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Modularity and its Effects on Operations and Logistics
A Case Study at IKEA Industry

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Preface

The master thesis is the final part of the Master of Science degree in Mechanical engineering. This master thesis was established and supervised by IKEA Industry and examined by the Department of Industrial Management and Logistics at Lund University.

We would like to take the opportunity to thank our supervisors at IKEA, Filip Banica and David Engvall for their excellent guidance and valuable feedback throughout the entire project. We would also like to thank everyone that we had the pleasure to get in contact with at IKEA and ÅF. All your guidance and feedback have certainly improved this thesis.

Finally, we would also like to thank Sebastian Pashaei, our supervisor at Lund University for all valuable comments and feedback during the entire thesis.

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"A smooth sea never made a skilful sailor"

-British proverb

Abstract

For a modern company to stay competitive on the market, efficient solutions and production systems are often needed. The customer also request more variants while still paying the same low price as before. To keep cost as low as possible several strategies and aspects can be analysed and implemented. In order for IKEA to meet their goals and to be able to deliver according to their plans for the IKEA 2020 strategy, a simpler supply chain and lower costs are needed. One possible way to achieve these goals could be to implement a modular product architecture. In this report the benefits and drawbacks of a modular product architecture is discussed.

Today IKEA has very little knowledge about how well their components in their products can be modularised in order to gain cost reductions in the manufacturing. Many of the products are designed with only the end customer in focus, which in some cases leads to an inefficient production process.

To get a better understanding of how a change in the product architecture could affect the cost at IKEA this study was conducted. The research was limited mainly due to the limitations in time but also since the request from IKEA was to analyse the solid wood range.

The research approach in this study has been to use a single case study methodology, since it is more flexible and well suited for this kind of problem where the authors aim to do an exploratory study. It is also suitable since the authors aimed to gain deeper knowledge about this particular case. In this case the data has mainly been collected through a literature review, archive analysis, observations and interviews.

To be able to calculate the monetary savings connected to the suggested changes in product architecture the products where first decomposed in order to analyse possible common components. Then a comparison between the old composition and the new with a reduction in unique components where conducted. The study showed that IKEA could reduce the number of individual components by 21%. Some of the components that could be reduced are bought from suppliers which reduces the potential savings that IKEA themselves can accomplish. However, the main goal is to lower the overall cost for the entire supply chain and if fewer unique components are needed the purchasing division can work more efficiently. Hopefully, this leads to that the components can be bought to a lower price, increasing margins throughout the entire supply chain.

When looking at the potential savings for IKEA several aspects where analysed. One of the major costs in the production where the cost connected to material use. The use of material is not directly effected by a modular strategy. This raises the question on what IKEA should focus on and what project they should prioritise. A modular product architecture contributes to savings in changeovers, reduced scrap, and less inventory. However, these are relatively small in comparison to the potential in reduced material.

Key words: Modularisation, Product architecture, Manufacturing, and Logistics

Sammanfattning

För att ett modernt företag ska förbli konkurrenskraftiga på marknaden måste de ofta sträva efter effektivare lösningar och ett effektivare produktionssystem. Dagens kunder begär oftare fler varianter som de samtidigt vill betala samma låga pris för. För att hålla kostnaderna så låga som möjligt kan flertalet strategier och aspekter utvärderas och införas. För att möjliggöra att IKEA uppfyller sina mål och når de målsättningar som de har satt upp i IKEA 2020 krävs en enklare värdekedja med lägre kostnader. Ett möjligt sätt att uppnå dessa mål är att implementera en modulär produktarkitektur. I denna rapport kommer fördelarna och nackdelarna med en modulär produktarkitektur att avhandlas.

I dagsläget har IKEA väldigt lite kunskap om hur väl komponenterna i deras produkter kan modulariseras för att uppnå kostnadsreduktioner i produktionen. Flertalet av produkterna är designade med slutkunden i fokus vilket i vissa fall leder till en icke effektiv produktionsprocess.

För att få en bättre förståelse om hur förändringar i produktarkitekturen kan påverka tillverkningskostnaden utfördes en studie på IKEAs byråer i serien Hemnes. Studien begränsades av att tiden var begränsad men även av att IKEA endast efterfrågade en analys av deras produkter tillverkade av limfogsskivor.

Tillvägagångssättet för denna rapport har varit att använda en fallstudie studerandes ett företag då denna är mest flexibel och passar bra för denna typ av problem där författaren har som målsättning att genomföra en beskrivande studie. Det är även passande då författarna strävare efter en djupare förståelse kring just detta fall. I denna fallstudie har data i första hand samlats in genom en litteraturstudie, arkivanalyser, observationer och intervjuer.

För att beräkna de monetära effekterna kopplade till de föreslagna förändringarna i produktarkitekturen bröts först produkterna ner för att kunna analysera gemensamma komponenter. Efter detta utfördes en jämförelse mellan den gamla produktkompositionen med den nya där antalet unika komponenter hade blivit reducerat. Denna studie visade att IKEA borde kunna reducera antalet unika komponenter med 21 %. Vissa av dessa komponenter som kunde bli reducerade köps in från underleverantörer. Detta minskar den totala besparingen som IKEA som enskilt företag kan uppnå. Dock är huvudmålet att minska den totala kostanden i försörjningskedjan och om färre komponenter behövs kan inköpsavdelningen effektiviseras. Detta då färre komponenter men en större volym måste köpas in. Detta leder förhoppningsvis till att komponenterna kan köpas in till ett lägre pris och att marginalerna genom hela försörjningskedjan kan ökas.

Flertalet olika aspekter för potentiella besparingarna undersöktes. En av de större kostnaderna i produktionen var kostnaden kopplade till materialanvändningen. Användningen av material påverkas inte direkt av en modulär strategi och detta får en att ställa frågan på vad IKEA ska fokusera och vilka projekt de ska prioritera. En modulär strategi leder till besparingar kopplade till både omställningar, kassationer och lagerhållning. Dock är dessa relativt små om man jämför med den kapacitet som finns i att minska materialåtgången.

Nyckelord: Modularisering, Produktarkitektur, Tillverkning och Logistik

Table of Content

Abbreviations

This table serve the reader throughout the report with used abbreviations, see Table 1.

Table 1: Table of abbreviation

Abbreviation	Explanation
WIP	Work in Progress
MFD	Modular Function Deployment
QFD	Quality Function Deployment
MIM	Modular Indication Matrix
DSM	Design Structure Matrix
AOE	Absolute Operational Efficiency
ROE	Relative Operational Efficiency
OE	Operational Efficiency
OEE	Overall Equipment Efficiency
KPI	Key Performance Indicator
RE	Rate Efficiency
AE	Availability Efficiency
QE	Quality Efficiency
DC	Distribution Centre
SKU	Stock Keeping Unit
FGW	Finished Goods Warehouse
COD	Chest of Drawers
RQ	Research question
ROCE	Return On Capital Employed

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1 Introduction

The chapter starts with describing the change in paradigm for manufacturing companies. Further the chapter includes a short description of the company, description of the problem, the purpose of the project, the research questions, delimitations, stakeholders, and an outline of the written report.

1.1 Background

One of the global megatrends is that the population with buying power increases. According to KPMG in 2022 more people will be middle class, living on 10 USD to 100 USD a day, than poor (KPMG INTERNATIONAL, 2014). This increased number of people with buying power will force companies to carefully position their brands and portfolios to fit the demand of this rapidly growing middle class (EY, 2015). The growing middle class is also spread across the globe, which is a challenge for companies that tries to have a global presence. For instance a product designed for northern Europe will not work in a warm and humid climate, such as India. Furthermore, there are different laws affecting companies in a global world, one example is that Japan has stricter laws regarding how much phenols that are allowed in the glue used in furniture[1].

