases in study by Wihinen (2012) found that contribution per unit was merely the same but contribution per hour could be four times bigger with products produced in larger batches. Even though the study did not discuss the complexity, it is still possible to recognize similar problems as facing with finding the balancing between internal and external complexity. Wihinen (2012) focused to the juxtaposition of marketing and production function. The key to finding the balance was a better cost system to communicate between interests and aim towards a common goal for maximizing profitability. In the case company, we discuss how product design decisions effect on the common goal for increase profitability. This can be done without sophisticated costing. However, in order to make informed decision between product qualities would require more “objective” costing system based on contribution per hour.

3. ALLIGNMENT OF PRODUCT AND PROCESS STRATEGIES

The existing theory discovers the trade-off between increasing product variety and production capabilities i.e. flexibility. The case company's production environment is based on batch process production, which makes it highly inflexible. Therefore, we have emphasized articles that have studied the problem inside process industries, where increased amount of product variations becomes a problem because of the incapability to change from product to another in an efficient way.

In this chapter, we discuss how product strategy and process strategies should be aligned. First, we open up process choices that managers must make in order to match their current product choices. Product-process-Matrix conceptualizes different production methods in contrast ability to produce different variety of products and vice versa.

Further, we consider what the effect is when product and process strategies are misaligned. What are the reasons that have brought companies to this situation? Most of all, what can companies do in order to correct this imbalance. This is discussed more deeply into these questions and brings down strategic managerial problems into real world context that are more suitable for the case company.

3.1 Product-Process-Matrix

The process evolution typically begins with a "fluid" process—one that is highly flexible, but not very cost efficient and proceeds toward increasing standardization, mechanization, and automation. This evolution culminates in a "systemic process" that is very efficient but much more capital intensive, interrelated and hence less flexible than the original fluid process (Hayes, R.H & Wheelwright, S.C 1979). The paper industry has made this evolution and become capital intensive business that is based on continues flow batch-process. This makes it hard to other competitors to enter this business. To understand this progress and how processes and products are linked together, this brings us to the fundamental production management concept, namely the Product-Process-Matrix (Leschke 1995). The framework introduced by Robert Hayes and Steven Wheelwright (1979) and illustrated in Figure 5.

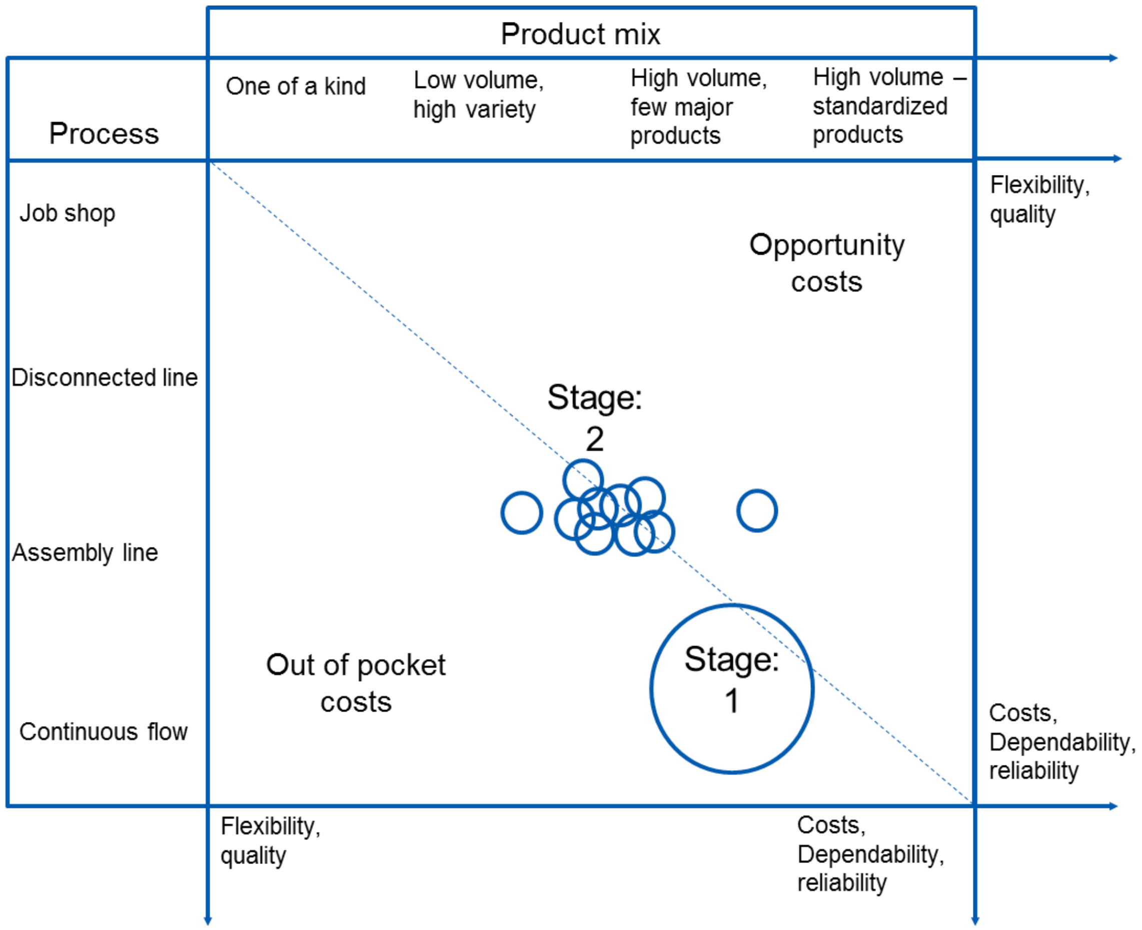

Figure 5: Product-Process-Matrix. Based on Leschke (1995) and Hayes & Wheelwright (1979)

Hayes and Wheelwright (1979) argue that given product customization and other competitive priorities should agree with the process choice. As seen in the Figure 5 companies should position themselves in both product and process dimensions. Product dimension starts from low volume and one of a kind product and moves incrementally to high volume and highly standardized product. Process dimension moves from a job shop and reaches continues flow. A company (or a business unit within a diversified company) can be characterized as occupying a particular region in the matrix, determined by the stage of the product mix and the choice of production process for that product mix (Hayes, R.H & Wheelwright, S.C 1979). Stage 1 and stage 2 positions roughly in the Product-Process-Matrix to illustrate how these different stages are positioned. The case company is in the stage 1, which is misaligned from the diagonal to represents, the problem of having too many products in contrast to the production process choice. Stage 2 consist of dozens different units and are scattered upper from the stage 1. These units are pretty close to each other; however, there are a few exceptional units recognized to have out of pocket costs or opportunity costs regarding the position in the Product-Process-Matrix. The Figure 5 is the starting point and conceptualizes what is the situation now in different stages and illustrate journey towards better process-product balance.

Safizadeh et al. (1996) made empirical study to investigate whether firms actually link their process choice to product customization and other competitive priorities as hypothesized, and whether compatible decision patterns lead to better performance. Analysis of data collected from managers at

144 U.S. manufacturing plants shows a strong correlation between process choice, product customization, and competitive priorities. Our study focuses on process industry, where Taylor (1980) conducted similar survey for 150 firms and they agreed about the implications of the matrix. The Product-Process-Matrix describes a relationship between the varieties of products that possible and the range of process patterns that are possible (Leschke 1995) and similarly vice versa.

Companies are facing new environment with increased competition, shorter product life cycles, rapidly changing environment and increased product variety. Companies must recognize the efficient operating point for manufacturing processes in new market conditions, moreover diagnose the mismatch between market's need and firm capability to meet those need. (Leschke 1995) Manufacturing performance suffers when there is mismatch between product plans and process choices (Safizadeh et al. 1996a).

Some continuous flow shops use component commonality and flexible automation to achieve more customization than would otherwise be expected. Without these initiatives, customization in continuous flow shops results in weak performance. (Safizadeh et al. 1996)

Previous part concerned more about different manufacturing methods, however when we are discussing about more detailed level, how we can adjust manufacturing more favorable for current products, we are talking about manufacturing **flexibility**. It tells about capability to produce broad ranges of products or variants with presumed low changeovers (Berry & Cooper 1999). Additionally, flexibility is ability to produce wide ranges of continually changing products with minimal the degradation of operation performance (Anderson 1995). In highly flexible production, process segments are loosely linked and material flow can be customized. Whereas inflexible production is rigid, standardized and process segments are tightly linked.(Leschke 1995) Gerwin (1993) points out the need to show manufacturing managers how to evaluate and change the flexibility of their operations and further develop the operational measures of manufacturing flexibility. However, Grossmann, Halemane and Swaney (1983) defined flexibility in chemical engineering context as the ability of manufacturing system to satisfy specifications and constraints despite variations that may happen in operation. What is common among all flexibility is that it is capable of managing risks associated with different types of uncertainty. These uncertainties are the results of variations in the temperature, pressure or flow rate of stream, state of equipment or fluctuations of price and demand of products (Mansoornejad et al. 2010) . These factors are closely related to the case company and they describe well about different forms of variations the process has to deal with. In Table 1 are different types of manufacturing flexibility in the context of chemical process. Next, we will open up these flexibility concepts that can be divided into a recipe, process, product and volume (Mansoornejad et al. 2010).

Table 1: Types of flexibility and their definition; based on Mansoornejad et al. (2010))

Flexibility	*Definition*
Recipe	The ability to adjust recipes in order to control input/output
Process	The ability to run process in different rages of conditions and hand disturbances
Product	The ability to make changeovers between batches economically
Volume	The ability to run production in different production volumes

Flexibility of recipes is a set of adaptable recipe items that can control the process output and can be modified to comfort any deviation from the nominal condition (Mansoornejad et al. 2010). Recipes are mostly used in chemical industry context to describe how products are to be produced using which materials. In the case company, recipes are better-known concept than bill of materials. The concept of flexible recipe is known in the case company and also introduced by Verwate-Lukcszo (1998) as a way to systematically adjusting the control recipes during the execution of the production tasks with the aim of enabling the process to perform under different operating conditions (Verwater-Lukszo 1998). In the case company, there is also an effective way to control product quality within standardized quality deviations. Recipes in the case company are an important factor because of the raw material is very inconsistent and therefore every batch is unique and the recipe must be adjusted for every batch to keep the end product within quality standards.

Process flexibility is a well-known concept in a chemical engineering process and it is better known as "process operability" (Mansoornejad et al. 2010). Wolff, Perkins & Skogetad (1994) categorized operability into: the stability of the plant, optimality, selection of measurements and manipulated variables, flexibility and controllability. Controllability tells about the ability of plant to move efficiently from one operating point to another as well as dealing efficiently with disturbance (Mansoornejad et al. 2010). In the case company environment, this mean controllability to change from quality to another and staying in the quality standards because there is can be variations in the raw material. Disturbance can be occurred when major customer needs a certain quality and production must make a major deviation from production planning i.e. "natural sequence". However, designing the optimal level of flexibility to face problems is a trade-off situation between the costs and flexibility of a plant. The objective is to minimize capital and operating costs and on the other side to maximize flexibility (Mansoornejad et al. 2010).

Product and volume flexibility are more deeply discussed later in this thesis from theory point of view and then deepen the understanding by applying theory in the case environment. Shortly, product flexibility is defined as capability of producing number of product lines and numerous variations within in the line (Gerwin 1993). Product flexibility is well-studied concept in pulp and paper industry, which has tried to find new products for markets by selling side products alongside the primary process. As a result, this has led to optimization problem inside product portfolio in order to maximize profitability (Ng 2004; Sammons Jr. et al. 2008; Laflamme-Mayer 2008; Mansoornejad et al. 2010; Dansereau et al. 2014). Finally, it is worth noting that manufacturing flexibility contributes to the flexibility of the whole supply chain. The flexibility of a supply chain involves the flexibility of all nodes: suppliers, manufacturers, warehousing and transportation centers. (Mansoornejad et al. 2010). These are considered later, when we are investigating complexity cost in the value chain.

Product-Process-Matrix conceptualizes a managerial challenge from the manufacturing and marketing point of view. Along the process dimension, efficient scheduling and material handling are critical for operating an efficient project or job shop. For Processes with rigid or continues flow, materials handling is less challenging and managing the investment and process technology becomes more important. In between, manufacturing management must effectively manage scheduling, material flow and process technology, but ensuring sufficient flexibility to meet the market's requirement is the most critical. (Leschke 1995) As production process changes, so does the managerial challenge and targets.

As moving alongside the diagonal different competitive mode can be discovered. In the upper half of the diagonal custom design, quality control and high margins are dominant factors to outlast. As we move to the lower half of the diagonal, we come to the case context seen in Figure 5. Hayes and Wheelwright (1979) emphasized the role of standardized design, volume manufacturing, finished good inventory, distribution and backup suppliers become important in the diagonal region, where stage 2 positions. Commodity products produced continuous flow as the stage 1 dominant competitive modes are vertical integration, long production runs, the economies of scale, standardized material, specialized equipment and processes. (Hayes, R.H & Wheelwright, S.C 1979) All of these can be recognized in the case company but there is room to improve the economies of scale and longer runs. Potential to improve these will be discussed throughout the text.

Hayes R.H and Wheelwright S.C (1979) had conceptualized this managerial problem as seen previously in Figure 1. Next, we discuss more closely the issues of Product-Process-Matrix brings out and what leads companies to move off the diagonal.

Every now and then management gets preoccupied with marketing and loses sights about the manufacturing capabilities. Hence, thinking strategy only through product and marketing dimensions, therefore focusing on a narrow column of the Product-Process-Matrix. Hayes R.H and Wheelwright S.C (1979) have explored following three issues:

- The concept of distinctive competence,
- the management implications of selecting particular product process combination, considering the competition, and
- the organizing of different operating unit so that they can specialize in separate the portions of total manufacturing task, while still maintaining overall coordination.

Distinctive competence leads companies to think about themselves partially good relative to their competitors, in order to guard themselves from outside attacks or internal aimlessness and to exploit a certain market. However, management gets preoccupied with marketing and loses sights about the manufacturing capabilities. Hence, thinking strategy only through product and marketing dimensions, therefore focusing on a narrow column in the Product-Process-Matrix. The advantage of the twodimensional point of view is that it permits a company to be more precise what its competence really is and concentrates its attention on a limited set of process decisions and alternatives, as well as restricted set of marketing alternatives. (Hayes, R.H & Wheelwright, S.C 1979) When companies try to differentiate, it can lead them to forget the other dimension of the Product-Process-Matrix.

Effect of position reflects when company undertakes a different combination of products and processes, and therefore management problems change as discussed previously. For example, when company moves from jumbled flow operation to more standardized one, the competitive emphasis moves from flexibility and quality to reliability, predictability and cost. For given structure that is based on quality or product development would choose much more flexible production operations than a competitor who has the same product structure but follows cost-minimizing structure. (Hayes, R.H & Wheelwright, S.C 1979). Alternatively, as in the case company with certain process structure, the ultimate object is to reinforce the process strategy by adopting the corresponding product structure. Hayes R.H and Wheelwright S.C (1979) describe that companies tend to be relatively aggressive along the dimension (product or process) where they the feel most competent and take the other dimension as given by the industry and environment. This describes well about the situation in the case company. The inner customers that they have to pleased give the product dimension, but their rigid production does not leave many changes to make radical changes to flexibility in order to match broad product mix “given” by the environment. Objective of this study is to challenge the idea of having current amount of product variations and hold a better position in the Product-Process-Matrix.

Organizing operations is a way to fragment the production in different process, in order to have suitable alignment between processes and products. Hayes R.H and Wheelwright S.C (1979) introduce interesting problematic with how to organize spare parts of their primary products. While increasing the volume of the primary products may cause the company move down the diagonal, the follow demand for spare parts may require a combination of product and process structures more toward the upper left corner of the matrix. There are many more items to manufacture in smaller volume and appropriate process tends to be more flexible than their primary product. Possible solution would be to subtract these production processes. Like in the case of Caux et al. (2005), where in a metallurgical plant where process was divided into sub processes; one inflexible metallurgical process and second more flexible cold stage process to match customers demand for different dimensions.

As the competitive emphasis has shifted toward cost, companies moving along the diagonal have tended to evolve from a product-oriented manufacturing organization to a process-oriented one. However, at some point, such companies often discover that their operations have become so complex with increased volume and increased the stages of in-house production that they resist centralized coordination. Management must revert to a more product-oriented organization within a division structure.

3.2 The impact of product variety on production performance

A number of companies that historically have organized themselves around products or markets have found that, as their products matured and as they have moved to become more vertically integrated, a conflict has arisen between their original product-organized manufacturing facilities and the needs of their process-oriented internal supply chain (Hayes, R.H & Wheelwright, S.C 1979). This is the situation with the case company's value chain. End product manufacturing facilities need a broad range of different products provided by process-oriented Case Company. These two faces in the value chain have different positions in Product-Process-Matrix as seen in Figure 1. The conflict between these different phases and fragmented bill of material in product-organized production facilities has led to situation in the Case Company that product variety has major impact on the process-oriented production. Next, we will discuss more about the impact of product variety on production performance with emphasis on process industries and with a few case examples.

According to Caux et al. (2005) process industries add value to materials by mixing, separating, forming or by chemical reaction and a process may be either continuous or batch. Batch processes are usual in metallurgical and food processing industries as well as in the Case Company. The main process is usually very inflexible like aluminum conversion and the more flexible part can be used to get product more customer specific dimensions or packaging etc. (Caux et al. 2006b). In batch process industries, the large number of finished products has led these industries to adapt a make-to-order strategy, i.e. customer orders transferred to the first stage of the process. The advantage of this strategy is to manufacture products with customer demands and without any stock of finished products. The drawback is large lead-time generated by this strategy since customers must wait for the entire process to be completed and wait for a slot in "natural production sequence". In addition, this may generate wastes or stocks because demands do not systematically match batch sizes. (Caux et al. 2006b)

For Many process industries, one objective is to be more responsive and therefore to minimize the lead-time, but the adaption of a make-to stock strategy is not possible because of the large number of finished products and their customization. This strategy would involve unreasonably high inventory costs unless the number of products is reduced. (Caux et al. 2006b)

Product variety is often assumed to yield competitive advantage by offering products tailored for specific market segments. This strategy should result in more total sales volume or higher prices and presumed profit gained by meeting demands that are more specialized. However, achieving competitive advantage through increased product variety is heavily dependent on the proper alignment of the marketing and manufacturing strategies. (Berry & Cooper 1999) Increasing product variety is a strategy among marketing managers to satisfy different market segments and customer needs. Additionally, momentum is coming from mass merchandisers expecting deliveries in small quantities directly to store with high service levels, specialized packaging and unique promotion combination (McDermott & O'Connor 1995). These should lead to better prices and higher profits by matching specialized demand. However, such product variation decision can have adverse implications for a manufacturing and distribution systems that are not always captured in cost, margin and non-financial performance estimates for such strategies (Berry & Cooper 1999).