Other trends of the market are the increasing importance of diverse product variants, increased product complexity and a need of receiving products at the right time. This change has forced companies to increase the rate of new product introductions to stay competitive. Because of this change a marketplace that is characterised by a global presences as well as increased uncertainty has evolved (Erixon & Stake, Modular product design, 2003). These changes have increased the number of products variants offered to the customers. As mentioned time has become more important for the market. In a survey performed within the manufacturing industry in UK, a majority of the companies reported that they perceived both an increase in demand regarding variety of products and a decrease in product lifetime by 25 percent (Åhlström & Westbrook, 1999). Traditionally profitability can be achieved through economics of scale but with this new trend this is not possible due to the lower production volumes (Tseng & Jiao, 1999).

This new marketplace created by the new trends, has been called many different things and there are at least as many different approaches for companies to stay competitive. Pine described in his book Mass Customization from 1999 this as a shift in paradigm from mass production to mass customisation (Pine II, 1999). In this new paradigm customers want to tailor their product to a specific need and to decide when the product is to be delivered. The interaction with customers in the production process increases the level of complexity. Companies have to adapt their operations and products to cope with these changes in the business environment (Erixon & Stake, Modular product design, 2003). This has created a need for a more granular segmentation and targeting strategies. This strategy derives from the idea that each small segment of customers values different qualities in a product. With tailored products for each segment it may be possible for the company to ask for a premium price (Conroy, 2015). On the other hand one way of solving this problem is discussed by Singh argues in his work from 2016 that companies could yield benefits in form of "make one, sell many principles", which basically is selling the same type of product for both the developed and undeveloped world, by using an affordable product strategy (Singh, 2016).

1.1.1 IKEA a brief description

IKEA is today a world leader in the home furniture industry. However, this has not always been the case. Originally founded by Ingvar Kamprad in 1943, in the beginning IKEA sold fountain pens,

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[1] Interview with Peter Becker, IKEA Group (2016-03-11)

cigarette lighters and nylon stockings among other things. In 1958 the first department store was opened in Älmhult, Småland, Sweden. At the same time the first mountable IKEA furniture was released as well as the first catalogue (IKEA Group, 2016a). Since then IKEA has continually increased the number of stores. Today IKEA has 328 stores and other operations in 43 countries worldwide. Furthermore, IKEA have more than 970 suppliers in 50 countries worldwide. The total number of employees today is more than 155 000 and a yearly turnover on 31.9 billion euros, which makes them one of the largest companies in the home furniture business (IKEA Group, 2016b).

Today IKEA is offering over 9500 products to their customers. Every year 2000-2500 products are replaced in range, meaning that around 25 percent of the products are removed from year to year (IKEA Group, 2016b).

1.1.2 IKEA in 2020

In the strategy 'Growing IKEA - Together 2020' (IKEA, 2012) IKEA aims to almost double their revenue, compared to 2014, to 50 billion euros by the year 2020. Furthermore, they want to increase the number of stores to 530, and enter new geographical markets. This means that the line of products may need to be altered to fit different living situations around the world. To achieve this goal IKEA has established four cornerstones, these cornerstone consists of a number of different drivers. All of the cornerstones of growing IKEA – together 2020 will be treated below and can be seen in Figure 1 (IKEA, 2012).

Figure 1: Simplified illustration of the cornerstones in Growing IKEA together 2020 (IKEA, 2012)

The first cornerstone 'Growing IKEA' has four drivers;

- Better products at lower costs
- A wider, more inspiring and beautiful offer
- A more vital IKEA
- A more accessible IKEA for the many

These four driver could be summarised to that IKEA wants to get closer to the customers by simplifying the shopping experience, meet the changing demand of customers faster, provide greater value to the customers, and lastly to a lower cost.

The second cornerstone 'People', is about understanding people´s needs at home and at work. This puts emphasise on creating a good work environment and understanding how people want to express their individuality at home.

The third cornerstone 'Sustainability', climate change is a reality. IKEA wants to provide to the solution of climate change both as a company and at home for the customers by developing and promoting sustainable solutions. Furthermore, IKEA tries to be resource and energy independent. Above just environmental aspects a social aspect is important for IKEA in 'Growing IKEA – Together 2020'

The fourth cornerstone 'Lower costs' is described as low prices and good quality can only be achieved through low costs. In this cornerstone two drivers are identified.

- Lowering costs
- Simplifying IKEA

The first one focuses on lowering costs throughout the entire value chain as a foundation on which the growth can be built on. In addition to reduce structural costs IKEA wants to evaluate if today's action are optimal for stimulating growth.

The second driver Simplifying IKEA is mainly about that as IKEA has grown, they have become increasingly complex and slow which could threaten future success. Especially in implementing changes and the time to market is way too long (IKEA, 2012).

1.1.3 IKEA Industry

IKEA Industry was established 2011 when Swedwood was merged into the IKEA group. Swedwood on the other hand was established in 1991 as a way for IKEA to secure a continuous supply of furniture. IKEA Industry is today responsible for producing three categories of products for IKEA, the categories are flatline, board, and solid wood. These three categories cover most of the larger furniture sold by IKEA. They are however not the only supplier of these types of products, which means that if another supplier is more competitive IKEA will source from that supplier rather than IKEA Industry[2].

IKEA Industry has today over 20,000 employees and 44 production sites in eleven countries, which can be seen in Figure 2.

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[2] Interview with Filip Banica (2016-01-22)

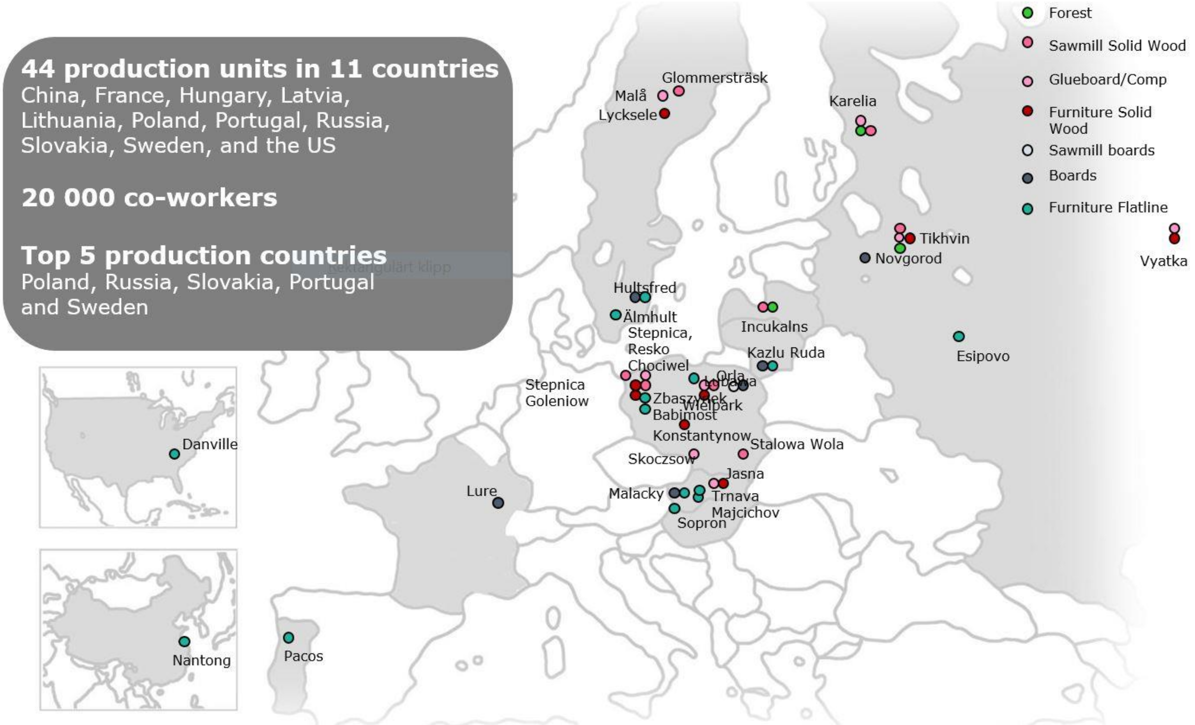


Figure 2: Locations and facts about IKEA Industry

Flatline products are produced in a quite innovative way for the furniture industry, the idea comes from how doors are produced. With a frame and a light filling material that is covered by a thin sheet of wood or other material. This technology is typical used in the famous Lack and Bestå series at IKEA, which includes tables, shelves, and storage systems. One of the Lack tables can be seen in Picture 1.

Picture 1: An example of a LACK table (IKEA, 2016)

Board products are assembled by chipboards, which is board that contains pressed wooden chips. The typical furniture in the board line is the chest of drawers and bedframes named Malm. A typical Malm chest of drawers can be seen in Picture 2.

Picture 2: An example of a Malm chest of drawers (IKEA, 2016)

Lastly is the solid wood line of products that contains glue boards, which are lamellas of wood glued together under pressure to larger boards. These boards are cut to the right dimensions and then formatted to the right shape. The most prominent line of solid wood furniture is the Hemnes line, which contains shelves, chest of drawers, bed frames, and bookcases. A Hemnes chest of drawers can be seen in Picture 3.

Picture 3: An example of a Hemnes chest of drawers (IKEA, 2016)

1.2 Problem description

IKEA does with the strategy 'Growing IKEA - Together 2020' want to enable growth for the whole corporation. The four cornerstones concern growth, people, sustainability, and lower costs. With the market in focus the growth is focusing on a wider offer to a larger part of the world, but at the same time keeping the good quality and lowering costs. The last cornerstone, lowering costs, focuses on lowering cost throughout the whole supply chain and costs related to the complexity of IKEA. The complexity of IKEA stems from the rapid growth, which also have made the corporation unnecessarily slow, especially when it comes to time-to-market for new products.

IKEA Industry faces a number of issues regarding this strategy. Focus will be on two of these issues, firstly as a part of the supply chain IKEA Industry do need to reduce costs, and secondly they need to reduce their complexity. However, since there is a request for a wider offer it might be difficult for IKEA to incorporate these changes. A wider offer creates a problem regarding batch sizes and will reduce the batch sizes due to the need of more different products. Smaller batch sizes are contradictory to lower cost due to more change overs and set ups, which means that each product have to carry a larger fraction of the overhead costs. At the same time a wider offer does increase the complexity and cost by increasing the number of different items that the supply chain is handling, storing and keeping track on. There are a number of issues that IKEA Industry are facing to be able to follow this strategy.

To address these issues IKEA Industry have considered a modular product strategy as a solution. The goals are to cut costs and reduce the complexity by reducing the number of unique components. The case study, which is the foundation of this report, is focusing on the internal supply chain of IKEA Industry and is supposed to contribute to future improvements in this area.

To conclude; IKEA Industry is in need to address issues regarding mismatches between operations and strategy. A basis for further investigations regarding modular product architecture is needed.

1.3 Purpose and research questions

The purpose of this master thesis is to evaluate modularisation as a method for IKEA Industry to decrease complexity and cost.

1.3.1 Research questions

- Is there any way to modularise the products in the solid wood segment, which enables an improvement in operational efficiency, which in this case refers to the relationship between production states?
- Would such modularity yield any reduction in production costs and decrease in lead time?

1.4 Directives and delimitations

To investigate all of IKEA's products during the set time frame for this project would be extremely time consuming. Therefore, the case study will focus on the solid wood range, and the Hemnes chest of drawers.

1.5 Target group

There are a number of different stakeholders in this project; IKEA Industry, suppliers to IKEA, authors, supervisors, and academics. These stakeholders do have different gains from this project. IKEA Industry will get a better understanding if they should work with modularisation through their supply chain. Other companies may be able to use the findings from this report. The authors will get better understanding of how a supply chain does work and how product architecture can influence it. Finally, academic and literature will gain a theoretical contribution as well as real life testing of theories.

1.6 Report outline

A short description of each chapter in the report will be presented below.

Chapter 1 – Introduction

The chapter starts with describing the change in paradigm for manufacturing companies. Further the chapter includes a short description of the company, description of the problem, the purpose of the project, the research questions, delimitations, stakeholders, and an outline of the written report.

Chapter 2 – Methodology

This chapter describes from a philosophical point of view the research and scientific approaches, with a motivation for which is most suitable for this project. The chosen method is described in detail. Lastly in this chapter triangulation is described, which is used to ensure that the project keeps its validity, reliability, and objectivity.

Chapter 3 – Theoretical framework

This chapter aims to presents the theoretical framework for this project. General information about modularisation, standardisation and product development will also be presented. The chapter will also include a section presenting advantages and disadvantages with modularisation in general.

Chapter 4 – Empirical study

This chapter will present the information collected from factory observations, interviews, and data gathering at IKEA. This will be followed by some comments about the collected information.

Chapter 5 – Analysis

This chapter aims to present the analysed material collected from the empirical studies and the collected information. The results will then be compared to existing literature.

Chapter 6 – Discussion

In this chapter the different findings from the analysis are discussed. The results, challenges with the analysis, limitations, and drawbacks are discussed. Important to remember is that this report focuses on the product assortment Hemnes chest of drawers.

Chapter 7 – Conclusion and recommendation

In the following chapter answers to the research questions, recommendations to IKEA, research implications, limitations, and possibilities for future research are presented.

2 Methodology

This chapter describes from a philosophical point of view the research and scientific approaches, with a motivation for which is most suitable for this project. The chosen method is described in detail. Lastly in this chapter triangulation is described, which is used to ensure that the project keeps its validity, reliability, and objectivity.

2.1 Research procedure

There are several ways to achieve the purpose of a study, but to build up the credibility of the report it is of utter importance to motivate the choice of research procedure (Björklund & Paulsson, 2012). To be able to motivate the choice of research procedure an explanation of the different scientific approaches, research approaches, and research methods will be presented. The explanations will put emphasise on when the different approaches and methods are preferred or not.

The methods and approaches will be structured according to (Björklund & Paulsson, 2012). The structure is presented in Figure 3 where the abstraction level gets higher, higher up on the y-axis. The three levels of methods are from top to bottom scientific approach, research approach, and lastly methods for data gathering.

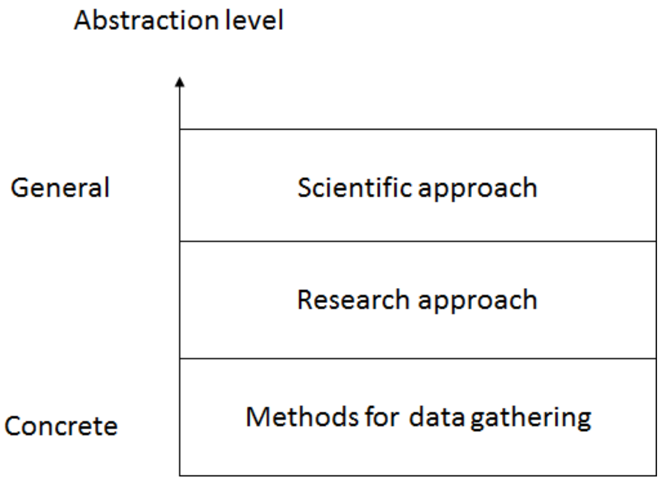


Figure 3: Illustration relation between levels of abstraction, inspired from Björklund & Paulsson, 2012.

However, both (Björklund & Paulsson, 2012) and (Gammelgaard, 2004) argues that the authors philosophical view of reality have a large impact on how the research approach and the scientific approach should be chosen. Therefore it is of importance to state which philosophical view this report is built up on. An illustration on how the philosophical point of view is related to the methods and approaches are illustrated in Figure 4.