To get deeper understanding, next will enlighten the effect of increasing product variations to production, with a few examples discovered from the literature. The point of these case studies in literature has been to examine the cost effect of adding product variety in manufacturing so that companies can make more informed strategic decisions concerning product varieties (Berry & Cooper 1999). For example, Toyota's Shatai subsidiary reports that efforts to increase product variety in its plant have cut into productivity, requiring much more time to clean up paint lines and change tools (Berry & Cooper 1999).

Case study with Plastech presented by Leschke (1992) is a great example that describes the unfavorable impact on business performance that results from using an inappropriate process of high-volume batch to support a market characterized by a low-volume high variety products without price enhancements (Berry & Cooper 1999). Companies must diagnose the mismatch between markets needs and firms' capabilities and it can be done in the following areas: production inefficiencies, declines in productivity, competitiveness and profitability (Leschke 1995). These measures are fundamental to every business and the challenge is to detect that reason behind the decline and the reason might be the miss alignment of product and process strategies. Discovering and understanding the effect of product variety is hard to detect because of its invisible nature and slow evolution of product variety ***that can be considered as given***. The case study revealed by Leschke (1992) demonstrates a rapid change in a customer base and consequently in production. Therefore, it was more visible to discover the misalignment. In shifting to a marketing strategy that targets low-volume/ high variety segments, it is often incorrectly assumed that the process choice for a low-volumes product is the same as that for high volume products (Berry & Cooper 1999). Case study by Leschke (1992) illustrates this point, additionally it is close to the case company's batch process production which makes it even more interesting.

The company in case study by Leschke (1992) is blending plastic polymers with 320 setups in a year and the company experienced rapid change by losing the two biggest customers leading to lose half of production volume in six months. It recovered from the meltdown and increased revenues 20% by increasing products, broadening product line and getting additional work from existing customers. In addition, production rates were up. Average throughout put increased 7.4% and average set-up time decreased 5 %. Despite production and marketing made great improvements, profits went dramatically 83 % down. Discovering financial statements through variance analysis, the biggest impact on profitability was direct labor and selling expenses. The reason why labor productive went down was not about that workers were less efficient, rather that management utilized operator's time that reduced labor productivity. Increased customers and total sales led to have more setups as a consequence increased direct labor costs and therefore cost grew faster than sales. (Leschke 1995) Failure to align marketing and manufacturing strategies in terms of product pricing and manufacturing flexibility in product mix can have serious financial consequences (Berry & Cooper 1999). In the next chapter, we discuss more closely how to correct the imbalance between product and process strategies. The analogy by Leschke (1992) was familiar also in paper industry as a person in financial department explained a following case:

"Paper industry faced a huge change in market 15 years backward as demand for paper declined. Sales team was able to sell the mill capacity in order to cope with high fixed costs. However, these factories were struggling with profitability as batches were smaller"

Berry and Cooper (2009) study identifies the cost of increased product variety which results from miss-aligned process choice decisions. Study gets its conceptual framework from early work by Blois (1980), which Berry and Cooper extended by developing a framework in which the alignment of marketing and manufacturing strategies can be viewed when increase product variety is proposed. Two dimensions are critical in the strategic decision of increasing product variety: the characteristics of buyer behavior is measured by in terms of price sensitivity and the current process choice decision in manufacturing, these dimensions are shown in Figure 6 seen below (Berry & Cooper 1999). The framework is a tool for managers to position their company to understand how the strategy based on increasing product variety fits.

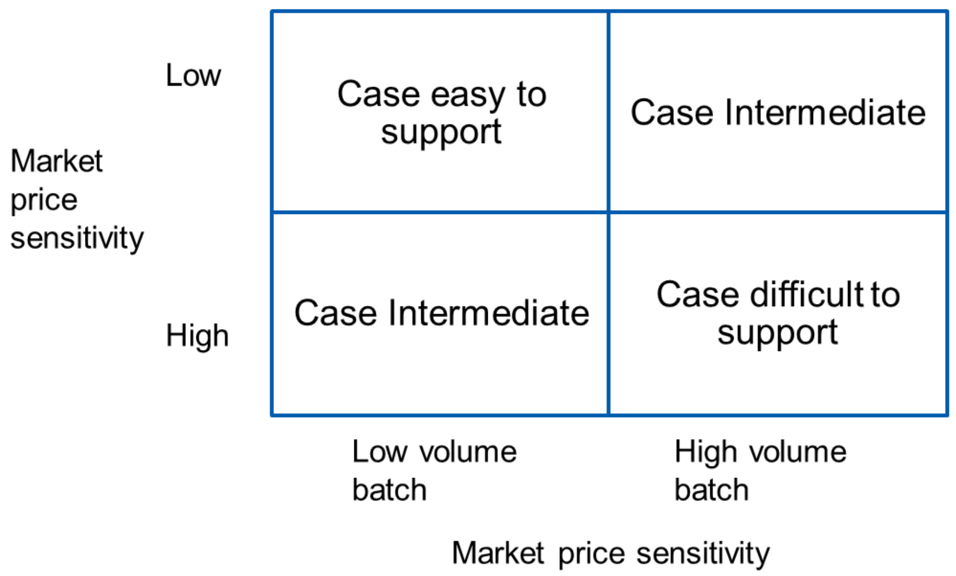

Figure 6: Product variety strategies for low volume products; source Berry and Cooper (1999)

The vertical dimension characterized the degree of price sensitivity in the market segments targeted to increase product variety. The low market price sensitivity represents segments where customers are willing to pay price premium for product variety. This distinction is buyer behavior is important in order to keep the legit profit margins. (Berry & Cooper 1999) Success of increasing product variety depends on how much the company has power in the market (Leschke 1995). In the Case Company's situation this place a role because customers are cost aware, whereas with the inner customer they would have a pricing power to move the cost caused by product variations. This framework brings out the importance of pricing in the case company's context and justifies better to customers that product variations have a cost effect. Overall, Pulp and Paper companies are facing global low-cost competitors with a declining market and over capacity (Dansereau et al. 2014). The vertical dimension characterizes the current and required investment in manufacturing capacity as we have been discovered earlier chapter (Hayes, R.H & Wheelwright, S.C 1979; Berry & Cooper 1999).

3.3 How to correct imbalance in Product-Process-Matrix

Creativity, Challenge and Courage: the Three C's

- *Shoichiro Toyoda, former President, 1980s*

In previous chapters, we have deepened our understanding about product strategies. Particularly, how increased product variety effect on production especially on batch-process context. Additionally, we have discussed the concept of production strategies and what flexibility means. In the case company's production environment it is hard to accomplish more flexibility in the process, therefore better alignment with Product-Process-Matrix means the better control of product strategies consequently product variations. Next, we discuss what companies can do, in order to correct the imbalance of Product-Process-Matrix.

There is increasing evidence that achieving competitive advantage through increased product variety is heavily dependent on ensuring the proper alignment between marketing and manufacturing strategies pursued by company (Leschke 1995; Safizadeh et al. 1996b; Berry & Cooper 1999). Firstly, company needs to understand that there isn't proper alignment between strategies. That requires internal information concerning a firm's process cost, capacity and delivery capabilities. Such information includes customer and market profitability analyses and cost estimates for supplying product in a various volumes (Blois 1980; Berry & Cooper 1999).

After understanding the potential misalignment and trade-off between product variety and process selection, hence understand the position in the Product-Process-Matrix. If a company is on the upper side of the diagonal, that means there is an imbalance between product and process strategies i.e. making highly standardize products in process that is flexible. Therefore, company could improve a manufacturing process in a more efficient direction by increasing flow and therefore lower product costs, consequently increasing capital intensity. Like in the case of Leschke (1995) and in the case company the problem is to have too many products in contrast to production capabilities i.e. the position is misaligned in the Product-Process-Matrix by being below the diagonal. Therefore, one possible solution is *to move right on the product dimension* to decrease the amount of product variety. Leschke (1995) listed the following solutions:

- Working with customers to reduce the variety of products,
- consolidating orders in larger production runs
- Or setting pricing policies to discourage small orders (e.g. quality discounts or charging a standard setup fee).

First and the second options are connected with the case company situation by introduction component commonality as discussed in the next section. Additional pricing options listed above are taken into consideration and implemented in the near future of the company.

Second option would be *to move up on the process dimension*. By continuing to reduce setup times and increase production rates. Simply adding more production capacity will not help because it adds to fixes costs while not making the firm more efficient at its current environment. (Leschke 1995) In our case, the road of moving upwards in the dimension would mean big investment, therefore we don not focus on possibilities given by production flexibility. Making the production more flexible to cope with the amount of product variety is simply challenging in the case company.

In the case presented by Leschke (2005) there was no particular reason in production or marketing units which led to sinking profitability. Both units did great results, despite the success of these two units the company profitability didn't improve. The reason for problems is managerial, because they are responsible for aligning production and product strategies. (Leschke 1995) Not aligning these two dimensions has led to the situation of partial optimization.

Other possibility to manage company's positions in the Product-Process-Matrix *is to scatter the production* in different parts in order to be better aligned in the diagonal. When Companies have multiple manufacturing facilities, they can organize operations in the following ways (Stevenson 2009):

- Different **product lines** to different plants,
- different **market areas** to different plants
- different **processes** to different plants

As Robert Hayes and Steven Wheelwright (1979) states Companies that are large enough can effectively produce multiple products in multiple markets like the case company. However, for such an operation to be successful, a company must separate and organize its manufacturing facilities for the best meet the needs of each product and then develop sales volumes that are large enough to make those manufacturing units competitive. Like Case company's facilities they are positioned in different positions in the matrix. Most companies in the packaging industry (e.g. the case company), they provide the examples of such product- and market focused manufacturing organizations. Regional plants that serve geographical market areas are setup to reduce transportation costs and provide better response to market requirements. (Hayes, R.H & Wheelwright, S.C 1979)

Recent research on mass customization in service industries notes the frequent lack of careful analysis of the investment required to support increased product variety strategies resulting in excess costs (Berry & Cooper 1999). The next chapter we will discuss more about these excess costs by increased product variety in form of complexity costs. Examples that illustrate "flexibility is free" arguments in the literature do not always apply, especially under high volume batch process settings (Berry & Cooper 1999). Product-Process-Matrix is the ultimate operation management concept (Leschke 1995). The results show that gaining competitive advantage through increased product variety requires a clear understanding about the process choice required to support the contemplated range of product volumes, and the cost and profitability trade-offs involved (Berry & Cooper 1999).

4. MANAGING COMPLEXITY COSTS

Next we will discuss about the monetary value of complexity, which is complexity cost. Relevant definition from this thesis point of view is provided by Thonemann and Brandeau (2000): "The cost of indirect functions at a company and its suppliers that are caused by component variety that affect almost every aspect of a company's cost, including accounting, logistics, material handling, production planning, purchasing, documentation, and research & development". (Thonemann & Brandeau 2000). Product variant-driven complexity is dependent on the number of and combinations of variants. Hence if there is no variants (e.g. Ford Model T) there is no complexity costs. Complexity cost does not refer on non-variant driven complexity, for example the process itself can be complex (e.g. chemical) but it does not cause complexity costs. (Schaffer & Schleich 2008). There is few studies that have calculated the amount of complexity costs related to overall costs. Child et al. (1991) reported that complexity costs range from 10-40 % of total costs. In electrical appliances one study concluded that 20% of total costs are related to product variety. Another study concluded that in German car industry the complexity costs are between 20-40% of total costs as seen in the Figure 7. (Marti 2007) In the next chapter we go more deeply to sources of complexity costs along different functions.

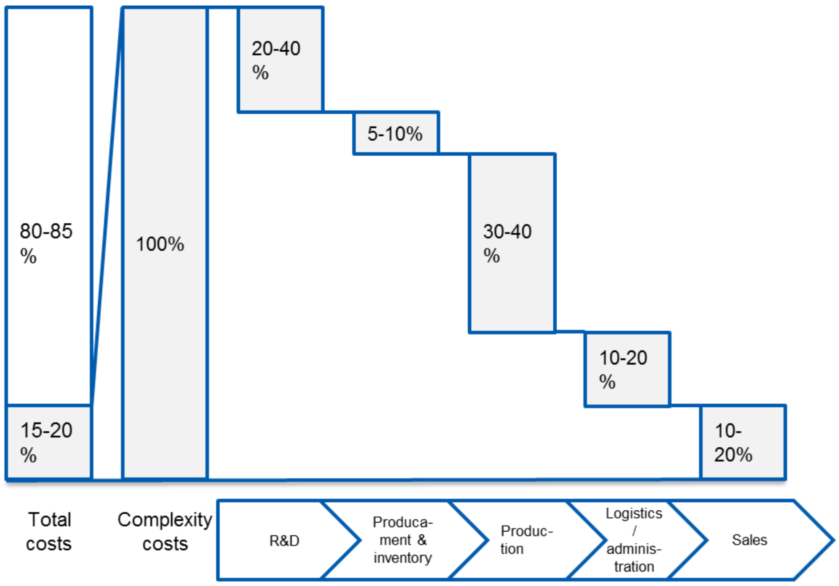

Figure 7: Complexity costs structure of an automobile manufacturer (Marti 2008)

A survey conducted by Schaffer and Schleich (2008) found that managers consider complexity as major cost driver, yet most managers and engineers do not have resources or expertise to conduct financial analysis to understand better complexity costs.

To understand better the complexity costs as cost driver it is good to visualize the variant three of the product variants. Schaffer and Schleich (2008) uses the word "variant driver" to describe different levels and product hierarchy. In Figure 8 is product three combined from Marti (2007) and Schaffer & Schleich (2008) that is later applied for the case company.

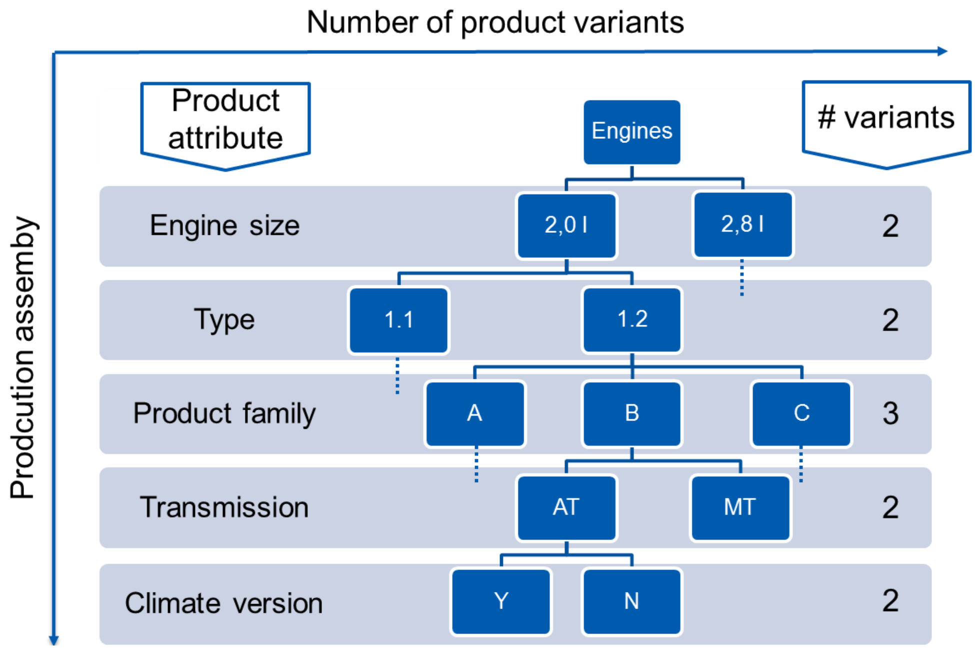

Figure 8: The variant tree example from automotive industry; based on Marti (2007) and Schaffer and Schleich (2008)

The point of variant three is to visualize the variant drivers, amount of variants and how these factors are connected. It is not the amount of variants that has to be considered evaluating complexity, but also the structure and how these different hierarchy levels (i.e. product attribute) contribute as a cost driver. (Schaffer & Schleich 2008) In process industry, the product variant three is pretty straight forward because as different variant drivers are created along the production process.

Next we will discuss sources of complexity costs in different functions of the company. Working in the case company it became pretty clear that product variations had impact in almost every function throughout the value chain. All of these effects were not captured well in literature as a whole, but complexity management answered the challenge to see the effect of product variety in major functions of the company. As Lyly-Yrjänäinen (2008) described that the literature about product variety mainly focuses on stocks and setup times (Leschke 1995; Berry & Cooper 1999; Hillier 2002; Er & MacCarthy 2006). In Table 2 is summarized major sources for complexity found in literature about the complexity cost and effects of increased product variety. I will open this concept function by function.

Table 2: Potential sources of complexity costs; gathered from Marti (2007) Schaffer & Schleich (2008) and Lyly-Yrjänäinen (2008)

R&D	Production	Supply Chain	Administration
• Quality control • Clearing up data • Data maintenance costs • Data Handling costs • Controlling costs • Quality problems and special inspections(Fisher 1995)	• Additional work plans • Production planning • More set-ups, changeover and tooling • Smaller batches • More chance for error • Sequencing Costs • Downtime Costs • Line Balancing/waiting time costs • Set-up costs • rework/Scrap costs • Diseconomies of scale	• Larger finished goods inventory • Walking time/transportation costs • Storing costs • Costs of stock out • Part selection and walking time • Increasing lead-time • Safety stocks • Increased throughout put time	• Bigger chance for error • More complex pricing • Production planning costs • Decreasing Backlog • Opportunity cost of customization • New activities needed

In production function Schaffer and Schleich (2008) have listed several activities as a source of complexity cost. *Sequencing costs* is problematic when there are different product mixed in the assembly line, thus making it hard to allocate costs on products. *Downtime costs* occurs when increased variants and changes between them lead to higher probability for mistakes which may cause a process shutdown. *Line balance/waiting time* becomes more difficult and less optimal as sequencing algorithms cannot eliminate all balancing losses due the increased variety. *Set-up costs* occur when changes are made to different product specifications and will cause set-up costs (e.g. waste or downtime). *Scrap/rework costs* are increased as risk for failure increases through increased product variety and may lead to a rework. (Schaffer & Schleich 2008) These cost effects are connected to diseconomies scales discovered as variety increases (Lyly-Yrjänäinen 2008).

From a supply chain point of view, the major drivers for complexity costs are dis-economies of scale, increased inventory levels, longer lead time and backorder levels (Schaffer & Schleich 2008). Thonemann and Bradley (2002) demonstrated what the effect of product variety in matter of lead time is. With real product data, they demonstrated that increasing product variety has increasing concave effect on the lead time, which resulted to hold more inventory. Schaffer and Schleich (2008) have listed more closely the effects also from the supply chain point of view. *Walking time/transportation costs* increase complexity costs since increasing the number of variants lead to an increased requirement for transportation and picking up a particular item. *Storing costs* rise as mentioned previously, while more parts with lower volume increase inventory levels, because the coefficient of demand variation increase requiring bigger safety stocks. *Cost of stock out* increases as safety stocks do not held while there are lower volumes per product variety to level out demand variation. *Part selection and walking time costs* increases while it takes more time to pick right product variety and consequently increases the risk of taking the wrong product. (Schaffer & Schleich 2008) Thonemann and Bradley (2002) demonstrated that the effect of product variety on lead time can lead to poor decision and companies might offer product variety that is wider than optimal (Thonemann & Bradley 2002). In the case company environment, the lead time has a big role because it is related to the service level, the natural sequence of production and to capital flow.

Table 3: Effect of parameter value changes on supply chain performance; source Thonemann and Bradley (2002)

Parameters	**Cost**	**Expected lead time**
Product variety	Concave increasing	Concave increasing
Setup time	Concave increasing	Linear increasing
Number of retailer	Concave increasing	Not affected
Demand rate	Increasing	Convex increasing

Thonemann and Bradley (2002) have concluded results how different parameters effect on supply chain performance in form of lead-time and costs as seen in Table 3. Literature discusses also how increasing product variety effect on managing supply chain from the information point of view. Increasing complexity is associated with costlier IT-systems (Marti 2007). In master data, all the variants must be created and maintained, additionally this data must be forwarded, checked, processed in the relevant level of the supply chain. (Schaffer & Schleich 2008) After all, implementing information technology should accelerate and smooth the physical flow of goods through supply chain, instead of using information technology to expand the flow of information (Cachon & Fisher 2000)

The increased number of variants require more controlling measures to keep all implemented processes. These practices can lead to situation where it is difficult to calculate production costs that is related to reality. (Schaffer & Schleich 2008) Therefore, accounting systems tend to assign too low fraction of overhead burden rates to low-sales variants, while standard variants with high volumes are burdened with too high fraction (Marti 2007). Additionally, manufacturing has to handle frequently changing sales forecasts as accuracy drops with more product variants. Low reliability with forecasts leads lower delivery reliability and climbing manufacturing costs (e.g. production planning, set-up costs). (Child et al. 1991) Changes in production planning in the case company can lead set-up costs and also effect negatively on other customers' deliveries.

We have discussed sources of complexity cost throughout the value chain and next open up how to eliminate them. Complexity costs are not easily reversed, thus when company tries to reduce product variety, it does not automatically eliminate related complexity costs as the majority of these costs are fixed costs (Marti 2007). To illustrate this effect Marti (2008) represented phenomena called "cost remanence", which can be seen in Figure 9.

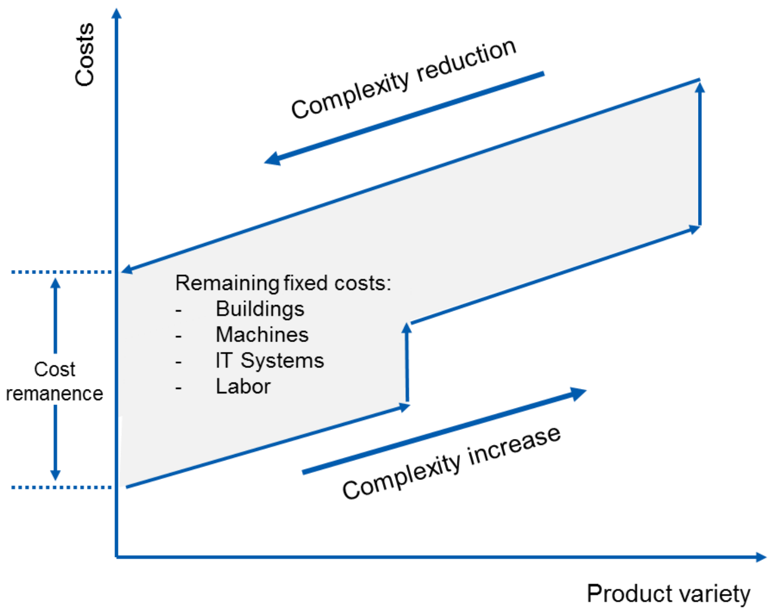

Figure 9: Reversibility of complexity cost (Marti 2007)

The costs caused by increased complexity (e.g. more flexible machines) are mainly fixed costs and therefore the elimination of complexity costs are a long-term task (Marti 2007).

Suzue & Kohdate (1990) presented a concept namely "variety reduction program" to decrease complexity costs by reducing the number and variety of parts and processes (Marti 2007) s.86. The philosophy is based on reducing parts within product variation, additionally simplifying and standardizing parts. As a result, Sony managed to reduce number of parts by 60 % in Walkman. Cost are divided into three categories: (Marti 2007)

- *Variety costs* are caused by the absolute variety of different parts and processes.
- *Function costs* are based on factors like product specifications and designed functions, i.e. how well customer requirements are translated in product structure.
- *Control costs* are due to activities that support and control the existing variety.

Cutting variety, function and control costs are performed in the following that are relevant for the thesis:

- *Fixed vs variable* technique differentiates between stands parts and variable parts that are effected by market needs
- *Multi functionality and integration technique* lowers the number of parts and process by integrating functions into smaller number parts. In next chapter we deepen to this technique understood as component commonality

- *Range technique* split product attributes (e.g. dimensions) into distinct ranges
- *Trend technique* organize product attributes values and their distribution in different dimensions to eliminate unnecessary product variants

In next chapter, we will discuss more closely the cost effect of component commonality as it is most relevant way to reduce costs in the case environment.

4.1 The cost effect of component commonality

Next we will go more deeply to the cost effect of component commonality that is applied in the case company environment later in the results section. If we want to discuss in the case company context about how to reduce internal complexity by decreasing product variety, we end up discussing component standardization or component commonality as used in this text and broadly in literature. It is an approach in manufacturing where two or more different components are replaced by a common one that can perform functions of those it replaced (Caux et al. 2006b). Previously, we have discussed how product varieties effect on production and through the value chain. Next, we will reverse the thinking and use the same analogy as Lyly-Yrjänäinen (2008) where increasing product variety should have the opposite cost effect as component commonality.

Commonality can be understood as how common certain things are and to go more deeply Lyly-Yrjänäinen (2008) introduces four questions to understand the different perspectives of commonality listed in Figure 10. In the case company context it is relevant to add question: “commonality, for whom”. In the long value chain, the commonality can be observed from different perspectives. What does the commonality mean for the stage 1 mill, stage 2 factories and to the entire company?

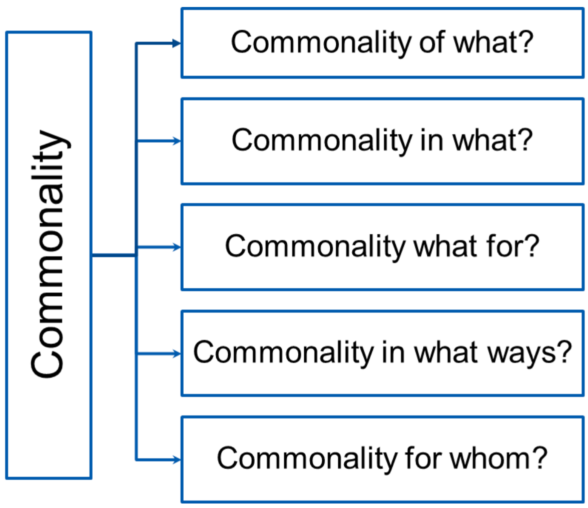

Figure 10: Perspectives of commonality; derived from Lyly-Yrjänäinen (2008)

Components are seen in the case context as the smallest level in product hierarchy that has an ID number (Lyly-Yrjänäinen 2008). The idea of component commonality is to use the same component across products (Labro 2004).

Component commonality is a way to offer certain variety of product with lower variety in their production (Lyly-Yrjänäinen 2008). The methodology is pretty much the same when discussing complexity management. The idea is either offer same amount products with lesser components, or increase number of products without the number of components exploding (Lyly-Yrjänäinen 2008) s.30. In the literature exists a lot of models, visualization and indexes trying to capture how many different components are needed regarding to functionality etc. (Lovejoy & Sethuraman 2000; Salvador et al. 2002; Blecker & Abdelkafi 2006; Marti 2007; Schaffer & Schleich 2008; Lindemann et al. 2009; Wan et al. 2012; Weiser et al. 2016b) These models aren't relevant in our case, thus we do not make a leap to these concepts.

4.2 Cost reducing mechanism of component commonality

Component commonality is seen in the literature as cost reducing tool and therefore answering the question: "commonality, what for? Labro (2004) published a review about: "the cost effects of component commonality" and concluded that it is too early to make general statements about the cost effect (Labro 2004) s.358. The focus in component commonality cost reducing literature has been in production, product development, materials management and logistics (Collier 1982; Thonemann & Brandeau 2000; Ma et al. 2002; Salvador et al. 2002; Lyly-Yrjänäinen 2008; Baud-Lavigne et al. 2012).

As we can see the component commonality effect on many functions of the company, which means lot of potential sources for cost effects. Caux (2006), Marti (2008) and most of all Lyly-Yrjänäinen (2008) have listed in more detail level different cost reducing mechanism behind component commonality listed in different function by function below. Lyly-Yrjänäinen (2008) has converted potential cost effects of customization and increasing variety into the context of component commonality, while these can be seen as opposite mechanisms (Lyly-Yrjänäinen 2008). In this way we get broader picture about different mechanism behind component commonality and as results we will conclude the most relevant cost effects in the case company.

In product development, can be saved resources and work, because there is less component to be designed because there is component commonality among products. This mean also faster time to market time with new products and simplifying engineering design process. Component commonality means also less products to be tested and demand for less support needed for manufacturing process. Below we have listed these cost reducing mechanism of commonality.

- Reducing the development and research cost (Caux et al. 2006b),
- Fewer component to be tested,
- Less support needed for manufacturing process. (Lyly-Yrjänäinen 2008)

Purchasing and material handling are rising topics in cost effect of component commonality. Same themes raised also in the case company. Having less components and variants to be handled affect hugely on administrative work and also in actual operations. In the case company the component commonality was contacted with driver use that effected positively on sheer amount of products to be handled. Case company is also used to talk about tons, which can be misleading as the main driver for cost is the packing unit and not tons. To summarize less complexity means easier handling and less supporting task. Below is listed potential cost effects of component commonality found in literature.

- Reducing the administrative cost because there are fewer components to manage. (Caux 2006, Lyly-Yrjänäinen 2008)
- Reducing the safety stock cost by using the uncertainties in the demands for finished products to achieve the same service level but at lower inventory levels. (Caux 2006)
- Reduction in the number of unsellable products (Perera et al. 1999)
- Economies of scale (Kim and Chhajed 2000; Kim and Chhajed 2001)
- Savings on fixed costs of distribution (Ramdas et al. 2003)
- A learning curve for repairing (Perera et al. 1999)
- Reduced training costs with decreasing complexity (Perera et al. 1999)
- Savings on the fixed costs of after sales (Ramdas et al. 2003)
- Less component information to be handled (Lyly-Yrjänäinen 2008)
- More accurate demand forecasting (Lyly-Yrjänäinen 2008)

Production is another important topic that is tackled in the literature and probably the main driver to increase component commonality. From case company perspective the production perspective is the most interesting part. Component commonality has positive effect as discussed in previous sector about the importance of to match production capabilities with product strategies. Literature has found following cost reducing mechanism of component commonality on production.

- Reducing the manufacturing costs through **economies of scale** (Caux 2006, (Rutenberg 1969; Ulrich 1995; Muffato 1996; Fu and Fong 1998; Robertson and Ulrich 1998; Fisher et al. 1999; Kim and Chhajed 2000; Desai et al. 2001; Kim and Chhajed 2001; Krishnan and Gupta 2001; Mirchandani and Mishra 2002; Thyssen et al. 2006)
- **Improved** Manufacturing Requirement Planning **(MRP) Systems** (Vakharia et al. 1996)
- **Quality improvements** and **facilitation of quality control** (Ulrich 1995; Eynan and Rosenblatt 1996; Krishnan and Gupta 2001; Nobelius and Sundgren 2002; Thyssen et al. 2006)
- **Improvements in productivity** (Eynan and Rosenblatt 1996; Nobelius and Sundgren 2002; Zhou and Gruppström 2004
- **Improved flexibility** (Krishnan and Gupta 2001; Zhou and Gruppström 2004)
- **Reduction in setup and retooling times** (Dogramaci 1979; Vakharia et al. 1996; Perera et al. 1999; Thonemann and Brandeau 2000; Mirchandani and Mishra 2002; Nobelius and Sundgren 2002; Zhou and Gruppström 2004; Thyssen et al. 2006)
- **Lower required investment in tools and equipment** (Robertson and Ulrich 1998; Fisher et al. 1999; Perera et al. 1999; Kim and Chhajed 2001; Ramdas et al. 2003)
- **Learning curve effects** (Ulrich 1995; Eynan and Rosenblatt 1997; Perera et
- al. 1999; Thyssen et al. 2006)

- **Fewer and shorter interruptions** (Perera et al. 1999)
- **Opportunities for increasing automation** (Perera et al. 1999)
- **Simplification of production control** (Kim and Chhajed 2001)
- **Improved resource utilization** (Bagchi and Gutierrez 1992)
- **Potential for automatization** (Lyly-Yrjänäinen 2008)

Component commonality effects positively on sales as the sales processes becomes easier with less complexity providing also better information with better commonality. Additionally, it effects on sales arguments as commonality has positive effect on deliveries, quality and responsiveness. However, the effect of component commonality effect on sales has not been considered in the research. Literature as found following effect of component commonality on sales.

- **Reduce delivery times**, as it also shortens the time needed for **product design** (Ulrich 1995; Fu and Fong 1998; Hillier 2000; Kota et al. 2000; Ma et al. 2002; Fong et al. 2004).
- Possibility for **improved service when market ne**eds can be met more closely (Robertson and Ulrich 1998
- Sales and quotation processes become faster (Lyly-Yrjänäinen 2008).

There is negative effects, when introducing component commonality. From the customer perspective there is a risk that product feel similar, which can effect on sales (Thyssen et al. 2006). To control this Robertson and Ulrich (1998) introduced the difference between internal (not visible) and external (visible) commonality, which has similarities with concepts of complexity management (Ulrich 1995; Thyssen et al. 2006). Point of internal component commonality is that it does not effect on customer value, i.e. non value adding which is close to lean thinking (Liker 2004). Additionally, component commonality can lock firms to certain component, thus making it hard to confront the internal force to change the component for a better technology (Ulrich 1995).

Table 4: Effect of component commonality on cost rate and driver in different hierarchy levels; based on Labro (2004) and Lyly-Yrjänäinen (2008).

Commonality Increase	Cost rate (e.g. €/units	Driver use
Supplier level	**Increase:** Closer relationship with supplier needed (Salvador et. Al. 2002)	**Decrease:** (Gupta and Krishnan 1999)
Component level # of components	**Increase:** Development cost are higher for more complex parts	
Order Level # of orders	**Constant**	**Decrease:** (Hiller 2002)
Batch level # of batches	**Increase:** More handling required (Thonemann and Brandeau 2000). Increase shop floor system disruptions (Vakharia et. al. 1996) **Decrease:** Scheduling easier (Benton and Krajewski 1990) Less set-ups (Collier 1981) less blockage (Talon 1989) Lower labor cost rate as fewer multiskilled laborers required, possibilities for automation (Perera et. al. 1999)	**Decrease:** (Thonemann and Brandeau 2000)
Unit level		
1. Price	**Increase:** Excess capability (Gupta and Krishnan 1999) **Decrease:** Higher quantity discounts and possibility competitions between suppliers (Fisher et. al. 1999, Ulrich 1995)	**Constant or increase**
2. Inventory Holding	**Increase:** Higher obsolescence costs due to higher probability of engineering changes(Ho and Li 1997) **Decrease:** Lower obsolescence costs due to increased interchangeability between products	**Decrease:** Collier 1982, Baker et al. 1986, Thonemann and Brandeau 2000)
3. Backlog	**Constant**	**Decrease:** (Perera et. al. 1999, Lee and Tang 1997)

Labro (2004) distinguished in his review a difference between cost-drive and cost-rate effects. This methodology proved out to be important in the case company to understand better about the cost effect of component commonality. In Table 4 we can see that cost hierarchy of component commonality can be divided in five levels: Supplier, component order, batch and order level. From these levels the cost effects are divided into cost rate (e.g. €/transaction or €/hour) and driver use (Labro 2004). Therefore, it is important to understand the overall impact of component commonality on both driver use and cost rate (Lyly-Yrjänäinen 2008). Lyly-Yrjänäinen (2008) illustrates the challenge to quantify the cost effects. For example decrease in batches is a cost reducing mechanism that mostly effects on diver rate (easy to quantify) and additionally might effect on cost rate due to learning curve effect (hard to quantify). In Table 4 gathered and listed cost effects are basically impossible to quantify with measurable transaction drivers. It requires time to see changes in resource consumption. Therefore, effects of increased component commonality on cost rate are difficult to quantify without ex-post cost and process information. (Lyly-Yrjänäinen 2008).

There has been recognized several cost reducing mechanism of component commonality as in appeared in Table 4. These cost effect are viewed from different dimensions like, in which level this cost effect appears; mill level, batch, order or unit. Cost effect can be observed from cost rate or driver use point of view and their combination. In the case company should be also careful about which drivers to use, because the industry is used to talk about tons, although after cutting process only the packaging unit is the dominant driver. Challenge in result is to recognize the most relevant cost effects and bringing them into right dimensions for better understanding about the cost nature.

4.3 Frameworks for analyzing cost effect of commonality

Next we will discuss more about different methods and frameworks used in the literature to find solution to find potential targets for component commonality. Lyly-Yrjänäinen (2008) found that studies as potential places to implement component commonality rather scarce. However, recent studies in complexity management has discovered few ways to find potential sources to minimize complexity, i.e. find potential components to reduce variety via component commonality. We discussed in previous section about Suzue and Kohdate (1990) methodology about variety reduction program, which handbook for managers to reduce excess variety. Next we will discuss following frameworks.

Cost models in literature and in practice become rather complex and example of this is activity based costing (ABC) analysis performed by Thyssen el al. (2006), where calculation requires detailed information about costs and processes. As companies recognize potential places for component commonality, these cost reduction potential still has to be implemented before these are turned into euros. This can be considered as the most critical managerial challenge. (Lyly-Yrjänäinen 2008). Changes in product platform take long to develop and bind resources (Marti 2007). Product and process solutions that are not visible to customers might be easier to implement, while there is only internal resistance to persuade (Lyly-Yrjänäinen 2008).

Variant mode and effect analysis (VMEA) introduced by Caesar (1991) provides an approach for managers to reduce product variety that is not perceived by customers, hence affected only by internal resistance. VMEA can be seen in Figure 11.