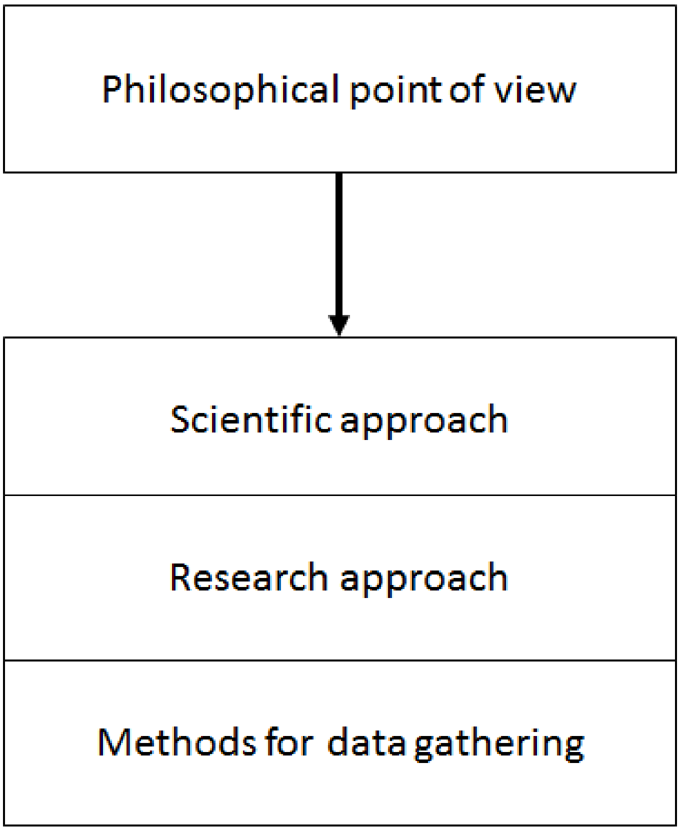


Figure 4: An illustration on how the philosophical point of view is related to the methods and approaches, inspired from Björklund & Paulsson, 2012.

2.2 Philosophical view

The research question alone should not determine the research methods. The methods should also be influenced by the author's view on reality (Arbnor & Bjerke, 2009, s. 6). In fact the research methods are grounded in philosophical points of view that stem from the researcher's paradigm (Golicic, Davis, & McCarthy, 2005). Guba describes in his article from 1990 a paradigm as a set of beliefs that guides action (Guba, 1990). The paradigm consists of three levels: ontology, epistemology, and methodology (Näslund, 2002).

Ontology deals with basic questions of reality, the two extremes of ontology are nominalism and realism. The difference is that nominalism views reality as a construct of the observer and realism views it as independent from the observer (Björklund & Paulsson, 2012).

Epistemology deals with how the world is seen and the relation between the researcher and the known (Näslund, 2002). The two extremes in epistemology are positivism and anti-positivism. Positivism sees knowledge growth as a cumulative process where knowledge is added to old knowledge. Knowledge is acquired by verification or falsification of hypothesis and theories, and the result leads to an objective and true knowledge. Positivism believes that the observer has no influence over the results, the same result will be achieved regardless on the observer. Anti-positivism on the other hand argues that the observer cannot be distinguished from the studied phenomena. Knowledge is gathered through understanding, not just the phenomena but also about the surroundings of the phenomena (Björklund & Paulsson, 2012).

Methodology deals with how the researchers gain knowledge about the world. Consequently the philosophical view of the observers has a great impact on methodological decisions for the researchers (Näslund, 2002), (Björklund & Paulsson, 2012), and (Gammelgaard, 2004).

2.2.1 The Philosophical view in this report

The philosophical point of view used by the authors in this report is an anti-positivistic view, since the authors do believe that knowledge is not just about the phenomena itself but also about the surrounding's. Since this master thesis has been written at a global company it has been hard to truly isolate one single event. The surroundings both on a macro level, changing the geopolitical climate and on a smaller scale in the factory will somehow affect the result. Even though the study aims at being as unbiased as possible some of the settings could be hard to replicate. For example, the price for oil was at its lowest point since 2004 during this study (Avanza, 2016). This affected the Russian economy and their currency plumbed and the production cost at IKEAs Russian factories decreased (XE, 2016). This chain of events eventually affects the production facilities producing solid wood furniture, which makes it hard to ignore the surroundings. Events like this might occur and like in this case totally change the current conditions. Therefore it is important to keep in mind that it is not an isolated phenomenon that gets studied, but the entire system that it operates within.

Furthermore it is believed that the authors will influence how the result is achieved and how that specific result is achieved varies depending on the authors. Depending on how questions are asked during interviews the answers might alter. Also when observing phenomena different persons tend to pay attention different activities. The authors believe that that reality is highly depending on which individual that is observing it therefore a nominalist ontology is considered.

2.3 Scientific approach

Depending on the philosophical view on knowledge the goals with the report can vary. To choose a scientific approach which view on reality is in line with the view on reality of the project will increase the credibility of the findings. Arbnor and Bjerke have in their article from 2009 developed a framework that consist of three approaches to business studies.

The three approaches in their framework are (Arbnor & Bjerke, 2009):

- The analytical approach
- The system approach
- The actors approach

2.3.1 The analytical approach

A researcher with an analytical approach strives to explain the reality objectively. In this reality patterns and causal relations can be investigated and disclosed through research. The effect of the researcher is kept to a minimum. The goal of the researcher is to find cause-effect-relations by decomposing reality in the smallest possible "elements", where the sum of the elements represents the reality. One of the more frequently used methods in this approach is quantitative data analysis (Björklund & Paulsson, 2012) and (Gammelgaard, 2004).

2.3.2 The system *approach*

A researcher with a system approach strives much like one with an analytical approach to explain the reality objectively. However, according to system theory the reality cannot be decomposed to smaller "elements". The reality rather must be understood in terms of mutually dependent "components", as a system with parts, links, goals, and feedback mechanisms (Lilienfeld, 1978). The system approach emphasises that the relations between components is equally important to the components themselves. Churchman stated in his article from 1979 that case studies are ideal for system analysis, where both quantitative and qualitative methods could be used (Björklund & Paulsson, 2012), (Churchman, 1979), and (Gammelgaard, 2004).

2.3.3 The actors approach

The actors approach does not see reality as an object, reality is rather the result of numerous social constructs. Knowledge is perceived as socially constructed, i.e. knowledge creation depends on the researcher's interpretations of a reality where the researcher is being a part of it. The approach is highly contextual and argues that determining cause-effect-relations are impossible due to the irrational nature of humans. Therefore, it is of utter importance to understand intentions to be able to understand reality, this is primarily done through qualitative studies (Björklund & Paulsson, 2012) and (Gammelgaard, 2004).

2.3.4 The scientific approach in this report

A system approach is taken in this report since it is believed that the reality can only be described through its parts and how these parts interact with each other. The researchers believe that many important aspects would be missed if any other approach were taken. Especially when many different functions are involved in the decision making process. A system approach is also in line with the philosophical view where it was stated that the surroundings affect the phenomena. With a system approach it is once again emphasized that a more holistic approach needs to be taken. If the problem is decomposed into too small elements there is a risk that there will be a sub-optimisation. In some cases detailed descriptions of narrow scoped problems are needed. However, to fulfil both the academic requirements and to meet the request from the company a system approach seemed most plausible.

2.4 Research approach

Which research approach that should be chosen depends on the goal and purpose of the project. The overall purpose of the research can vary (Höst, Regnell, & Runeson, 2006). Four different purposes will be described below (Björklund & Paulsson, 2012).

- Descriptive: projects which have a purpose of finding out and describing how the subject actually works.
- Exploratory: a project with a purpose of trying to establish deeper knowledge regarding how the subject works or is performed.
- Explanatory: research that tries to find a cause-effect-relation and explanations on how the subject works.
- Prescriptive: These types of studies aims at solving an identified problem.

Depending on the purpose of the project different approaches can be chosen. Four different approaches will be described below and motivation to which approach chosen will be done last, see Table 2.

Table 2: The differences between different approaches modified from Bjöklund & Paulsson.