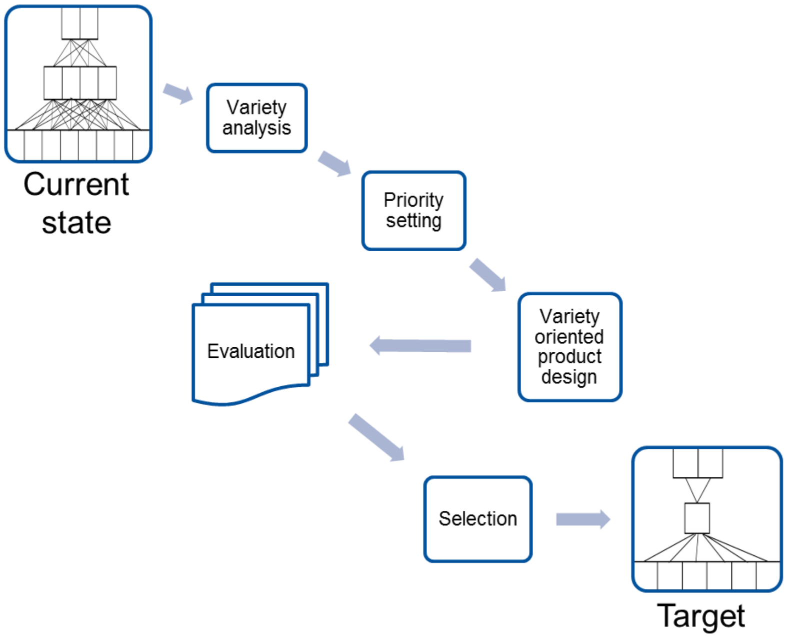

Figure 11: Variant mode and effect analysis; based on Caesar (1991) and Marti (2007)

In the methodology, following steps are variety analysis, priority setting, variety-oriented product design, evaluation and lastly selection. Next these steps will be unfold:

- *Variety analysis*. The product structure and its variety is investigated for example with variant three as in Figure 11 to visualize the current situation over assembly process.
- *Priority setting*. Based on variety analysis the most potential component to reduce variety are indicated
- *Variety-oriented product design*. New design concept are generated that have necessary variety and maximum amount of standardized components.
- *Evaluation*. The design concepts are evaluated with key measures and figures reflecting both design and cost issues. (Marti 2007)

This is rather straight forward iterative approach that does not answer the effects of component commonality, but assists to conceptualize required steps to reduce product variety. VMEA is iterative process that does not capture the overall effect of variety like complexity cost does. Lyly-Yrjänäinen (2008) presented framework for analyzing cost effects of component commonality on cost management context as seen in the Figure 12.

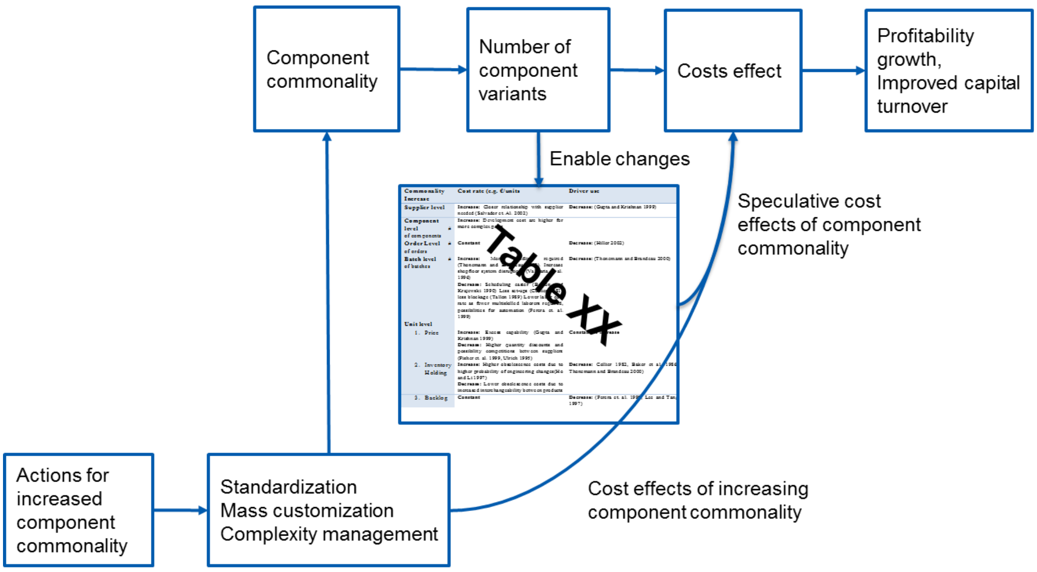

Figure 12: Conceptualizing cost effects of component commonality from Lyly-Yrjänäinen (2008)

Component commonality should decrease costs because there is a smaller number of components, which has direct cost effect. Additionally, there is derived cost effects due cost reducing mechanism of component commonality and with actions increasing component commonality. (Lyly-Yrjänäinen 2008) In the thesis is used the same approach where direct cost effects are estimated and also derived costs as seen in Figure 12. To sum up all these cost effects Thyssen et al. (2006) presented a conceptual framing to understand the trade-off between component commonality and evaluate overall cost impact of commonality combining short and long term effects (Thyssen et al. 2006).

5. RESEARCH METHODOLOGY

Research started as the case company decided to offer chance to make thesis for a one of their mill. There wasn't clear field study, which gave great opportunity go more deeply observe the company reflecting between case company and literature. As a result, there was a lot of interesting findings throughout the process and challenge was to find relevant scope for the master thesis. The business and company was a completely new field, therefore in the beginning the focus was on learning the production, business environment and of course employees. In the beginning, there was a lot of support from the former mill manager, which supported in the research project to learn mechanism running the mill. Interventionist research method helped to get deeper emic-level access to gather valid empirical data regarding how product variety effected to this unique production settings.

Research was conducted to mill that in other city where actual worked happen. Visits to the case mill took place on average 2 days per month. Also visits to the case mill's inner customers helped to understand the stage 2 better. Working in headquarters made it possible to get information about an overall performance of the company. Additionally, there was visiting management from other factories and ERP-workshops, which made it possible to ask people questions and gain a better overall picture of the company. Major support and guidance for the thesis came from the case mill manager and additionally production manager and controller gave support to reflect thoughts. Even though getting a lot of support from others the actual research topic was constructed with constant bouncing between case company and literature.

5.1 Research process

The project started with discussion that thesis is about product management. The message was that there were simply too many products. I was handed out data about last 8-month sales of inner customers, which was very helpful throughout the process. This gives a good picture about products, which the case mill offers. Additionally, it gave a good insight about the products itself. In Figure 13, there is "project journey" to describe the study process in an emic and etic level. Emic describes observes within case environment or system and etic perspective describes more about the outside viewpoints (Suomala et al. 2014). It is essential to understand that project journey describes how the process of the project occurred to the researcher and not the actual thesis as presented. Numerous extra branches are excluded from Figure 13 (e.g. simulations for product portfolio or ABC). Overall, the figure gives good insight into the process and reflects it on emic and etic viewpoints.

Description by Suomala et al. (2014) about the role of interventionist researcher describes well the relationship between the researcher and the case company. Additionally, the study by Suomala (2014) applies as a reflective analysis to an interventionist case study from Lyly-Yrjänäinen (2008). Interesting part is that the study from Lyly-Yrjänäinen (2008) has the same aim of investigating the cost effect of component commonality, which enables good chance for discussion about differences and similarities to our research methodology. Next, we reflect how the intervention appeared through this research process. First, description from Suomala et al. (2008) about fieldwork matches to experiences as an interventionist researcher. Fieldwork was done as an accepted and trustworthy member of the community i.e. “insider”. This research approach enabled better communication and actions in emic level. However, the key is to find balance between emic and etic levels and constantly reflect between these perspectives (Suomala et al. 2014). Balancing between emic and etic levels throughout the research process is presented in Figure 13. Constant reflection between emic and etic levels was a crucial in this study because as an interventionist researcher, there was handed out the responsibility to find the ultimate research question that pleases the stakeholders.

There exists also a major risk pointed out by Suomala (2014). Field researcher is responsible to resist all kinds of prior prejudices as a researcher itself and most of all resist external pressure to accept one-sided information, leads, values or critique. In the research process, the external pressure from different stakeholders was challenging because some people naturally tried to promote their own agendas or the status quo. As one of the directors put it:

“The industry has long traditions of doing things in a similar way, therefore it is important that new people come and point out new ways of doing things, because they are not blind yet for how things are done”

Key to fight back against these tensions was to buy an access by introducing the effect of component commonality among dimensions. Buying the access with this rather narrow subject enabled better discussion and facilitated a foundation for broader questions about the effects of product variety. For example, approaching people by asking question: “what would be the effect if there is one common diameter that would decrease the amount of variants by 30-40 percentages?” Contrary, the reaction would have been different for a much larger question: “are there too many products?” Buying an “access” by showing results how diameter effects on amount of variants, it facilitated for better discussion and opened people more by starting at a very detail level question. Bringing the research in the framework provided by Suomala & Lyly-Yrjänäinen (2012) is a good way to analyze the interventionist research compared to others similar studies. The horizontal axis is scaled from 1 to 5 from weakest to strongest interventions. This study is scored two, as the study did not have to intervene into a new project, rather trying to find the scale and solutions for having too many products to make it as a development project. In vertical axel, in the framework is focal point of intervention from scale 1 to 5. This scored as two, because the component commonality was a way to find cost effect for a common diameter; however, the research question itself was a part of bigger entirety. (Suomala & Lyly-Yrjänäinen 2012)

In the beginning, it become clear that process industries have many unique features therefore theories and empirical studies from “normal” production does not apply in process industry. This got me critical articles outside the batch-process industry. For example I was not comfortable using the concept of component commonality because products in batch-process industries are not physically dismountable components. Better understanding about subjects got me look more deeply about the fundamental idea behind component commonality.

The process started from product management as given from the case mill, which is a very broad field of innovation management, product portfolio management and marketing. At the case mill point of view the product variants and too many of was the silent message that needed to be controlled and understood better. To conceptualize product variety effect on production led literature about Product-Process-Matrix Background and interest in cost management lead to look for an answer by decreasing the amount of products through a better product costing and hence support decision making in product management. This deepened into cost systems in pulp & paper to better capture unique industry. Afterward became that this field went at too detailed level compered to case company, but it provided good insights about the industry and production process. Company was in the middle of major ERP-project and mill controller advised to consider: “how does the life look after new ERP, with more transparent value chain?” That was a turning point to the study. Focus was more about understanding what it the actual problem behind product variants. The thesis converted more on a strategic level, concerning product design.

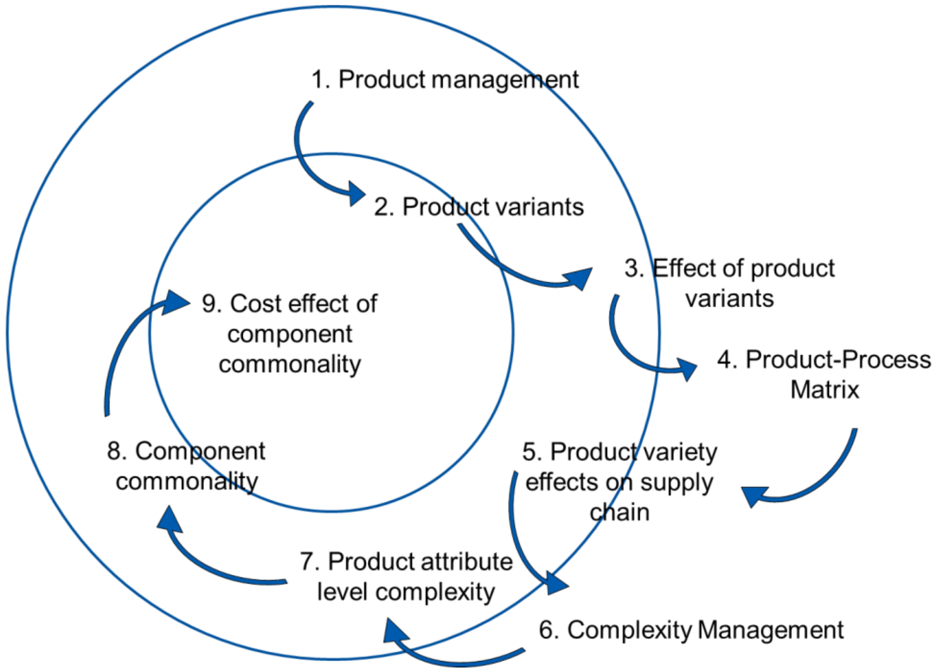

Figure 13: *Project journey brought to emic-etic level*

Studies about product management in Germany had discussed the effect of product variety on a whole value chain. That really captured the essence in this study, because at emic level it became clear that product variety level effected through the supply chain. Additionally, it helped to understand the sources of complexity, where it shifted and how could it managed. Product design decisions have been taken as granted and determinate by inner customers with only a little chance to effect. As consequence, the focus on results was to estimate cost effect of component commonality in one of the product attributes. This also helped to get intervention, while there was restricted scope to gather information, thus getting support and data more easily. This has the features of iterative process, as a way to test what is the cost effect with one product attribute and after that apply it possibly to other attributes. Point is to turn big strategic question into very specific question. On the contrary, turning low internal complex question into high external complex question. In a way, mass customizing the research question.

Table 5: Meeting, interviews and workshops to capture how material was gathered

Location	Date	Contacts	Information
Stage 1	1.7.	Mill manager,	• Factory tour to know paper production process, supporting functions and people. Discussion about the problem and potential aim for the thesis.
Stage 1	5-6.7.	production manager, controller, production planner	• Learning more about raw material, recipes' (BOM), product qualities, waste, costs, production capabilities, maintenance, malfunction production planning, inventory end products, market view, customer behavior and ERP-project.
Stage 1	13- 14.7.	Mill manager, production manager, controller, R&D	• ERP-project workshop: Product ID management, cost centers, cost allocation, scope in ERP(quality-effort) • Partial optimization between stages • Discussion about whether thesis should support the ERP -> result: no • Ended with discussion with mill manager about thesis
Helsinki	23.8.	Consultants, controllers	• ERP-project Workshop(Observing); product costing, master data. Finance and controlling.
University	29.8.	Professor	• Presentation: introduction of company and their problem • Discussing about the problem, objectives and process • Receiving guidance to theory and how to continue
Stage 1	29-30.8.	Mill manager, production manger, controller, R&D	• ERP-project workshop: : Product ID management, scope in ERP(quality-effort), end-to-end • Rough calculation about cost effects in waste% and inventory
Stage 1	27-29.9.	Mill manager, production manager Controller	• Conception about complexity costs and calculate the cost effect with component commonality • Discussion about different options to calculate cost effect
University	28.9.	Professor + Mill manager	• First official meeting: discussion about current situation and how to calculate the cost effect
Stage 1	6.10	Production manager, controller,	• Production manager: detailed discussion about driver use and cost rates in production • Controller: cost rates of different direct costs • Production planner: gathering real production data from runs
Stage 1	17-18.10	Production manager	• Measuring effects in production: packaging function (stopwatch) • Commonality in diameter does not effect to overall productivity • Observation in production between paper machine and cutting process
Stage 2	27.10	Production manager	• Factory tour: production, supporting task, corporation with stage 1 and workers
Stage 1	1.11.	Professor + mill manager	• Professor visits in stage 1: discussion about current situation, • Focus in discussion about results • How to build from here an intact thesis.
University	1.12	Professor	• Checking progress and approving the subject
University	7.12	Professor	• Checking progress and target for development
Stage 1	9.12	Mill manager	• Checking progress and development ideas. How to bring thesis into finish

When estimating the cost effect of component commonality, it required interviews and data. Meetings and interviews are gathered in table 5 and all the gathered data are in table 6. Interviews were rather informal as I simply presented my situation and question, which led to discussion. Interviewing logistics manager, production planner and production manager was conducted as semi constructive in order for better preparation and better discussion. Production data was gathered from previously mentioned datasheet and additionally real production planning and supply chain data. Also information was gathered about the cutting process simply with a stopwatch. This helped to get better understanding about the process and what workers think about the effects of potential component commonality of certain product attribute. Controller and production manager provided cost data by giving used cost rates in packaging function. Additionally, information about different raw material prices, product costing and selling prices was given. These data required asking because as a researcher there was no direct access.

Table 6: Gathered data in research process

Data	Data feature	Information
Product data	Excel	• Inter products produced in last 8 month
Production data	Production planning-software	• Production plan, trimming data, waste%,
Production capabilities	Shop floor gathered data	• Lead-times, cycle times, productivity
Inventory	External inventory provider	• Inventory data about different product and. Long-term progress in inventory changes
Logistics	Excel, interviews	• Logistical cost, services, transportation logic, time and criteria
Company information	PowerPoint, quarterly internal news.	• Overall information about different production sites, products and economic performance
Cost information	Excel	• Product level costs: fixed & variable, cost centers, packaging material cost rates.

In Table 6 is gathered all the data sources and closer information about the data. In the beginning, the case company provided information about the product data and company information. The rest of data is gathered and requested, as they were needed. There was a lot of support to get information, however as thesis worker there was no open access to all production data and therefore required to be in contact with a person responsible for that field.

The major events and what was done in order to get these study questions are summarized to the following list.

- Started with very broad question and new business environment
- Time to reflect between the case context and literature.
- Target to enlighten the world after more transparent supply chain.
- Effect of product variants
- Mass customization of research question
- A lot of support from different organizational functions.

Figure 13 repents well how the research project is connected with the actual research. However, it does not capture all the possible side paths during the journey, which is part of an iterative process. As my task was to study the effect of having too many products, it was natural to find solutions through better cost awareness. After while it became pretty clear that combined with the ongoing

ERP-project it was too late to contributes that and therefore guided by the controller to look for the world after the new ERP system that should bring more transparency to the whole value chain. Instead of finding the answer from cost data I started to investigate what is behind these cost and that led me to investigate product driven complexity cost and how to decrease it. This made the question lot more strategic and bigger than originally thought, but it also makes it lot interesting to go more deeply into the root cause of costs.

5.2 The case company background

The case company is rather young company, but the mill itself has more than 60 years of history. The case company was from 20 years separated from a bigger forest company. Additionally, the amount of stage 2 manufacturers has been gradually increased making inquiries. The history of being part of bigger company and rather independent units can be seen in the current state of the whole case company. The company produces paper and further processes it into tubes as presented in Figure 1. The company is mostly associated to the tube production (referred as stage 2) and paper production (referred as stage 1) is more like serving the stage 2. From economic perspective, the focus should be capital-intensive stage 1. Tube production is highly competitive and the market is full of small producers. The case company is one of the leading tube producers with a history in heavy tubes, which have made it possible to compete with quality. Most important factors in competition are quality, delivery reliability and price. The cost of tube in marginal for a customer but it is important because the customer wraps its products around it and therefore important for quality of end customer products. The tube has to endure customers processing, handling and rewinding. The product must last all these steps and therefore quality is an important factor. Delivery reliability is important because it is unacceptable that customer's production interrupts because tube stock outs. Still the price is an important factor because there is a lot of low cost producer making it hard to justify the higher price in maturate business.

Previous was about the overlook about the business settings of stage 2. Next, we focus on stage 1 and the case Mill where the thesis was conducted. In the beginning, it became clear that the business has unique features. In batch process industries, the large number of finished products has led these industries to adapt a make-to-order strategy, i.e. customer orders are transferred to the first stage of the process. The advantage of this strategy is to manufacture products with customer demands and without any stock of finished products. The drawback is large lead-time generated by this strategy. Customers must wait for the entire process to be completed and after that wait for slot in natural production sequence. In addition, this may generate waste or stocks because demands do not systematically match batch sizes. (Caux et al. 2006b) The case company strategy is make-to-order. However, the difference is that for inner customers the mill stores paper that is afterwards dispatched to stage 2. Storing is required because of the natural sequence of the production that lasts 25 days. Bathes are produced going for higher qualities in a discrete way and following of sin-curve by gradually decreasing to lower qualities. The low grade lasts approximately 18 days and for 7 days is produced the high grade. This means that customers must order the product enough to last for the whole cycle plus delivery time. Additionally, customers must place their order one week in advance the cycle. This means that stage 2 must estimate paper consumption for 30 days in two weeks advance for a certain product. Combined the situation that stage 2 business is based on delivery reliability. Although this can be an extremely hard task for stage 2, however stage 1 is responsible for storing costs. This may lead to a moral hazard because normally there is trade-off between inventory costs and demand uncertainty. At the moment, stage 2 places order for stage 1, which responsible of the inventory costs. This leads to moral hazard to place larger order just in case and therefore increase actual safety stocks bigger than required. Bigger orders increase additionally the natural cycle and therefore increase uncertainty even further.

To go more deeply into the Stage 1 setting it worth explaining about the process itself. The production itself is based on a large-scale and old paper machine, which is rather inflexible production method. The main drivers are productivity, runtime, waste. In short, the goal is to run the paper machine as much, while maximizing productivity and minimizing interruption, costs and waste. The production process is following presented in Figure 14 in very rough scale.

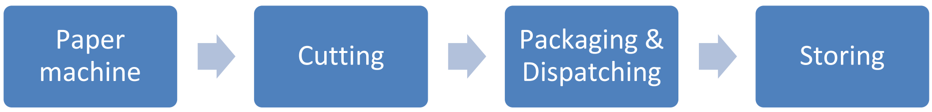

Figure 14: Rough manufacturing process of the stage 1

In Paper machine is produced the actual product, which is paper. The process is running the whole time despite planned or unplanned disruption of the production. Paper is rolled into mega roll (15tonnes) and further processed in the cutting process approximately in 5 tons batches. Paper machine is the bottleneck and setting the productivity. Immediately when the mega roll is ready it is moved into cutting process that is finished few minutes before the new mega roll is ready to be further processed. In cutting process the large rolls are cut into size the customers want them. If diameter is different, it must be processed in different cutting process batch. After the paper is cut into dimension the customers want, it is followed by packing and dispatched to outsourced storing service near the harbor.

6. THE COST EFFECT OF COMPONENT COMMANLITY IN THE CASE COMPANY

6.1 Complexity inside the case company value chain

Respect for people and constant challenging to do better—are these contradictory? Respect for people means respect for the mind and capability. You do not expect them to waste their time. You respect the capability of the people. Americans think teamwork is about you liking me and I liking you. Mutual respect and trust means I trust and respect that you will do your job so that we are successful as a company. It does not mean we just love each other.

- *Sam Heltman, Senior Vice President of Administration (one of the first five Americans hired by Toyota, Georgetown)*

Lindemann (2009) states that complexity management is easily understood narrowly in the literature as variety management. Focus should be understanding what is causing structural complexity in products and processes. In the case company context, the source of structural complexity is broad external complexity that is multiplied by fragmented needs, methods and processes of internal customers.

Companies' desired approach of being a customer driven in the environment where requirements are increasingly diverse is a surefire way to add unnecessary costs and complexity to operations (Gilmore & Pine II 1997). The case company is no exception. Product variations rise in small step, therefore it hard to understand that product variations are behind the complexity. Stage 2 does it best to serve customer needs and these are reflected to stage 1 in batch-process environment, which performance is sensitive on increased product variety as discussed on Section 2.2. Both dimensions of Product-Process-Matrix are taken as given. Process dimension is given by industry and product is set by market. To align these dimensions is a managerial problem and can be affected through mass customization and common product design. The case company understands its limited process capability but cannot communicate it though the company. There are efforts to guide inner customers to make better orders by better pricing and liming smaller orders. Additionally, there is flexibility of recipes, process, product and volume with certain limits. But these methods do not solve the structural complexity, that is caused by conflicting needs of product-organized stage 2 and process oriented stage 1(Hayes, R.H & Wheelwright, S.C 1979).

Current situation has led to complexity cost, which potential sources recognized in theory section are summarized in Table 2 for different functions of the company. These complexity costs are turned later in the text to the cost effect of component commonality. The effects of complexity can be seen in a broad scale in the company. The main driver of complexity is the sheer amount of variants that challenges the organization and production to cope with different variants. In organization, the problem is the amount of variants that makes decision making harder as different products delude each other. In manufacturing, the challenge is linked to smaller batches and set-ups that are challenging for the case company production. Another factor is the uniqueness of the product. This means that the products are not interchangeable, which requires more customer specific service and gives no room for flexibility. Flexibility means that errors are hard to fix. This might mean difficult decision between customer satisfactions or make a separate batch deviating from the natural cycle.

External complexity has been tripled down in the value chain, which is the opposite of delayed differentiation. Objective of delayed differentiation is to have the point of differentiation late as possible in the value chain. Unfortunately, this does not apply to the case company. The point of differentiation is not managed and it is hard to understand the effects of fragmented product design. Nevertheless, before implementing delayed differentiation the following steps should be takes as discussed earlier in the Section 4. Original Figure 4 in the case context would look the following as presented in Figure 15.

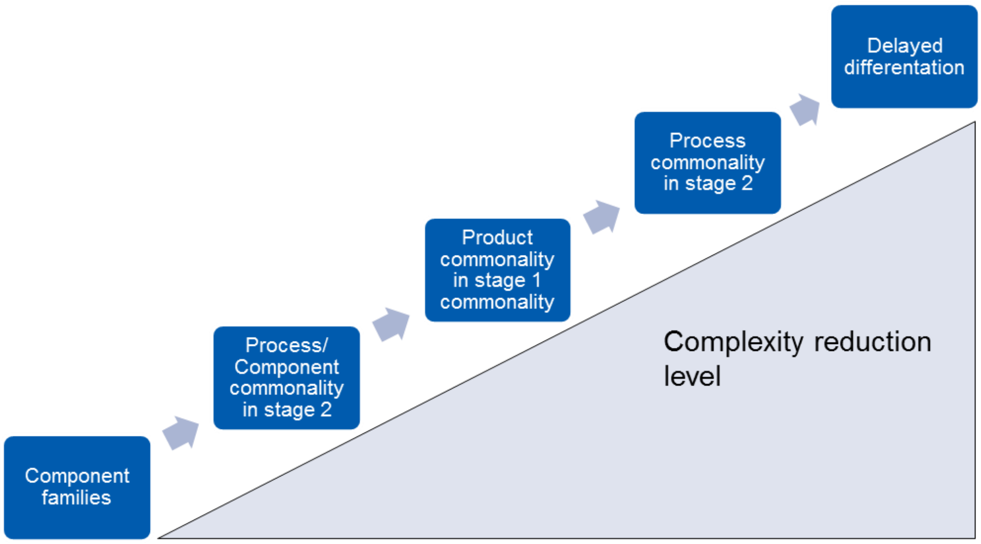

Figure 15: The logical sequence for implementing complexity based variety management in the case company; derived from Blecker Abdelkafi (2006)

The point is to reduce complexity and Figure 15 represents the phases and potential. In the case company, the first step has been achieved, although there is also potential for improvements. In the case context with a long value chain, the first steps starts by building commonality among stage 2 that facilitates product and process commonality in stage 1 and reduces complexity. Increasing commonality is a strategy for implementing variety management at product level. At process level, variety management would be implementing delayed differentiation, where the point of differentiation is pushed late as possible. This strategy has been implemented successfully in few stage 2 factories as the deliver full length tubes and the final cutting is done just before it enters customer process. In one of the factories, this has been pushed all the way by being part of the bigger customer process by getting real time production data from the customer. Delayed differentiation has the most potential of reducing the complexity, but in the case we focus on the potential of component commonalty in stage 1 enabled by commonality in stage 2.

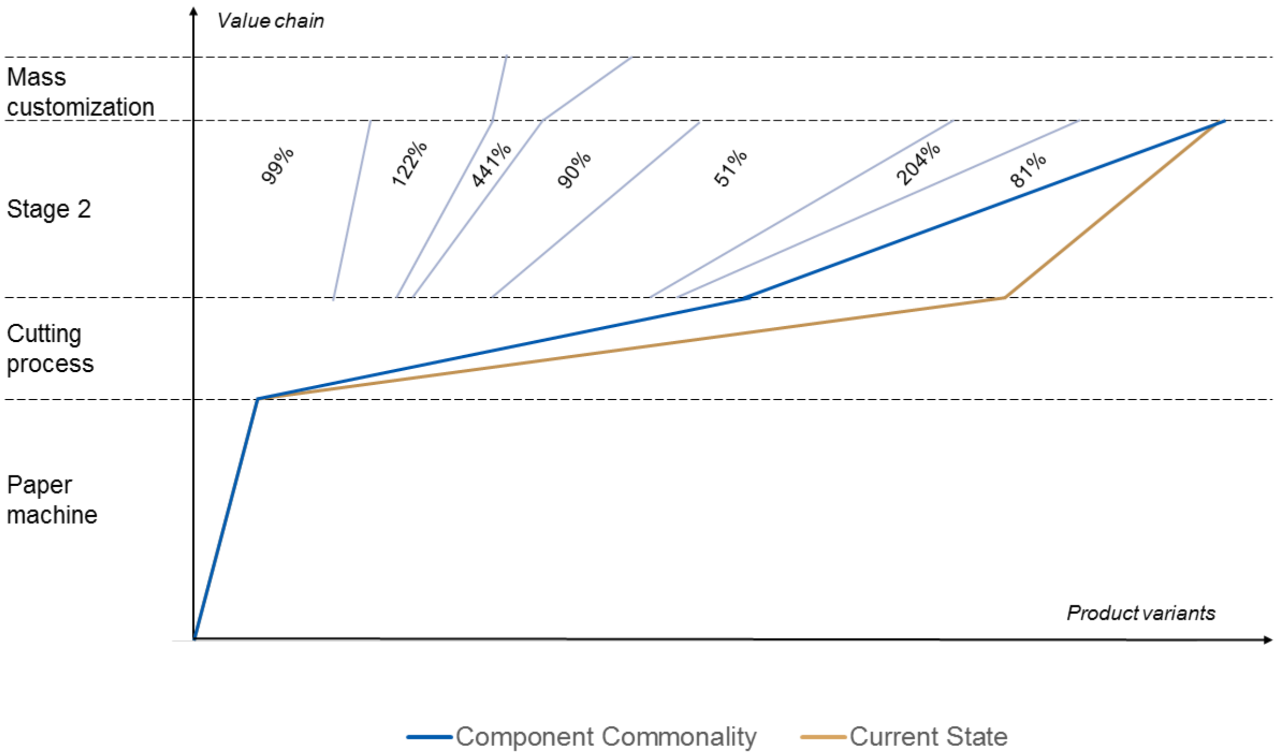

Figure 16: Product variety increase as moving further in the value chain

In Figure 16 is a presentation about how product variant increase as moving longer in the value chain. The figure is presented in actual proportion in product variants and the chain is represented roughly. As we can see, the amount of product variants explodes after the paper machine. The blue line represents the potential of component commonality discussed in the next chapter. The stage 2 value chain is also divided into customer and placed from the biggest customer to smaller in tons. Percentages are calculated from the stage 1 perspective as they represent the deviation from the average produced tons to customer divided by the amount of product variants produced to them. For example, the largest customer that percentage is 99%, describes that the ratio between order in tons and ordered product variants is just above average. The third largest customer percentage 441% means that the orders in tons are 4.5 times larger, as the amount of product variants are at average level. The same stage 2 manufacturer is the representative of mass customization and smaller external complexity.

6.2 Component commonality in the case company

Component commonality is not something new to the case company; while there have been similar actions in order to manage complexity. In the past, the case company rolled its paper into the three different tube diameter according to customer needs. Different tube diameter meant set-up and unique product ID. Case Company decided to standardize the diameter and challenge customer needs in order to have bigger batches and other benefits caused by component commonality. Second example came from stage 2 manufacturer that realized that its paper storing costs and management was unbearable. As production manager said: “we took sense in our hands” and they decided to have product width dimension every 2cm instead of every 1cm. Afterwards they discovered that this product design change didn’t effect on product quality but decreased the number of product units held in stock. Both examples are ways to implement component standardization in order to control the number of units produced or assembled. These were done independently at unit level when situation become unbearable. There were thoughts in the case company that amount of unique product produced by unit should be one key performance indicator in order to evaluate performance.

Next, we will answer the Figure 10 questions about different perspectives to commonality. In the case company, we discuss commonality of product components that have their unique product ID code (Commonality of what). Commonality is done in order to decrease the current amount of product variants to decrease costs (What for?). Commonality is achieved by standardizing product variations of inner customers (What ways?). In the thesis, we contribute by adding question: “commonality, for whom?” The literature about component commonality has not commented on context of two-tier supply chain. In this context, the component commonality has different effects depending on perspective. We emphasize the case company perspective (Stage 1) but also bring insights from the whole supply chain point of view (e.g. including effects in stage 2). In next section, we discuss more closely about question: “commonality in what” by selecting the potential product attribute, hence implementing commonality between products and among product generations (Lyly-Yrjänäinen 2008).

Next, will be used the methodology introduced in Section 4.4 by Caesar (1991) to reduce product variety that is not perceived by customers. At the beginning of the project, I had similar strategy in order to keep reasonable scope and afterwards found this approach. This approach avoids the challenge of balancing the trade-off between internal and external complexity, hence making it good approach to begin to reduce internal complexity. **Variety analysis** is the first step, where we visualize the product variant three as presented in Figure 16.

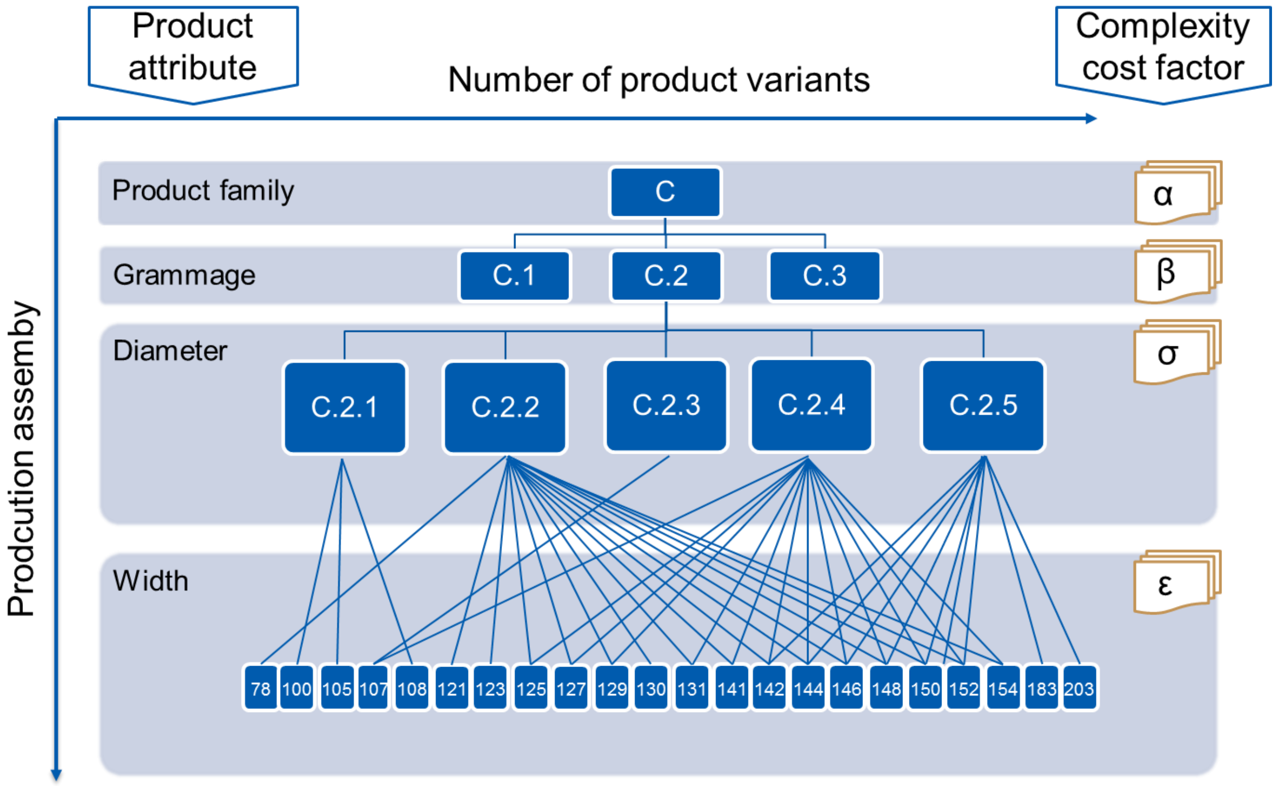

Figure 17: Product variant three of product family C

Product variant three is dependent of the following attributes: strength, basis weight, diameter and width. Customer selects between these product attributes, hence product ID is dependent on these factors. The only attribute that does not effect on end customer (Stage 2 customers) is diameter, which depends only the production requirements of stage 2. The width of paper has also minor effect on end

Product quality specifications, hence there is also potential to harmonize variants between inner customers and is therefore excess internal variety. In the right side of Figure 17, there is indicated a complexity cost factor. The point of this is to illustrate that different product attributes contribute differently to the complexity cost. For example, adding one variety more in grammage has different impact in to the complexity costs than adding one width more. Product variant three additionally reveals the sequence how products are produced. There are no connections between attributes and variant three represents more like waterfall as we go later in the production assembly. Product attribute choices in product family and grammage are connected to the highly inflexible paper machine and diameter and width are determined in a more flexible cutting process. That means that alpha and beta factors are far more complexity cost potential. Additionally, in upper level product variant three there would be big potential as each variant requires own batch, therefore increasing product variants incrementally as diameter and plenty of new width must be produced. Therefore, the different product attributes affect differently as we discuss just the numerical amount of new product variants. As a conclusion complexity cost must be understand differently as we increase or decrease the variety of certain product attribute. The total cost effect is dependent of complexity cost factor and how it effects on the total number of products.