Approach	**Purpose**	**Primary data**	**Design**
Survey	Descriptive	Quantitative	Fixed
Case study	Exploratory	Qualitative	Flexible
Experiment	Explanatory	Quantitative	Fixed
Action research	Prescriptive	Qualitative	Flexible

2.4.1 Survey research

A survey is a random examination through questions, with a descriptive or explanatory purpose (Rosengren & Arvidson, 2002). A couple of examples on surveys can be to describe how many uses a specific computer program, what the most important issue is for a company, and how the service is perceived.

2.4.2 Case study research

Case studies are used to study a contemporary phenomenon, especially when the phenomenon is hard to distinguish from its surroundings (Yin 1994). A case study is describing a specific case, and the findings are not generalizable to other cases. On the other hand if there is a case with similar conditions, the chances to get to the same conclusion are high. Furthermore, if several case studies are performed it is possible to identify patterns regarding the phenomena (Höst, Regnell, & Runeson, 2006).

2.4.3 Experimental research

To find a cause-effect-relation and to be able to explain what different phenomena depends on, a more controlled method is needed than case studies and surveys. This is where experiments have an important role. An experiment is primarily used since it is possible to test different parameters' effect on the studied object by varying the parameters and performing the experiment again. To get a good result a systematic approach is crucial otherwise the vast amount of possible effects would be too large (Höst, Regnell, & Runeson, 2006).

2.4.4 Action research

For a project that has a purpose of improving something at the same time as studying it, it is possible to use so called action research (Robson, 2004). This research approach is similar to case studies. For a project of with a prescriptive purpose this approach is valuable (Höst, Regnell, & Runeson, 2006).

Action research follows four steps:

- Plan – Identify the problem and its causes, this could be done in the same way as in a case study.
- Do – Suggest and implement solutions to the problem.
- Study – Measure if the implemented solutions have led to any improvements.
- Learn – If the solutions did solve the problem they should be permanent.

2.4.5 The approach in this project

In this project a case study will be used to study modularity in a producing company. The use of a case study is in line with theory, this due to that the overall purpose of the report is to exploratory describe possibilities for the researched company. A case study is also preferred when the phenomenon is hard to distinguish from its surroundings. It has previously been stated that a system approach is used due to the need of a holistic view and since the surroundings affects the result; a case study is therefore in line with this approach. Another positive effect from a case study is that the design of the study is flexible. Since the data is mainly qualitative new findings might occur during the study that forces the author to shift from the original focus. The authors also want to get a broad spectrum and to take a holistic view on the problem. The use of a single case study is suitable due to the need of deeper knowledge regarding the company. However, the result may not be generalizable to other cases.

In this report a deductive approach has been used. This since the report starts of in the literature regarding modularity, product architecture and supply chain management. Then a case study has been performed at IKEA Industry where data has been collected. Then the data was analysed and conclusions were made upon the result that was found. With this report the authors aims to test if IKEA Industry could benefit from a modular strategy rather than creating new theories regarding cost saving.

This approach was mainly chosen because IKEA Industry wanted to investigate if a modular product architecture could lead to savings in production cost and reduction in lead times. If the request from IKEA on the other hand had been to investigate if savings can be made in the production then an inductive approach could have been more suitable. In that case data from the production facility should have been gathered and analysed. Then depending on the analysis suitable theories could be used to describe the existing situation.

2.4.6 The working progress in this report

The case study in this project was conducted according to a model developed by (Kotzab, Seuring, Müller , & Reiner, 2005). The first step of the model is to determine the research questions, then instrument development, data gathering, data analysis, and lastly dissemination. The model can be seen in Figure 5. However, there were some stages that were added and some stages were not included, the structure can be seen in Figure 6. In stage 8 the testing of ideas was conducted through calculations and not through actual changes in production. So all in all the work was conducted according to the adjusted model.

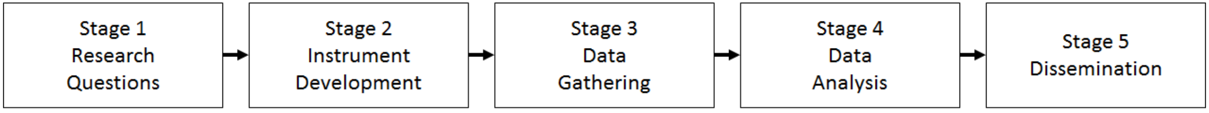


Figure 5: The basic steps of a case study adapted from Kotzab, 2005.

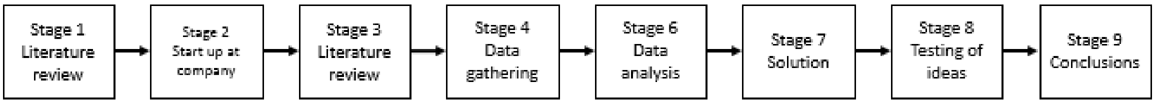


Figure 6: The basics steps of this case study.

2.5 Methods for data gathering

There are numerous ways of gathering data and information. Some different methods will be described with advantages and disadvantages as well as when a specific method is to prefer.

2.5.1 Quantitative or qualitative data

Data that is gathered can be quantitative or qualitative. Quantitative data consists of things that can be counted or be classified, such as quantity, colour or, weight. While qualitative data is made of words and descriptions, the data is characterised by its richness of details and it gives a multi-dimensional view of the problem (Lind, 2014) and (Höst, Regnell, & Runeson, 2006).

The largest benefit with quantitative data is that handling of big data is facilitated, which makes it possible to use statistical analysis and calculations. The drawback is that the quality of the data is largely depending on how it has been gathered, the data can never be better than the method used to gather it. The benefit with qualitative data is that it is very detailed and it is possible to interpret it, which makes it possible to derive different conclusions. The drawback is that the data can be interpreted in the wrong way, which can lead to wrong conclusion if they are only based on qualitative data (Denscombe, 2009).

2.5.2 Literature review

Literature is in this case all forms of written material. The biggest advantage with a literature review is that the researchers can under a relative short time take part of much information. The study helps to map the existing knowledge in the area and build a theoretical frame of reference (Björklund & Paulsson, 2012).

However, there are some disadvantages with a literature study. The data gathered from a literature review is secondary data, the data can have been produced for a different purpose than the purpose of the project. Therefore, it is of utmost importance that the researchers are aware of that the information can be biased and not cover the whole situation. There is also a risk that important information is missed due to chosen search words and which databases that was used (Björklund & Paulsson, 2012).

2.5.3 Lectures, conferences, and similar

To attend lectures, conferences, and similar makes it possible to collect information relevant to the project. The form of this presentation can vary from a small group of specialist to large lectures with over 300 attendees. No matter which type of lecture it is the thing they have in common is that they are presenting secondary data. Therefore, this type of information source has the same disadvantage as a literature review as well as the same advantage, access to large amounts of data in a short period of time (Björklund & Paulsson, 2012).

2.5.4 Interviews

There are different forms of interviews. All questions can be decided on beforehand and asked in a specific order, this is called a structured interview. Another way to approach an interview is to decide on areas of discussion and questions are asked based on the answers from the respondent as well as on previously asked questions, this is called a semi-structured interview. Furthermore an interview can just be a form of discussion regarding a topic and questions are developed during the discussion, this form of interview is called unstructured interview (Björklund & Paulsson, 2012).

The advantages with interviews are that the information gathered is directly relevant to the study, primary data. They also provide a deeper understanding since questions can be altered to each respondent and what they have answered. There is also a possibility to analyse body language and other signals from the respondents. But interviews are time consuming and can be cost intensive due to travels needed to meet respondents (Björklund & Paulsson, 2012).

2.5.5 Questionnaires

Questionnaires are a standardized form with beforehand established questions. The questions can vary, they can be grade on a scale 1 to 7, a simple yes or no question, and the respondent can be given the possibility to answer freely to the question. To whom and to how many the questionnaires are sent depends on which questions the researchers seeks to find answers to. The advantage of questionnaires is that with quite low effort it is possible to acquire large amounts of primary data. The disadvantages of a survey are that there is a risk for misinterpretations, shorter and not as explicit answers as wanted, no possibility to analyse other signals, and that the response rate often is low (Björklund & Paulsson, 2012).