Priority setting is next step where the most potential attribute is discovered. From this perspective, diameter is the potential while standardizing that we have huge potential to reduce amount of product variants. Additionally, it is not a customer driven and it is therefore excess complexity. If we think variety reduction as from a long-term perspective, it is also inventible target as it differentiates among stage 2. It would mean that if we build commonality among grammage, it would mean that stage 2 would not benefit from that as diameter stays as a differentiating product attribute. Additionally, from the thesis perspective it is the most potential, as it does not challenge customer satisfaction nor paper production and keeps. In Table 7 is summarized the potential on component commonality for the diameter.

Table 7: Effect of diameter component commonality on number of product variants

	Present #variants	Component commonality	Extension to widths (<1cm)
All products	100%	- 30%	- 41%
Product family A	45% of all products	- 37%	- 48%

First we used sales data of inner customers for last 8-month, which describes well the current product variants in portfolio. Simply by calculating all possible combinations of product attributes and its variants we would get total 10 times more product variants. Next was evalueted how one standard diameter would effect on number of units produced and results can be shown in the Table 7. Product family A is important product family and interesting, while there is lot of potential decrease in product variants and adding products that would just have one centimeter gap we combined to see the potential for future work of component commonality. Technique combines different dimensions and standardizes them into more reasonable level is called range tecnique (Marti 2007). As as result number of product variants would decrease 30% and with high-end product portfolio we would cut 48% of product by standardizing diameter and harmonize width within 1 cm difference.

To bring these changes into tonnes we get better picture with 8-month period of inned customers sales data. Therefore, it is better understood the effect of component commonality on batch sizes. In Figure 18 there is in vertical dimension cumulative sales in prosentual tonnes and on horizontal dimension product variants from the largest to smallest product variants (tonnes).

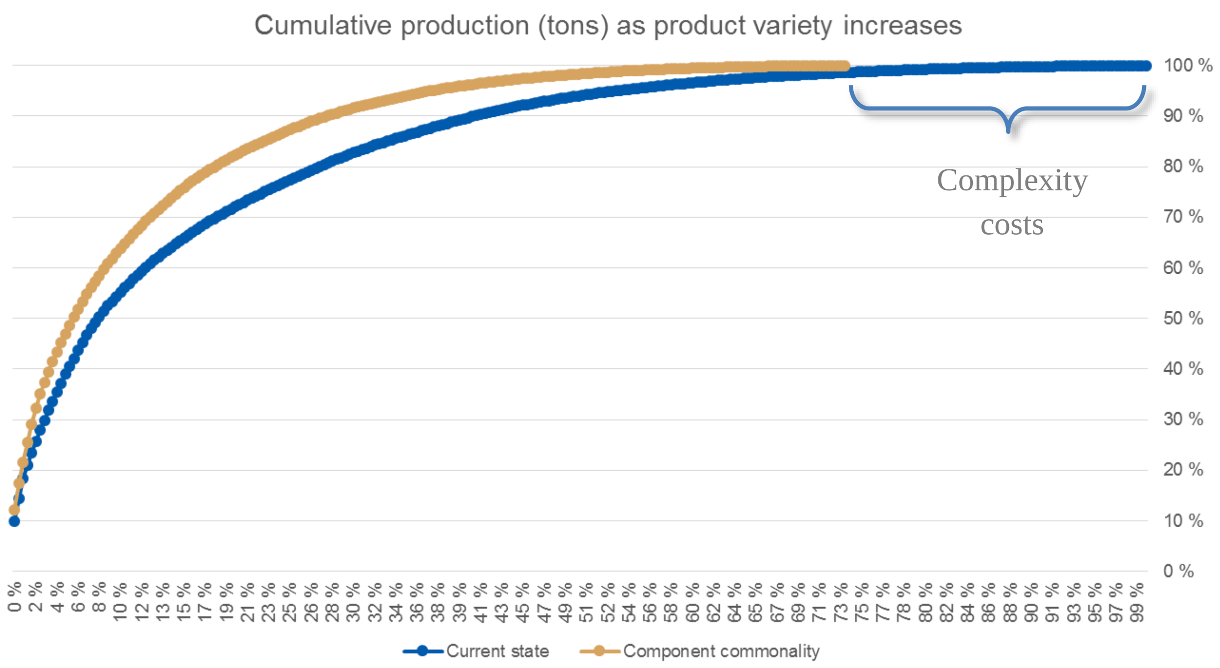

Figure 18: Cumulative production (tons) as product variety increases. Current situation compared to component commonality in diameter

Basically, in this thesis try to understand what is the complexity cost of last 30% product variety tale that is caused by product diameter. The next phase in VMEA is **variety-oriented product design**. Component commonality of diameter is the answer to this problem. Additionally, the awareness of complexity and managing it form of variety-oriented product design. Complexity cost was key to understand what is causing the complexity and how it is divided into internal and external. That resulted in the same conclusion that diameter is a major source and it is the potential target for decreasing complexity.

Last stage of VMEA is **evaluation** and in next section we go more deeply of evaluating the effect of component commonality. This is done by selecting cost objectives that are greatly effected by component commonality and discussing additional effect reflected by theory. Unlike analyzing complexity costs from the whole company perspective, VMEA is targets more to most potential product variants and reduces variety in a way of an iterative process.

When component commonality is increased by replacing several product-specific components into a common one, this new component must fulfill the functional requirements that it replaced. This means that having one common diameter must fit into stage 2 manufacturers. That requires investments to production machines called winder in order to fit larger diameter puck into a tube machine. One of the stage 2 manufacturers have invested on winder in order to fit bigger plies, because it means less changes and work. There for there exists also compensation on stage 2 factories.

6.3 The cost effect of component commonality for product attribute

”We took sense in our hands and reduced the amount of product variants in widths, in order to make life easier for us. Afterwards it became clear that reducing the amount of widths did not affect negatively on product”

- *Stage 2 production manager*

This chapter focuses on calculating and evaluating the cost effect of component commonality on a diameter, because it is recognized as potential source to decrease product variety, hence internal complexity. We rhythm the discussion in the following chapter by opening up direct cost effects calculated, then discuss about speculative costs and finally about potential opportunity costs of mass customization or delayed differentiation. The discussion about commonality in diameter is conceptualized in Figure 19. Component commonality leads to decreasing amount of components, which has a direct cost effect discussed in flowing chapters. Commonality in diameter results three major direct cost effects, which we calculated: change in driver use, longer production runs and changes in supply chain. Number of diameter enables also changes that are discussed at level that is more speculative. These more speculative costs are derived from literature and discussed in the case company context.

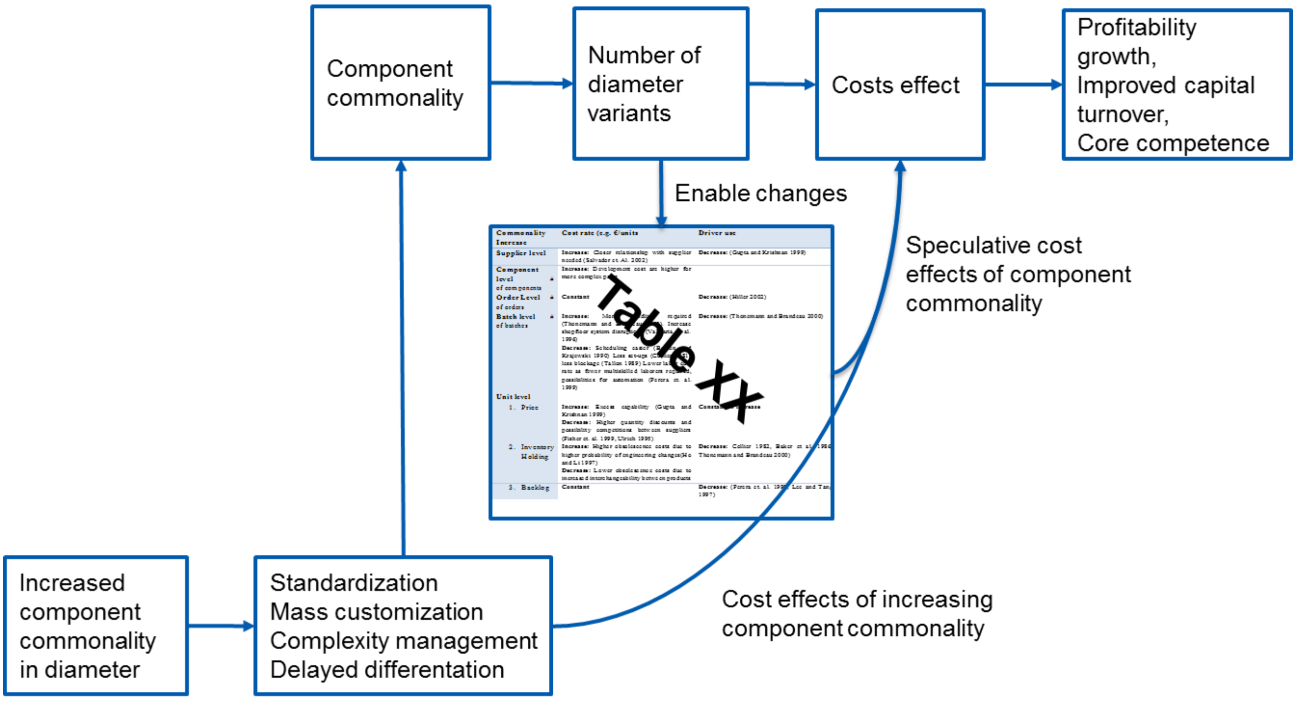

Figure 19: Conceptualizing direct and derived speculative cost effects of component commonality for product diameter; derived from Lyly-Yrjänäinen (2008)

Also throughout the text, we keep in mind Figure 4 to conceptualize costs at different levels (batch, unit, and mill). Commonality increase effects can be different between cost rates versus driver use. The point of this cost discussion is to improve profitability. Improvements via component commonality are connected an objective to improve capital turnover. Component commonality is also connected the core competence of the case company.

6.3.1 The effects on cost driver use

"People handling paper in operations do not care how many tons they have to move - only the amount of units"

- *Production planer in stage 1*

Component commonality affects either on cost rate or driver use. In the case company, the standardization has effects on average diameter by increasing it larger, while larger diameter is common objective in value chain because it means less set-ups in production. As diameter increases the amount of units to be handled decreases after cutting process, while there is more tons per unit as output of tons is constant. This has positive effect on operations, while there are less units to be handled. This major bonus results from component commonality, because it effects on driver use. Case company is used to talks about tons as a major driver, but it can be misleading, while in reality after the cutting process the major driver is amount of units to be handled.

In Table 8 is calculated how amount of units change as diameter changes. In this table, production is constant and it last year production for inner customers. From there I was able to calculate average output in tons for each day. After setting how much each unit weights depending on a diameter, it was trivial to calculate average output in units instead of tons. It is notable that these are calculated by averages, while in reality diameter changes in daily basis in production. Additionally, to surprisingly positive effect on driver use, component commonality stabilizes the process. Stable process is first steps in lean management, which not have been discussed in the component commonality literature (Liker 2004). In conclusion, component commonality effects on average diameter and therefore decreasing the amount of units to be handled in packaging and logistics, where a unit is the cost driver instead of tons.

Table 8: The cost potential of diameter component commonality because of the change in cost driver use (Note: number changed due to confidentiality)

Driver use on different diameter		Packaging Material and Labor					
Diameter (mm)	Units/day	A	B	C	D	E	Total
A	132 %	560 €	990 €	47 €	70 €	151 €	
B	122 %	516 €	913 €	43 €	64 €	139 €	
C	113 %	477 €	844 €	40 €	59 €	128 €	
D	104 %	443 €	782 €	37 €	55 €	119 €	
E	100 %	424 €	749 €	36 €	53 €	114 €	
F	97 %	412 €	728 €	35 €	51 €	111 €	
G	91 %	384 €	678 €	32 €	48 €	103 €	
H	85 %	359 €	634 €	30 €	45 €	96 €	
Delta (Now to CC)	15 %	65 €	115 €	5 €	8 €	17 €	211 €

After calculating the amount of units produced per day for inner customers, it is time to determine the cost rates for all major direct costs in packaging. I choose packaging because it is clear process and known cost centers. The major direct material costs were tubes, pallet, stickers and band. Each of these have known unit prices and represented majority of direct material costs. There is also an unit price for labor and it is justify to calculate because the labor in packaging is possible to reallocate Required labor was calculated how much time it took for packaging machine complete one unit and from there it was possible to determinate how much time the new driver use would save. Unfortunately, there was for no price for machine hours. As a result, we can calculate direct cost savings from difference between the current average diameter E and the new standard diameter, which is larger than the average. These costs are reasonable when consider in a yearly scale or potentially applying to the whole production capacity. By calculating to the whole capacity, it was possible to validate the calculation by comparing with previous years realized costs.

With component commonality it is possible to decrease the amount of variants to be handled but additionally this has bonus effect by decreasing the amount of units as diameter increases and production (tons) stays constant. This means less handling in units from the cutting process to stage 2-winder machine. By calculating the change of output units, we are able to decrease the amount of units 15, 2% to be handled in rather long supply chain. That means less handling in logistics and less set-ups in stage 2 factories. This has cost savings potential, but unfortunately out-of scope of this thesis for deeper analysis to estimate monetary effect.

6.3.2 Longer production runs

In general, when you try to apply the Toyota Production System (TPS), the first thing you have to do is to even out or level the production. And that is the responsibility primarily of production control or production management people. Leveling the production schedule may require some front-loading of shipments or postponing of shipments and you may have to ask some customers to wait for a short period of time. Once the production level is more or less the same or constant for a month, you will be able to apply pull systems and balance the assembly line. But if production levels—the output—varies from day to day, there is no sense in trying to apply those other systems, because you simply cannot establish standardized work under such circumstances.

- *Fujio Cho, President, Toyota Motor Corporation*

Biggest advantages that arose in component commonality literature are cost reducing effect of economies of scale (Ulrich 1995; Robertson & Ulrich 1998; Fisher & Ittner 1999; Caux et al. 2006b). In the case company component, commonality means longer production runs in the cutting process. Different diameter requires a new batch in cutting, but this does not apply to widths. In a daily basis in a production plan, there is exactly the same product in quality specifications, but only diameter differentiates. Therefore, it requires its own batch. Major task for production planning is “trimming” 5 meter width cut able rolls into widths that customer wants. As a result, the cutting process produces several plies that are packaged to units. Trimming part is done with the help of optimizing software that tries to minimize waste, blade set-ups and satisfy customer order requirements. The final decision and adjustments are done by production planner. With component commonality, it is possible to have longer production runs in the cutting process. Hence, the optimization is easier with more widths and as a result minimizing waste. Waste is a major measure in paper production and therefore it was relevant cost objective to understand the cost effect of component commonality. Component commonality of diameter does not directly effect on the inflexible paper machine, but it affects the batch sizes in the cutting process.

To investigate waste were used real production data from production planning but not realized data on waste, because it was not possible to allocate for different batches. To understand the effect of bigger batch size there were executed an opposite approach to collect data. First, real production data from a batch was collected including, batch size (tons), waste from trim, amount of cutting rolls, required set-ups between them, total blade changes and also manually was calculated leftover plies that didn't fit into a customer packaging unit. As a result, it was possible to calculate waste and results are summarized in Table 9. In second phase, the real batch was cut into three different ways. One was cut in three different batches and also cutting into two batches was done two different ways. The point of cutting batch into a three different ways was to eliminate randomness to get better results. This was repeated to another batch that was cut once into two batches. Selected batches were the largest possible batches in order to get realistic batch sizes. This method does not capture perfectly the reality of component commonality. For example, there was no benefit from combining the same width to the same batch. Also calculating the single plies that do not fit to a complete customer-packaging unit is based on ideal situation these plies are not used to replace broken ones. Despite these shortcomings, the calculation gives a good picture about the effect of having longer production runs in cutting when executing component commonality.

Table 9: Difference in production waste between component commonality vs. current shorter production run.

	Component commonality	Current state	Percentage	Absolute
Order size(Gross tons)	145,25	145,25	0 %	0
Order(net tons)	144,859	143,619	0,9 %	-1,24
waste%	0,27 %	1,40 %	-418 %	1,13 %
Tons/set-up	36,313	37,653	-4 %	1,341
Single pucks (#)	2	5	-167 %	3
Collectable pucks	2	61	-2933 %	59
Blade tooling	90	118	-31 %	28
Single puck waste(t)	0,294	0,685	-133 %	0,392
Total waste%	0,47 %	1,87 %	-296 %	1,40 %

Next are analyzed results systematically comparing the longer production run (i.e. component commonality) and average split results. There are no changes in gross batch size and the same amount of tons is delivered. There is possibility on order size in order to minimize waste, but still keeping the tons per cutting rolls as constant and keeping results comparable. This case happened in the other measures (see. Appendix 1). A net batch size considers the waste lost (tons) spotted in next row. Waste in tons and percentages was represented in optimization software and these numbers were possible to verify. Amount of cutting rolls represents how many rolls are coming from paper machine rolled into the right dimension for cutting process. Waste that results from “trimming lost” is transformed into euro by determining average price and subtracted by the raw material price as this waste can processed again. Calculating with the average price is justified while this waste is lost sales.

Set-up results for shorter runs there must more blade changes in order to keep waste in reasonable amount. Set-ups mean more work, longer lead-time and possibility to make mistake with blade changes (i.e. waste). Set-ups decreased by 17% in longer runs, which would in long observation reduce waste and work. Remainder represents the amount of plies that did not fit into customer packaging unit, hence waste. This means pure waste and it calculated as “single puck waste” – the second form of waste calculated. There is also reported “collectable plies” that require extra works, because in cutting machine output did not complete packaging units. Collectable plies require more work and there exists risk for failure. Blade changes describe the sheer amount of blade settings that has to be done during the cutting process set-up. Each blade change requires work and involves risk of waste because it is performed manually. As a result, amount of blade changes decrease 31%, which would effect in retro perspective, but impossible to allocate to waste. Therefore, blade changes cost effects are more in the speculative side.

As we combine the two forms of waste from trimming lost and remainder, the waste percentage drops from 1.87% to 0.47%, which means 1.87% less waste for this particular batch. This was done for another batch and results were same 0.61%. These might sound like small numbers but in process industries minimizing waste is one of the major objectives, where small numbers can have big difference on a yearly basis. When bringing these numbers into a yearly scale, it is notable that even a 1% decrease in waste has a large impact.

To extend this examination of component commonality effect on the cutting process to different cost effects derived from Table 10. As discussed previously economic of scale is a major driver that is decreasing both cost rates (e.g. waste) and driver rates (e.g. less blade set-ups). Next, we have listed major cost reduction effect derived from literature to the case context.

Table 10: Combined speculative cost effects with longer production runs

Positive effect on MRP system	• Easier to optimize production plan
Quality improvements	• Paper quality on edges better, while less variety in width trimming • Less material waste in cutting process.
Improved flexibility	• Products more interchangeable • Shared risk for order volume changes in trimming(fulfill order requirements) • Better chance to except smaller order with commonality
Quality control	• Less quality control, while bigger batches • Reduction in unsellable products
Improvements in cutting process productivity	• Less set-ups • Bigger diameter, thus shorter lead time
Learning curve effect	• Changes to make improvements as process becomes standardized • Chance to share more product information (R&D)
Reduction in setup and retooling	• Less blade changes and set-ups • Bigger runs -> more tons/set-up
Fewer and shorter interruptions	• More stable process with less variety (heijunka) • Less set-ups and risks for failure that reflects to whole production
Opportunities for increasing automation	• Handling, transportation • Automated production planning and order intake
Lower requirement on equipment	• Different dimension requires different packaging materials
Sequencing costs	• Hard to allocate costs to different products; what really is the cost effect of dimension and batch size
Downtime costs	• Variety in cutting and packaging leads uncertainty and may reflect on production.
Line balance costs	• Spot orders disturbs natural production cycle
Rework costs	• Too much waste, hence completely new set of cuttable roll
Production planning cost	• Less batches in cutting process, less production planning

6.3.3 Changes in supply chain

The more inventory a company has, … the less likely they will have what they need.

- *Taiichi Ohno*

When discussing the effects of product variety in the whole case company, it usually leads to high inventory levels. Discussions in literature have emphasis on inventory levels and lead times that product variety increases (Da Silveira 1998; Fisher & Ittner 1999; Ramdas 2003; Blecker & Abdelkafi

2006). In reverse, when discussing component commonality the benefits are related to decreasing inventory levels, amount of products to be handled and faster lead times(Collier 1982; Perera et al. 1999; Ma et al. 2002; Lyly-Yrjänäinen 2008; Baud-Lavigne et al. 2012). Large stocks and long lead-time are problems that are recognized throughout the case company organizational levels. These are tough as "given" because the long natural cycle of production, but next we lighten up the effect of component commonality on supply chain performance in the case company.

At the beginning of the thesis, the aim was to focus on how product variety has effect on production but later it became clear that variety has impact on supply chain and inventory levels too. To present this difficulty, the production manager was questioning:

"How come we must make a major deviation in production plan in order to run batch for our inner customer during the whole weekend, meanwhile there is thousands of tons paper in the inventory?"

In background there was probably stage 2 manufacturer that ran out of paper that was needed to deliver and serve important customer. Production manager is aware of that reason behind here is increasing product variety that has led to situation that the company has customer-based inventory instead of products based. Spotted from inventory level report, there were not a single product in stock that belonged to at least two inner customers. From inventory data can be stated that product customization is pushed to all the way customer, specific products that requires own inventory place to each customer.

Situation is not easy from stage 2 perspective either. Production cycle has major effect because that means that stage 2 must place it paper orders 1-2 weeks ahead the actual production of the product and they have to forecast the need particular product for 25 over the production cycle. Demand forecast for month combined to delivery security and customer specific stocks result are on evident outcome for high inventory levels. There is also moral hazard because the case company is carrying the cost of inventory and stage 2 is responsible for service orders. Therefore, there is major moral hazard because no one is responsible for trade-off between inventory costs and service level. Stage 2 also promises 2-week delivery time after order, which is not on line with the production settings of stage 1. There is a lot of conflicting objectives and the result is high inventory rates. Factor that supports this supply chain is relatively steady demand for paper and backlog orders. Still uncertainty caused by the long lead-time of stage 1 may lead to longer order sizes that result longer natural cycle, hence feeding more uncertainty to the orders as lead-time increases. All these factors lead to situation presented by production manager and highly customized products increases the uncertainty, lead times and inventory levels.

To investigate the inventory levels in thesis was calculated the change in safety stocks as component commonality is presented for diameter. This view has been emphasized in the literature and relevant for the case company as there was decreasing amount of product variants, as tons stay constant. These calculations can be seen in the Appendix 1.

There was no information that could have resulted to calculate the effect of component commonality overall to inventory levels. Instead, the change in safety stock was calculated by using the snapshot of inventory level that included information about stock levels for a particular product (ID) and customer information. Additionally, information was gathered from the 8-month sales report of inner customers, in order to calculate average demand for a specific product in a customer level. Information for calculation was gathered average lead times for customers from supply chain manager. Information about the production cycle was needed to calculated total lead-time to order. Situation is rather ideal, but justified because there is not information about stock level and with safety stocks. It is justified to use this ideal situation with real production data. For situation was assumed that orders are calculated for fixed-time interval with 99.9% service level and standard deviations for demand set to 27% derived from the 8-month sales report.

Actual calculation for changes in safety stocks is done by first calculating current ideal safety stock level by given information for formula with fixed-time interval. In second phase, are recognized products from the inventory report, where only difference between products is a diameter. These are calculated together and considered as a same product. In third phase, the safety stocks are calculated to these new common products. From there we can calculate the difference of safety stocks before and after component commonality for the inventory level snapshot.

Inner customers used the majority of warehouse capacity that is currently outsourced. Additionally, the amount of products that are effected in the inventory is 58% when discussed in tons. This is effected by in which point of natural sequence the production is and therefore changes in inventory occur. As the demand variations of customer are divided into several customers, therefore the required safety stocks do not have to be that large. These changes are calculated independently for each product effected by component commonality and as a result, the safety stocks sank 27% for common components. Therefore, the literature view that component commonality effects on inventory is evident. However, this seems relatively a major drop, but in tons the change is not that substantial. Without component commonality, the safety stock levels are between 15-16% and with component commonality, the safety stocks 8-14% of the placed order. The absolute change in tons is not major direct cost effect, but there are other positive effects with component commonality on inventories.

Discussion and observations in both stages revealed that component commonality has another positive effect than just on safety stocks. First of all the ordering process is not well managed. Stage 2 place orders (i.e. paper requirement forecast) based on history data without taking into account how much material is in the inventory. This work is done by stage 1, where is scarce information on inventory levels, but now clue what is behind the forecast. This can lead situation where too much or little order is placed on production.

Previous method was used to calculate what the inventory level should be. This revealed that inventory level should be -32,0% lower level and implementing component commonality the inventory levels to drop -36.9%. This also gives perspective of the effect of component commonality. This observation exposed the potential that might result with better ordering practices and information in the value chain. When observing 5-year inventory level, there is lot of volatility. Behind that is most certainly maintenance breaks. However, with rather stable demand it might be that bigger orders (excess safety bumper) lead to steadily increasing inventory level, which has counter effect by conscious decreasing of inventory into more bearable level.

Major positive effect of component commonality is risk management for stock outs. This partly related to shared safety stocks between customers enabled by component commonality. Similar actions have been taken already in some occasions as a stage 2 manufacturer runs out of a particular product it can take a similar product with a smaller diameter. From sales data, it was possible to determine that 2% of the deliveries were smaller in a smaller diameter, which indicates that the stage 2 manufacturer had stock out, but replaced it with a smaller diameter. During a visit in stage 2 manufacturer, the production ran into this problem. On Thursday, they spotted that on Monday production plan they were missing in stock one paper width even though other widths were in stock. Because of missing one width, the delivery to a customer was at risk. Therefore, the options are delaying the delivery, wait until it comes to production cycle in stage 1, ask for stage 1 to make a special batch for them or hope that in the stock exists the particular product in a smaller diameter. The 2% is a small number, but as in this example, the customer deliver was dependent from one missing product. This example illustrates the advantages of risk polling and reveals the scale of it with a help of sales data.

Risk pooling by taking a smaller diameter means that stage 2 manufacturer has to change more often the raw material in their own process and stage 1 must accept the request that there is enough that product for other customers. Interchangeable components partly exist to enable faster lead-time on surprising orders or failures. Component commonality with a common product base between stage 2 manufactures would support this, build more trust, and enable to order smaller batches by decreasing the safety buffer.

Calculated 28% decrease in safety stock was based an ideal situation, but in the case environment the uncertainty in supply and demand i.e. safety stock level is based more or less on “intuition”. Component commonality would support to decrease this uncertainty for stage 2 as awareness about better interchangeability and trust increases. This would decrease inventory levels and improve inventory turnover. Additionally, the practice for interchangeability already exists, which itself reveals that there is a need to this possibility. In Table 11 is listed cost reducing mechanisms that are derived from literature to the case environment.

Table 11: Combined speculative cost effects in supply chain

Administrative costs	• Fewer components to handle
Reducing safety stock	• More inner customers sharing the same product, hence reducing uncertainty with same service level
Reduction in unsellable products	• Better inventory turnover rate -> product less likely gets old • less unique product getting dusted
Savings on fixed costs	• Lower inventory levels • Possibility to reduce expensive outsourced warehousing
Reduce training cost with decreased complexity	• Less variety, hence easier to train • Chance to make prototypes with better commonality
Less component information to be handled	• Each unique diameter product makes data handling and processing for decision making harder
Shorter documentation on logistics	• Less complexity with one common diameter
More accurate forecasting	• More volume per product, hence less variance • Errors in forecasting to fix with component commonality
Less complicated orders and invoicing	• Less complexity in orders with common diameter • More flexibility with common diameter
Less walking time /transportation costs	• 19% less units stored (snapshot)
Lower storing costs	• Customer specific warehousing transformed into product specific
Decreasing risk for stock-outs	• With component commonality is possible to change between products
Easier part selection	• In warehousing and dispatching easier where each object is. It is hard to see the difference.

In conclusion, in listed cost effects in Table 11 there can be highlighted few major drivers. Firstly, in the case company with component commonality there arises as a bonus; as diameter increases the amount of handled units decrease -15.2% throughout the supply chain. Amount of unit is a major driver for activities, even though billing is done in tons. However, driver change does not effect on actual inventory size in euro nor tons. Due to component commonality, there are less units in store, which makes inventory management easier and increase the inventory turnover rate for common products. Reason behind lower inventory level is lover safety stocks. This was presented rather theoretically with real production data. Nevertheless, in everyday decision making in order size, uncertainties in supply and demand lead far greater level of safety stock. Component commonality would lower this uncertainty with more interchangeable products i.e. increasing existing flexibility for dispatching. Lower safety stock has a positive feedback loop as it lowers order size and therefore natural cycle shortens, hence decreasing uncertainty and inventory levels. Consequently, with lower inventory levels and less units going through the supply chain there exists cost effects as presented in Table 11. Overall, supply chain becomes less complex enabling easier data handling, better decision making and service for administrative activities. In next chapter, we discuss how these cost reductive activities and mechanism are reclaimable.

6.4 Overall cost effects of component commonality

Since Toyota's founding we have adhered to the core principle of contributing to society through the practice of manufacturing high-quality products and services. Our business practices and activities based on this core principle created values, beliefs and business methods that over the years have become a source of competitive advantage. These are the managerial values and business methods that are known collectively as the Toyota Way.

- *Fujio Cho, President Toyota* (from the Toyota Way document, 2001)

Next is combined possible cost savings starting from direct calculated ones, which are extended with derived cost effects summarized in Table 12. Additionally, we discuss speculative opportunity cost that component commonality provides. During the text is provided reflection about how these cost can be reclaimed i.e. cost remanence as presented in Section 4.4. Decision making between operative cost savings and possible development costs are also considered.

The direct cost effects as presented in Section 6.3 are direct packaging cost that includes direct material and direct labor for packaging and warehousing. The labor cost can be taken into account, because these jobs can be resourced to other duties, hence it is cost saving. The major driver for cost savings was decreasing the amount of units as output after cutting process. This reflects all the way to stage two, where is less work for handling and less time required for set-ups. Component commonality is also reflected at lower inventory level with smaller safety stock (theoretical and reality). Cost effect could be calculated because the inventory is outsourced, which mean less procurement, while less tons. Component commonality leads to longer production runs in the cutting process, therefore allowing better optimization and interchangeable products, hence reducing waste. The cost saving was calculated as lost sales because of the flexible order size with customers. Waste was evaluated by distracting from average price the price of a raw material that own waste replaces. Cost savings from the longer production run had the most potential cost savings when considering direct costs that could be calculated. As seen below the cost effect of smaller safety stock is minor when compared to other. However, there is lot of other positive effects in component commonality that were difficult to take into account

- Direct packaging cost effect – 231k
- Stage 2 handling cost effect – 126k
- Lower inventory level – 14k with theoretical and – 104k in reality
- Longer production runs in cutting process – 556k cost effect on waste.

Total direct cost savings are 924k in a yearly basis as component commonality is implemented into diameters. To enlighten the possible derived cost effects requires post observations, in order to capture cost effect. It is challenging to understand in euro how fewer units to be handled effects on the entire supply chain. Less units mean easier handling and warehousing but the real cost effect occur in long-term and are hard to recognize even afterwards. Lower inventory level means better capital turnover inside the company. Less units and variants enable lower inventory level and better management. There are less highly customized products waiting for order, unlike with components that are more common.

Results with longer production runs in the cutting process were promising as there were used a real production data. However, there is still room for speculative costs as the calculated cost effect with component commonality account between 0.4% to 3% of waste although the overall waste percentage is 8-9% on average. That means that there is still major part of the waste taken not into account. How much the bigger runs would improve in reality the waste percentage, is still difficult to evaluate. The point is that there is still potential to decrease the waste percentage, as we could not calculate the cost effect of decreasing set-ups, blade tooling, better product interchangeability and more steady process with longer runs. This requires time and most of all implantation, to recognize the true potential of component commonality on waste.

Table 12: Effect of component commonality on cost rate and driver in different hierarchy levels; derived from Labro (2004) and Lyly-Yrjänäinen (2008).

Commonality Increase	Cost rate (e.g. €/units)	Driver use
Stage 2 level	**Decrease:** Less uncertainty in orders, reduce R&D costs and increases speed for introduction.	**Decrease:** less set-ups in stage 2, Allows smaller order size, Less units handled (-15.2%)
Component level # of components	**Decrease:** Less unique components, less complexity, Easier data handling	**Decrease:** 1 standard component instead of 10 unique.
Order Level # of orders	**Decrease:** More flexibility with orders. **Increase:** Interchangeable orders require work	**Decrease:** Less uncertainty, hence smaller orders
Batch level # of batches	**Decrease:** Scheduling easier and less work, lower probability in material waste, better batch optimization	**Decrease:** Less set-ups, better productivity in cutting, less blade tooling
Unit level		
1. Price	**Decrease:** Less waste, less packaging material, better quality, less unsalable products	**Decrease:**
2. Supply chain	**Decrease:** Scheduling easies, better inventory turnover, better interchangeability, lower inventory level, lower inventory handling cost("safety stock")	**Decrease:** Less units handled (-15,2%), less storable units (-19%), required space

In Table 12 is gathered more or less speculative cost effects of component commonality either in a cost rate or on a driver use. These different factors are connected to direct cost effects presented earlier. With speculative cost effects, it is better to understand the effect of commonality on different drivers and cost rates. These facilities for better understanding, instead of forcing speculative cost effects into absolute cost estimates. Responsible for the ERP-project questioned the point of even calculating the cost effects of component commonality as the outcome is most likely positive and progress in the right way.

Component commonality supports case company's investment in common ERP-system inside the value chain, which includes opportunity costs for component commonality. Better information systems and transparency will not make the value chain itself more efficient because of the internal complexity. Component commonality among the value chain would unleash the hidden potential with common ERP-system. The number of different product variants also astonished supporting consultants implementing the ERP-system into different units. The improved transparency of the value chain via new ERP-system combined with better commonality would help case company's effort to decrease inventory and improve the capital turnover rate. Better ERP-system would also have major support on squeezing the cost potential of component commonality. As discussed previously the reduction of complexity have a nature of cost remanence and decrease of complexity cost is a long term task and requires actions, where new ERP-system would play a vital role.

Features that are important to case company's core competencies or to gain competitive edge are supported by component commonality. The business is based on quality and reliable deliveries. Component commonality is connected to these important strategies and best of all it is more suitable for the inflexible stage 1. Commonality would bring security on deliveries and still turn the inventories at level that is more reasonable. Longer runs in cutting process reflect all the ways to the paper machine, as there are needed fewer adjustments in the edges. Running a paper machine is like trying to keep the course in sailing; more the course is changed, more variance is in the direction. It takes times to make adjustment and with steady objective, it is easier to keep inside the quality standards, as it is possible to make smaller corrective adjustments. Amount of waste produce also signals about the quality aspect.

In lean management, the first step before improvements is to standardize the process (Liker 2004). Component commonality therefore facilitates for small improvements all the way to the possibilities of automation from material handling to administrative work (Child et al. 1991). The common thing is the possibility for learning effect like discussed in the literature. Additional component commonality would be a first step towards managing the complexity inside the value chain. For example, to implement delayed differentiation becomes more relevant as there is more commonality. Alternatively, safety stocks could be in the form of mega paper rolls. Instead of going to wait for order in the inventory that never happens, the paper could be set into intermediate stock after paper machine and cut into right dimension when order occurs. Now the stage 1 has inventory for every possible dimension attribute (i.e. width or diameter). This could be realistic as the amount of safety stock in product family A could be stored in one mega paper roll (15tonnes). This form of delayed differentiation could not be done unless process commonality in stage 1 is transformed into component commonality in stage 2. Calculating a price tag for this is impossible as the potential cost effect might be from lost customer to core competence.

In order to gain better perception about the potential of different speculative cost effects, different factors was calculated to communicate better about cost saving potential and to get better understanding about the proportions how different cost drivers behave.

- Lowering 1% of waste is a 560k cost save potential
- Lowering 1 tons of inventory saved X € per tons
- Improving the paper machine productivity with 1% has X € cost effect potential
- Tons/set is conceive and saturates, when batch size reaches ~100 tons

These factors help to understand the potential cost effects of different factors and validate the discussion with speculative costs. To sum up all these cost effects Thyssen et al. (2006) presented a conceptual framing to understand the trade-off between component commonality and evaluate the overall cost impact of commonality combining short and long term effects (Thyssen et al. 2006). All the possible cost effects are just speculative, without implementing actions towards component commonality. Major development costs that needs to be done is investment on the process commonality on stage 1, which means investments in production machines in order to fit a bigger diameter. Additionally, this project requires time for planning, especially if it is expanded to widths. There must also take into account that there has been investment in stage 2 to a larger diameter in order to reduce required work, thus in the investment exist payback time for stage 2 in addition. Component commonality project does not effect on sales because the variety reduction does not effect on customers. However, it could have long-term positive effect as with increasing commonality the stage 1 delivery performance improves decreasing lead-time and flexibility.

7. DISCUSSION AND CONCLUSION

We view errors as opportunities for learning. Rather than blaming individuals, the organization takes corrective actions and distributes knowledge about each experience broadly. Learning is a continuous company-wide process as superiors motivate and train subordinates; as predecessors do the same for successors; and as team members at all levels share knowledge with one another.