2.5.6 Observations

Observations can be performed in two ways, the observer can be a part of what he or she are observing, participant observation, or studied at a distance. The observer can use different tools like stop watches or can base the findings on more subjective estimates. Since observation can be performed in many different ways and study many different objects, there is no clear advantages and disadvantages of observations other than they can be very time consuming (Björklund & Paulsson, 2012).

2.5.7 Experiments

Experiments are the use of an artificial mini-reality, which can be controlled by changes in given variables. During the construction of a mini-reality some simplification of the reality is done. Furthermore, if experiments are not common practice in the specific field of research, the researches must describe and motivate how the experiment was performed, what was measured, and how the measurement was done. The main advantage of an experiment is that the researcher has control over variables that could affect the result and the experiment may be repeatable for increased reliability of the result. The disadvantage is that it is both time and resource consuming, and the simplifications made in the model can make that the result not applicable in reality, due to the complexity of reality (Björklund & Paulsson, 2012).

2.5.8 Archive analysis

Archive analysis can be seen as the analysis of data and archive material developed for another purpose than the purpose of the project. One example is old reports from finished projects can be studied, to be able to understand the development of the company during a specific period. Since the documents are developed with a different purpose than that of the on going project it is of importance to take that fact in to consideration. Furthermore, external documents of a company may bring a different picture than the documents, which are internal for the company.

2.5.9 Method used in this project

The four methods to gather data in this project are literature review, interviews, archive analysis, and observations. The literature review will be used to gathered basic knowledge regarding the subject and make sure that the authors have enough knowledge to make a solid analysis. Interviews will mainly be used to gather information regarding possibilities and challenges that will not possible to achieve through other methods. Interviews will also be a very good way for the authors to be able to understand how the researched company does work not only in form of how each process is performed but also interactions between functions. The archive analysis will be used to be able to calculate some quantifiable measures to be able to evaluate the actual gains. Lastly observations have been used to be able to fully understand how the material flow actually looks and what challenges there is in the production. An illustration of which method that will be used for secondary or primary data respectively qualitative and quantitative data can be seen in Figure 7.

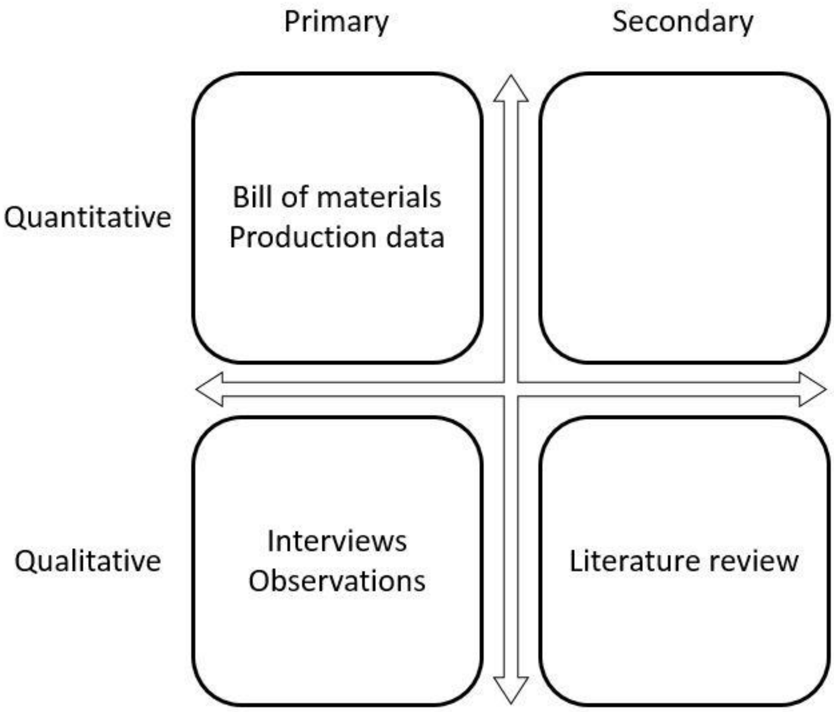


Figure 7: Illustration of the different data sources used in this project

Literature review

The literature review was based on a combination of different search terms related to product architecture, product design, manufacturing, and supply chain. These word where then combined into different search strings, the method was one word from category A, one from B, and one from C each time. The word used in this report can be seen in Table 3 and an example of a search string is TOPIC:(modular design) AND TOPIC: (supply chain) AND TOPIC: (efficiency) from Web of Science. The data bases used in this report were mainly Web of Science, Elsevier, Emerald, Scopus, and Ebscohost. These databases were chosen since they are widely recognised in the research society and consists of reviewed articles.

Table 3: Search terms used in this literature review

Category A	Category B	Category C
Modular design	Supply chain	Efficiency
Integrated design	Operations	Cost
Product design	Logistics	Lead time

To get a more thorough understanding about modular product architecture, literature in form of published books were also studied. This gave the authors a good basic understanding about the modular concept. The books studied in this master thesis were mainly borrowed literature from Lund University library. To get a thorough understanding of a subject it is often recommended to start by reading books. This since they usually are written by authors with extended knowledge about their field.

It is important to remember that literature is a secondary source of information and that it can be biased depending on the author. Important information might also be overseen if critical search words are missing.

However, the literature in this case provided the authors with extensive knowledge about the field of modularity and product architecture. Leading to a good base of knowledge that the rest of this master thesis could build from.

Interviews

Interviews were held with different people throughout IKEA to get input from different functions. The interviewed persons were from product development, production, supply chain management, and general management. To decide which persons to interview it was first important to identify the persons with enough knowledge in this field so that they could contribute to the thesis. It was also important for the authors to get a good understanding of the entire company. Therefore, together with the supervisors at IKEA eight employees from different parts and with different competences from IKEA where chosen for interviews. All of the interviews were semi structured; the interview guide and the interviewees can be seen in Appendix A and in Appendix B.

The interviews in this thesis are as previously mentioned semi structured. The reason that the interviews were chosen to be semi structured were due to the need for the employees opinions on modularity. If choosing a structured interview there is a risk that the interviewees do not get asked the right questions. If the interviews are unstructured there is a risk that the interviews do not become productive. A semi structured interview also has the benefit that questions can be altered depending on the person interviewed and if an interesting topic is presented. In this kind of interview the authors estimated that it was most probable to get good exploratory answers while the interview stays within a pre-set area.

To make the interviews as reliable as possible both the authors aimed to attend at all interviews. Both authors were present on all interviews except the last one with Petra Carlberg where only one of the authors was present. All interviews were performed in person or on in a videoconference. It was always preferred to perform the interviews face to face. But in some cases it was not practicable. After the interviews the answers were transcribed and sent back to the respondent, so the respondent could make corrections. In the report have the answers from the respondents been made anonymous.

Observations

To get a clearer picture how the production actually was performed in this case a visit to IKEAs factory in Wielbark, Poland was made to gain knowledge regarding the production. During the visit a guided tour through the factory was performed, to remember the visit notes where taken during the tour. It was also given some time to walk the production line and study the different production steps in depth after the guided tour. This provided the authors with additional information about the system and the different stages of the production could be studied as long as needed. Due to safety reasons the observation was a non-participant observation. During this visit at the factory no data were collected from the machines. The observations were strictly visual and the main purpose were for the authors to get an understanding about how a solid wood furniture is produced. The visit and the observation clearly helped the authors to connect production data to the manufacturing process. It also facilitated the description and mapping of the manufacturing system.

Archive analysis

The archive material mainly used in this report consists of bill of material and production data from IKEA Industry. One of the challenges when analysing the archive material was that the material was not intended for this master thesis. The production data presented required some analysis before it was possible to use in a constructive way. The main reason why using already existing data is due to the time limit. If the authors would generate all data themselves the time frame would be exceeded. Another aspect with the archive material is the reliability. In some cases different sources can present different result. If such a case would occur it is extra important to critically review the sources. Aside from these drawbacks archive analysis can be seen as an efficient method to collect large amount of data that often has a high degree of reliability. Therefore this is a preferable method to use in this master thesis.