- *The Toyota Way document 2001, Toyota Motor Corporation*

First, we built an understanding how the external complexity connects via product design into internal complexity, which results complexity costs driven by having product variants. Instead of balancing between internal and external complexity, in this thesis we focused on excess internal complexity, not driven by a customer. Observation with product hierarchy helped to discover how different product attributes were linked to production process and product functionality. Findings about the number of variants led to understanding that product dimension defined in more flexible cutting process multiplied the total amount of product variants. Objective to product variant reduction was the most potential for diameter, which varied based on heterogeneous stage 2 production requirements and therefore was not customer-driven.

Effects of product variety i.e. complexity costs could be discovered throughout the value chain. Relatively independent stage 2 manufacturers are responsible for making the product requirement decisions to satisfy their customer requirements. Slight differences between product dimensions have exploded the amount of product variants. These product design choices effect on different functions of the company and lead excess complexity costs. In production, this causes more set-ups, smaller batches, more waste and variety in production. In supply chain, complexity costs involve more variants to be handled, hence larger inventory level, longer lead-time and lacking responsiveness. Complexity cost in administration is related to handling with more variants requiring more planning, controlling, demanding decision-making and bigger chance for complicated orders.

The nature of product-driven complexity costs are devious, since it is hard to detect and in the case company no one is responsible about product design at company level. However, in case context there was possible to select well-defined targets for component commonality cost effect observation. First, component commonality has major impact on main cost driver, which affect to functions after cutting process and all the way to stage 2 manufacturers. The changes in driver use was possible calculate and consequently direct cost effect on packaging materials and labor. Additionally, there is a great deal of other positive effects in case environment from overall process flow or required handling as amount of units decrease. Secondly, component commonality allows longer production runs in cutting process and hence minimizes waste, which is important performance measure to process industry. The cost effect was calculated with real production by splitting orders and calculating the effect on waste. This calculation captured the direct cost effect; still the positive impact of component commonality would affect other ways too and not covered completely by calculation. Component commonality has positive effect on supply chain by decreasing safety stocks and facilitating better responsiveness. The effect of commonality on safety stock with theoretical inspection was minor, however the current decision-making and moral hazards involved has led to a high inventory level. With better commonality, it is possible to decrease uncertainty involved with supply and demand. Benefits involved with increasing commonality are connected to competitive factors and challenges of the case company, hence it is challenging to turn these into cost factors.

There exist several ways to decrease complexity cost. In this context, we discussed the potentials of mass customization to manage internal complexity. There is possibility to push differentiation late as possible, which is most potential way especially in batch-process context. In this thesis, these methodologies were used more into conceptual thinking and recognizing the cost potential in the context. There was taken few steps back from delayed differentiation and in the case company was investigated more closely how component commonality works. It was as a potential and already implemented way in the case company to reduce internal complexity. Companies should bear in mind that complexity itself is not bad, but having excess complexity or not managing complexity is not justified. In the case company environment, this turned out to be in alarming situation. It should be taken under consolidation that decreasing complexity cost with component commonality is a long-term task, because the cost might be fixed and it requires action to squeeze out the potential by managing fewer components.

Following results were presented in technical meeting where major stage 2 producer gathered to stage 1 mill. Stage 2 representatives agreed that there is potential to make harmonization among stage manufacturers. Surprisingly, the problem with component commonality was not the lacking potential or technical challenges, but difficulty to share the benefits between counterparts. The problem is that cost reduction is mostly in stage 1 and stage 2 is facing the investment. This investment problem turned out to be the biggest obstacle. Additionally, the company had resulted in similar conclusions almost ten years ago. Therefore, the problem turned into managing vertical and horizontal integration as discussed by Pellinen et al. (2016), where agency theories, suitable performance measures and compensations become important. Therefore, the managerial problems is not just aligning product and process strategies, but additionally implement these optimal solutions from whole value chain perspective and facilitate management systems perceiving towards vertical and horizontal integration.

Contribution to literature was built by making connection between theories and through discoveries from the case company. Additionally, in the case company was similar findings as in the literature. Major connection was built between component commonality and complexity cost. There has been minor discussion in complexity management about the potential of component commonality, but no other way around. These theories compliment well each other and they were in fundamental role to understand and describe the situation, and most of all entering into the cost effect of "having too many products". Similar connection was done between Product-Process-Matrix and the problem of balancing between internal and external complexity. The framework for aligning product and process strategies supports well the conceptual discussion to complexity management by explaining how these strategies might conflict, the evolution perspective and how companies can in strategic level position themselves along the ideal diagonal (Leschke 1995; Marti 2007).

For component commonality literature this thesis contributed by making similar findings and also reflecting and giving proportion through different discoveries in the case company. These are done especially from the cost effect point of view. In this thesis, was done similar method as Lyly-Yrjänäinen (2008) by turning the opposite cost effect of component commonality, which in this case was turning complexity costs into the possible positive cost effects of component commonality. With this method, more detailed level and broad cost effects found throughout different functions. The emphasis of component commonality literature has been in inventory level and supply chain. Findings support these findings but the cost effect with lower inventory in the case company was modest. Positive effects are involved with better responsiveness, flexibility and service level. All these have positive influence by lowering the uncertainty and therefore decreasing need for safety stocks, hence shortening the required production cycle. In component commonality literature there was no discussion about the potential positive effects on driver use, as found in the case company. This is inventible effect especially in the batch-process industries with rather simple products, because different product attributes and features are highly connected to process and therefore to performance. The potential target for component commonality was the diameter, which affected to how many different units were produced, as output in tons was kept constant. However, the number of units was the main driver after it was determined. Therefore, it had big impact in the long value chain and additionally with changes in this driver was simple to turn into cost effects. This is unique feature for process industries and might have major effect, as there must be done choices for standardization.

Literature emphasis on strategic questions in component commonality has been marginal. Complexity management revealed the potential of considering the internal complexity and what is the advantage on managing it. In the case company, component commonality is a way to manage internal complexity and it has huge impact also competitive factors like; quality, supply certainty and cost competitiveness, which are important for both to the industry and case company perspective. Additionally, component commonality has not observed the effects of commonality in a two-stage supply chain i.e. answering the question: “commonality for whom”. Inter-organization cost management would be interesting field to extend this discussion further. Study provided interesting insights how the cost effect of component commonality occurs in batch process context. Additional, component commonality in the context of vertical integration is more potential as there is better possibilities to decrease excess internal complexity i.e. non-value adding processes.

To conclude the contribution to the literature, there is several ways to balance between internal and external complexity i.e. making choices between customization and economy of scale. Lean management is originally Japanese way to manage complexity by decreasing complexity or muda (waste) in lean terms and consider what is valuable, which is balancing between internal and external complexity. North-American way of decrease and manage internal complexity is standardization (e.g. component commonality) in order to balance between internal and external complexity. German has brought own way to frame this question with the help of complexity management by combining different ways discovered in the literature and practicants to conceptualize the external complexity that is leading to internal complexity. All these are different ways to conceptualize choices between product and process strategies. Link between these two strategies is product design that replies to required variety for customers and still be efficient for production process.

At practical level, complexity cost is rather abstract. However, solutions from component commonality are concrete. Therefore, pilot calculations were executed with the support of component commonality as seen in section 5.4. Context was close to real world settings and from there it is logical to scale up to different product hierarchy levels. It was deliberate choice to observe only diameter and not move up to widths that is next logical step to decrease internal complexity. Harsh evaluation discovered that there would another 25% decrease potential with number of product, when harmonizing width requirements between Stage 2 manufacturers. Widths would affect positively on supply chain performance as with diameters, but it is lacking some benefits. For example, it would not help to make bigger runs in the cutting process, but it would decrease amount of set-ups. Additionally, there is not positive effect on a driver use. As a result, the positive effect would be by decreasing amount of product variants. Width is linked to end product, therefore component commonality questions would have bigger impact on stage 2 performance. At the moment product choices done by stage 2 is rather arbitrary, therefore there is potential to expand component commonality on widths. Expanding can be done also to higher product hierarchy level that are immensely connected to stage 1 production performance and to stage 2 product performance. In this level, component commonality would have the biggest impact to overall performance. More harmonized product design among stage 2 would enable bigger batches and possibility to pick more suitable quality specifications from stage 1 perspective. However, this observation cannot be done with taken into account the whole customer base of stage 1 and not just inner customers. Expanding to quality specifications requires holistic view and great understanding about the end product quality specifications.

This this can be expanded inside the company and consider the potential of mass customization in stage 2. More controlled customization would lead also have positive effect on stage 1. Enlargement to stage 2 requires better understanding about the customer i.e. balancing between internal and external complexity. Additionally, the role of sales emphasizes as moved closer towards end customer. Question is about turning customer needs more suitable to production and lower the uncertainty involved with demand. To conceptualize is complexity management is also relevant in the stage 2 context. Product design decisions in stage 2 involve possibility to extend to possibilities in modularity. Modular design principles e.g. component sharing (Marti 2007) already exist in some extent but they are not well defined. Modular approach in product design would enable more coordinated product design among stage 1 factories. Better product design and complexity management should be ways get rid of partial optimization between different production stages.

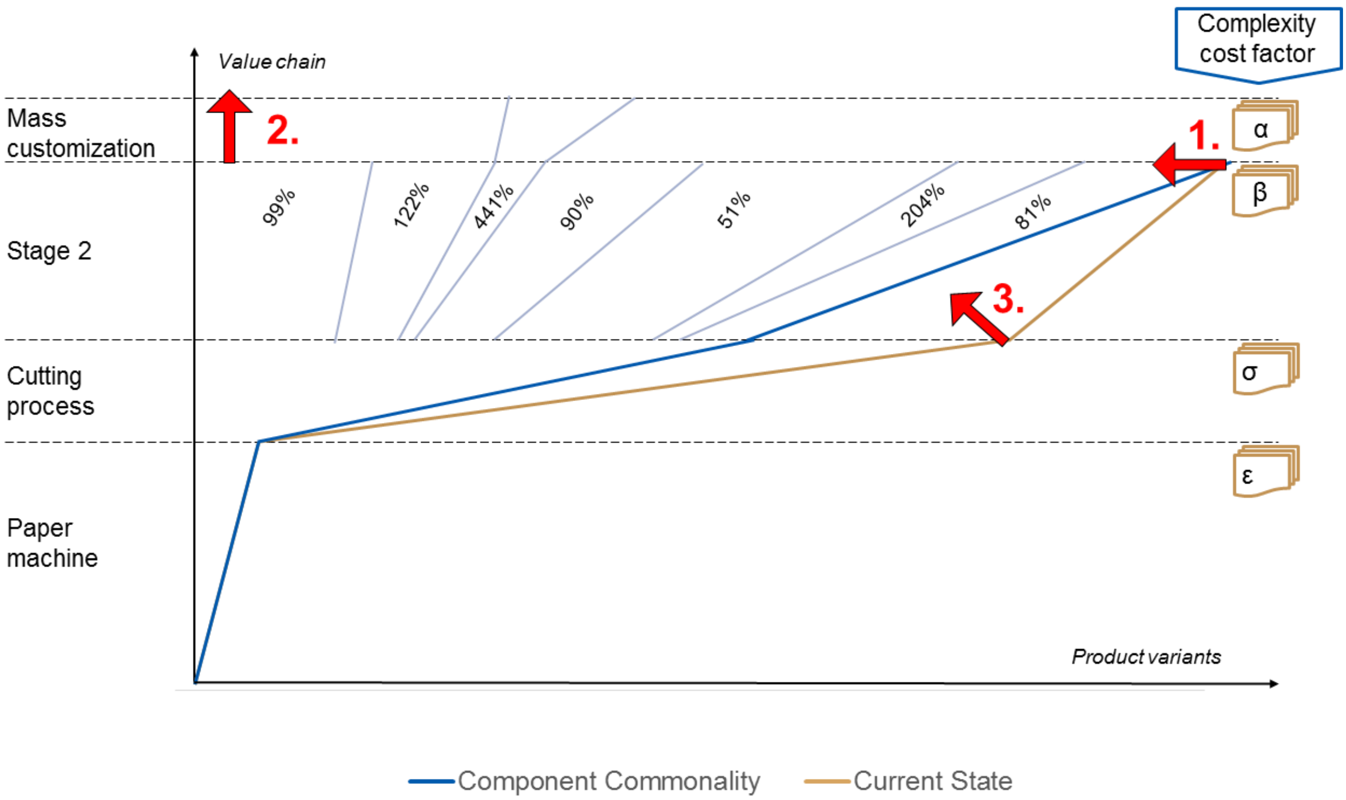

Figure 20: Three ways to decrease complexity costs in the case company value chain.

In order to get better perspective about the value chain, Figure 20 ties together value chain and complexity cost. Most of all combines the ways to manage the complexity in the case company's value chain. It represents how complexity increases as moving forward in the value chain. Dividing the stage 1 into two parts illustrates how the more flexible cutting process increases the sheer amount of product variants. Percentages illustrate how many different variants different customers order in contrast to ordered tons. Complexity cost factor represents the amount of complexity costs each variant causes in a particular process. In literature, this is not emphasized as the point where variant is introduced must be taken into account and not only numerical amount. In this case, abstract complexity costs are simply the amount of product variants multiplied by complexity cost factor. The potential ways to effect are represented in red arrows and they are:

1. Balancing between external and internal complexity
2. Pushing the point of differentiation late as possible in the ways of mass customization
3. Eliminate excess complexity that is not driven by customer

Complexity management can be understood as a way to minimize the area of complexity by pushing the point of differentiation late as possible or simply balancing between external and internal complexity. Options 1 and 2 were excluded from the results scope. However, these are important ways to manage the complexity. The thesis focused on third option, by calculating the cost effect of component commonality on diameter that is not customer-driven and is therefore excess complexity. The figure illustrates visually how the product variety is produced in the value chain. Additional way would be representing the number of product variants produced as key performance measures. Production manager represented that amount of product produced should be one of the important factors when managers evaluate the performance of different manufacturers. Additionally the group controller revealed that this has been a small project to take amount of product produced per production as one of KPI measures.

In order to keep this extended study in control, several choices were made to limit the research. First of all the study focused on component commonality in diameter and excluding other product attributes. This helped to buy an “access” to the case company and worked as an interventionist shield in the battlefield of various competing ideas, agendas and interests as described by Suomala et al. (2012). Interventionist research suits for our case because it started as a scarce assignment concerning product management that effect on every function in the value chain, which means many conflicting interests. Narrowing the scope and buying an “access” with the focused research question, controversy allowed turning the problem into larger question to investigate theoretical questions and from the case company perspective more strategically interesting questions. Interventionist research method suits well to environment with lot of conflicting agendas and requirement to construct an interesting question. Interventionist approach allowed to piloting a cost effect of component commonality and enabled for better discussion and managing neutrality in the research process. In this study was emphasized the role of research question for buying the “access”, which rather worked as “the shield” in interventionist battlefield.

From the complexity point of view choosing diameter as objective was fertile, while it was not connecter to external complexity. Diameter is excess complexity driven by stage 2 production requirements. Other product attributes were connecter to end customers and most of all related to end product quality specifications. Extension to different quality specifications would have effected on productive, which would have major economic impact but simultaneously making the calculation harder and less valid. Considering these questions would have required better experience in this unique industry. Therefore, in this study we limited the observation merely in diameter, which complexity cost factor is lower than with product quality specifications. Extension into quality specifications would have major impact on productivity and quality as discussed in Section 3.2.

To simplify things we assumed that production tons would be constant as with no chance on sales either. There might have positive effect on sales the responsiveness is better and supply security improves. Negative impact might occur when there are changes to the actual product. In calculation, there were done also some assumptions as discussed previously. The largest limitations were done by considering only internal customers of stage 1. This assumption could not have been done for quality specifications regarding only internal customers. However, focusing on internal customers it is easier to accomplish changes by convincing internal resistance than customer requirements.

Combination of rather independent stage 2 units and increasing external complexity has resulted multiplied internal complexity in stage 2. This slow evolution is hard to detect and reason behind it is conflicting objectives between production stages and therefore risk of partial optimization. The aim of this study is to present what is the result of having conflicting product-process strategies. Let us imagine if the case company could design from scratch the stage 1 product portfolio required to supply paper for stage 2 manufacturers. Would the result be having current amount different diameters and widths? Intuitively the response would be questioning what is the point of having this many different product dimensions. To complement this response, the objective of this study is to answer the question: “so what, if we have this many product variations – what is the effect?” Variety in a diameter is product complexity driven by internal requirements and thus excess internal variety that is not justified after understanding the direct and speculative cost effects. The emphasis of this study was to understand the cost potential of component commonality for diameter and therefore decrease excess internal variety. After that is worthwhile thinking the opportunities of mass customization in order to push the point of differentiation late as possible in the value chain. Accomplishing these requires developing the product design collectively between production stages. As a conclusion, it is time to be more intelligent about case company’s complex environment and look again, what would be better way to solve this. This is achieved with better product design by eliminating excess product variety and pushing the point of differentiation late as possible. The Point of good product design is turning complexity into meaning and controlling it in an efficient way.

Result section focused on cost potential of component commonality on stage 1, but there is far greater advantage from the strategic point of view. Component commonality and its advantages are highly connected to the existing competitive advantage in the business e.g. delivery reliability, flexibility and quality. Therefore, efficient management of component commonality might be important competitive factor and the aim is to resolve how to customize. There exist a strategic scope with component commonality in the case company context with long vertical integration enables possibilities for integration of design and production (Ulrich & Ellison 2005). There is possibility to produce wide range of products in stage 2, that stage 1 serves by delivering common products in mass production. This brings a strategic question for make-buy question or potential acquisitions.

Managing complexity can be reached all the way to external complexity, by changing customer’s mindset from “getting the product there” to product being there” (Gilmore & Pine II 1997). Therefore, the company could do the existing practice more simply for both parties, which is disruption in the current business that actually exists already in small scale. This approach would enable chance to manage product design and supply chain beyond stage 2 and harness is more suitable for the case company (e.g. increasing component commonality or decreasing bullwhip effect). From the user experience point of view, the head design of Twitter stated: “substations from the product are the most meaningful one”. This would apply also in the case company in order to decrease complexity for different parties.

Digitalization and better information systems are considered as a way to manage complexity. In order to manage complexity product design and the point of differentiation should rather be under consideration, while these are the root cause of complexity and IT-systems are just a tool to manage it better. The point of complexity management is reasoning the environment better by turning high external complexity into low internal complexity and vice versa. Additionally, identify how external and internal complexity links with product design choices. Lastly, to understand the principles that make company a successful is by managing complexity. From the case company perspective, it is moving towards commonality in stage 2 in order to mass customize the value chain. In this way, component commonality, delayed differentiation and mass customization are ways to build core competence and competitive advantage for the case company.

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