2.6 Credibility

The credibility of a study depends on three aspects; validity, reliability, and objectivity. These aspects always have to be considered in any scientific context. A short description of the aspects can be seen in the list below. (Olhager, 2016)

- *Validity:* The extent that the researchers actually measured what they intended to measure.
- *Reliability:* To what extent would the research yield the same results if repeated.
- *Objectivity:* To what extent does the beliefs of the researchers effect the results.

2.6.1 Ways to increase validity

Using multiple perspectives by using so called triangulation can increase the validity of a study. Triangulation is when two or more methods are used to achieve the same goal. There are also other ways to use triangulation; (Olhager, 2016)

- Data triangulation: Is when different sources of data are used.
- Theoretical triangulation: Use different theories on the same data.
- Evaluation triangulation: Different persons evaluate the data.

2.6.2 Ways to increase reliability

The reliability of the research can be increased by the usage of control questions in interviews and surveys. Triangulation can also help to increase the reliability of the research (Olhager, 2016).

2.6.3 Ways to increase objectivity

By clarifying and motivating the different choices made in the research the reader is able to self-determine if the research is objective or not. When referring, it is of importance to not have any factual errors, no biased factual selection, and lastly try to avoid emotive words.

However, only a researcher with a positivistic point of view on reality can perform an objective study without involvement of subjective values. A researcher of an anti-positivistic point of view rather views honesty, ethics and moral more important to evaluate a study. (Olhager, 2016)

2.6.4 In this report

Data triangulation has been used in this project in the case of production and product data was gathered from different factories regardless of having a focus factory. This data have then been compared and the differences have been addressed by using the most relevant source as a reference. Furthermore the product calculations have been done on the technical description of each product combined with data from production.

To keep this report as reliable as possible the authors have aimed to, when fact was stated, use several sources. This in order to triangulate the fact. Also when discussing theories and methods several sources were preferred. The quality of the sources was also of importance. In some cases old articles needed to be complemented by newer research, especially in fields where the conditions change rapidly.

To get a reliable result from the interviews at IKEA it was of utter importance that they were executed in a correct way. An interview guide was prepared before the interviews. This to be able to ask the same questions to several employees, if doing so the answers could more easily be compared. Employees from different parts of IKEA were also chosen to get a broader view over the company. Also having a diverse group of responders increases the reliability. This since employees at one department tends to work in the same way.

When observing a production facility there is a risk that the employees would not show the entire facility in order to hide something. However, this was not the case in Wielbark, Poland. First a guided tour was given, and then the authors could without supervision walk around in the factory observing the employees in natural conditions. This increases the reliability that what was observed corresponds to how the everyday production looks like.

The objectivity can be discussed, however the authors do have an anti-positivistic point of view and therefore they cannot be seen as totally objective. The researchers have no interest in how the researched company evaluate the result and they have tried to stay as honest, ethical, and morally neutral as possible.

3 Theoretical framework

This chapter aims to presents the theoretical framework for this project. General information about modularisation, standardisation and product development will also be presented. The chapter will also include a section presenting advantages and disadvantages with modularisation in general.

3.1 Product architecture

To understand the concept of modularisation the term product architecture must first be defined. Ulrich states in his article ‘The role of product architecture in the manufacturing firm’ from 1995 that "*product architecture is the scheme by which the function of a product is allocated to physical components*". Product architecture decisions are made during the early part of the design phase where research and development often plays a lead role. The product architecture can be a key driver for the company’s manufacturing performance and is therefore often very important (Ulrich K. , The role of product architecture in the manufacturing firm, 1995).

In informal terms product architecture can be seen as how the function of the product is allocated to physical components. Or more specifically; (Ulrich K. , The role of product architecture in the manufacturing firm, 1995).

- The arrangement of functional elements.
- The mapping from functional elements to physical components.
- The specification of the interfaces among interacting physical components.

Product architecture can roughly be divided into two different architectures, modular and integral. Modular architecture is a one-to-one mapping of functional elements in the function structure to the physical components of the product. It also specifies the decoupled interfaces between components. Integral architecture has a non-one-to-one mapping from functional elements to physical components (Ulrich K. , The role of product architecture in the manufacturing firm, 1995). In this report mainly modular architecture will be discussed. However, standardisation can also be seen as a possible product strategy in the component level.

Erixon states in his paper from 1994 that product architecture can be treated on three different levels where the potential for modularity mainly is in the product range-, and product-level, see Figure 8 (Erixon, MFD - Modular Function Deployment: en metod för att rätt modulindela förtegats produkter, 1994).

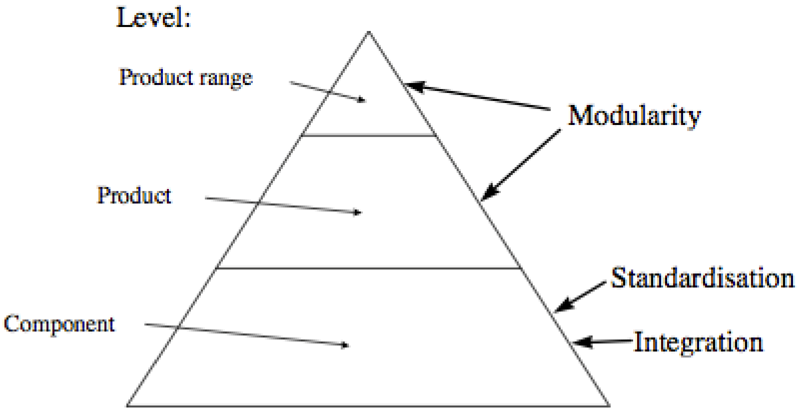


Figure 8: Levels of product architecture adapted from (Erixon, 1994)

Erixon has except of his licentiate paper from 1994 also written several other books and articles in the area, including his doctoral thesis, Modular function deployment- A method for product modularisation from 1998 among others. This together with his work at the consulting firm Modular Management has let him contribute to the body of knowledge within this field for several years. Erixon could therefore be seen as a reliable author within this field. However, Erixons work often revolves around the methodology how to implement a modular strategy. Therefore other sources are reviewed in order to get a complete picture over all aspects concerning a modular product architecture.

3.2 Product Modularity

Product modularity is as previously described one of mainly two possible product architectures. However, in literature several different variants of product modularity can be found. To begin some different variants of modularity will be presented. The categorization shown in Figure 9 was first presented by (Ulrich & Tung, 1991) and has later been further developed by (Ulrich & Eppinger, 2012). Other authors like (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998) and (Pine II, 1999) also categorize modularity in this way. A further explanation of the various module categories will be explained in the following sections.

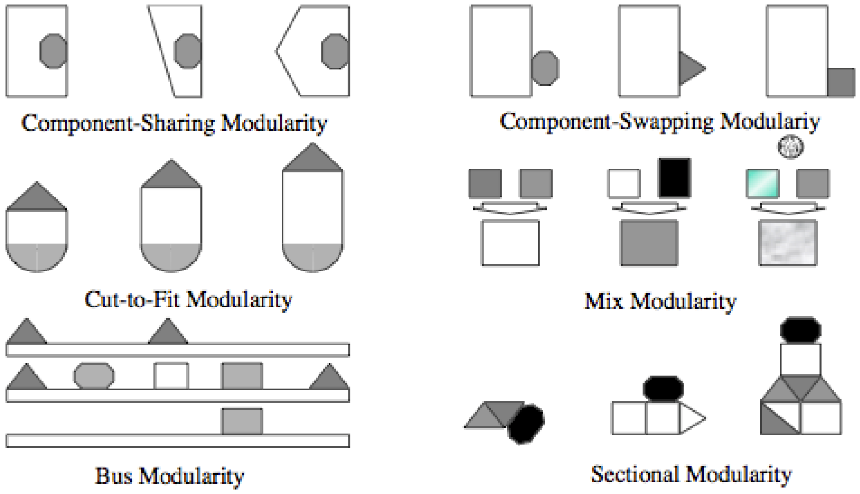


Figure 9: Variants of modularity (Pine II, 1999)

Component sharing modularity

In component sharing modularity the same component can be used in a variety of products to provide economies of scope. This is mainly done for product lines whose costs are rising faster than the number of products. This kind of modularity never results in true customization, but it allows low cost production of a variety of products. This kind of modularity is especially suitable for product lines with high variety that needs to reduce the number of parts, but also to reduce the cost of an already existing product line with high variety (Pine II, 1999).

Component swapping modularity

Component swapping modularity is a complement to the component sharing modularity. In this case different components are paired with a basic product, creating new varieties. This type of modularity is in many cases very similar to the component sharing modularity. Many products where a base product is produced centrally and then customized on-point are of the component swapping modularity type (Pine II, 1999).

Cut to fit modularity

The cut to fit modularity is similar to the two previously presented modularity types. However, in this case it is possible to vary one or more components within pre-set or practical limits. This type of modularity is most useful for products where a customer greatly values that some components can be continually varied to match the individual customer's requirements and preferences (Pine II, 1999).

Mix modularity

The clearest distinction of mixed modularity is that when the components are mixed together they themselves become something different. For example paint that are mixed together. In this case, which in a good way represents mix modularity, the components are not visible in the end product (Pine II, 1999).

Bus modularity

Bus modularity uses a standard structure on which different kinds of components can be attached. This concept can somehow be a bit difficult to grasp since the bus can be hidden or abstract. But in general it is some kind of base which components can be connected to (Pine II, 1999).

Sectional modularity

The final type of modularity is the sectional modularity. This type provides the greatest degree of both variety and customization. This type provides the possibility to combine any types of components as long as they can be combined through a standard interface. A good example is Lego that provides an infinite way of combinations through their locking-cylinder interface. This type of modularity is the most robust of the six mentioned, but also the most difficult to achieve (Pine II, 1999).

3.4 Benefits and drawbacks with modularisation

A modular strategy comes with both benefits and drawbacks. Scale and scope advantages are possible if the same module is used in various products. Modularity can also create larger variety of products. However, modularity might lead to excess cost due to overdesign and inefficient performance (Hölttä-Otto, 2005). In this section some benefits and drawbacks of modularisation will be discussed. For an overview of the benefits and drawbacks with modularity see Table 4.

Table 4: Benefits and drawbacks with modularisation

Benefits	**Drawbacks**
Shorter development lead time and shorter time to market	High initial cost
Economies of scale and scope	Risk of becoming too cost efficient and losing sight of customer needs
Simpler procurement due to fewer components	Risk of increasing the product development complexity
Increased opportunity for sales to address certain markets	Risks connected to change in suppliers required to produce the new modules
Inventory pooling	Risk of creating products that would be cheaper to produce as an integer
Time for skill developing activities	Easier for competitors to copy a module rather than an entire product
Reduced risk of forecast errors	Requires technical understanding from the company

3.4.1 Benefits of modularisation

In 2010 the Corporate Executive Board published a modular design playbook with guidelines for assessing the benefits and risks of modular design. In that report some benefits are described (Eager, Elsam, Gupta, & Velinder, 2010).

First they address the research and development process. In this process a modular design fundamentally change this process. In this case instead of an integrated design the product design seeks to address market needs as well as create a framework that can take advantage of a variety of discrete modules. Companies can also shorten the development lead times by using modular components. This since the modules can be developed and tested simultaneously. Module designs and materials can also be reused causing a shorter development time (Eager, Elsam, Gupta, & Velinder, 2010). Another positive benefit except the shortened development phase is that it can reduce the time to market (Hölttä-Otto, 2005).

Another function that benefits from a modular strategy is manufacturing. By doing this fewer components needs to be produced making it possible to drive scale. The manufacturing process also benefits from a possible reduction in the assembly line. If components can be sub assembled into a module before the final assembly the lead time can be decreased. The increased volume also allows the manufacturing facility to reduce the relative amount of changeover. This since fewer unique components needs to be produced. The manufacturing also tends to get more flexible since the different modules can be manufactured independently of each other (Eager, Elsam, Gupta, & Velinder, 2010).

Procurement also benefits from a modular design since the number of unique parts in a product are reduced. It might also make it possible to engage in deeper relationships with some suppliers due to larger volumes. It is also possible to reduce the inventory since fewer unique components are procured. In this case it is especially the total safety stock that gets reduced (Eager, Elsam, Gupta, & Velinder, 2010) and (Baker, Magazine, & Nuttle, 1986).

Another function that also benefits from a modular design is marketing and sales. This since companies can map up customer needs and segments. This makes it possible for sales to offer a wider product range for the customer and to make the product more customised. It is also possible for the customer to upgrade modules in their products which can lead to increased sales and a more satisfied customer. It is also possible to in a simpler way repair the product if only a module need to be repaired and not the entire product (Eager, Elsam, Gupta, & Velinder, 2010).

If there is freed capacity due to reduced changeover times there is also more time for skill developing activities among the workforce (Ståhl, Industriella tillverkningsstem - länken mellan ekonomi och teknik, 2012, s. 270). One of the benefits with a well-trained work force is for example the ability to operate several stations. This will lead to a more flexible and stable production since an absent employee can be replaced and the machine can continue to produce components. Personnel can also more easily be relocated to stations that needs more capacity or to avoid balancing losses (Ståhl, Industriella tillverkningsstem - länken mellan ekonomi och teknik, 2012, s. 287).

The risk for an error in forecast also decreases when using a commonality strategy due to fewer unique components (Zhou & Grubbström, 2004).

3.4.2 Drawbacks of modularisation

Even though a modular design can provide several benefits there are also some disadvantages with this design strategy.

Firstly, the initial cost to reconfigure existing products and processes are high. Changes in the product composition might cause a disruption of the flow of products in the supply chain. It can also be difficult to predict the actual savings, which might lead to problems in requesting capital from the management. It is also possible that companies becomes too cost-efficient and loses sight of the customers need. In a worst case scenario this can lead to lost market shares and revenue. A modular design can increase product development complexity. To avoid this it is important to assigne clear ownership and to plan the process well.

When adopting a modular strategy it often leads to a change of supplier. When dealing with new suppliers there is always a risk that the company can experiences delays, incorrect specifications and poor material quality. There is also the possibility that the company needs to share technical expertise to the suppliers in order for them to meet the specifications. Then the company might lose their technical advantage against the supplier.

Some products that are cheaper to produce as an integer might need to be modularised when the range of products are modularised. This can create higher cost for the products. The designers must also have a broad technical understanding to be able to construct modules that can be applied in several products. If the design team does not have this skill the company might miss some of the synergies with a modular design. It is also easier for competitors to copy a module than an entire product. This might lead to more competition in the business. This can be avoided through rigorous patent documentation of the key modules in the product architecture. (Eager, Elsam, Gupta, & Velinder, 2010)

3.5 Modular drivers

In Erixons doctoral thesis from 1998 twelve different driving forces behind modularisation are mentioned. The drivers can be found over the entire product life cycle and are further presented below. These drivers can often be seen as generic drivers but in some cases they need to be complemented by company specific drivers (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998).

In the article Modular function deployment-using module drivers to impart strategies to a product architecture from 2014 Lange and Imsdahl discuss modular drivers. They also uses the previously mentioned twelve generic modular drivers as a base for their article. However, they emphasise the possibility for companies to add specific drivers for their market. For example the medical industry might have a driver connected to regulations in order to use a modular strategy. They also cluster the different drivers depending on where in the products life cycle it can be placed and from the perspective of which persons that expresses the driver, see Figure 10 (Lange & Imsdahl, 2014).

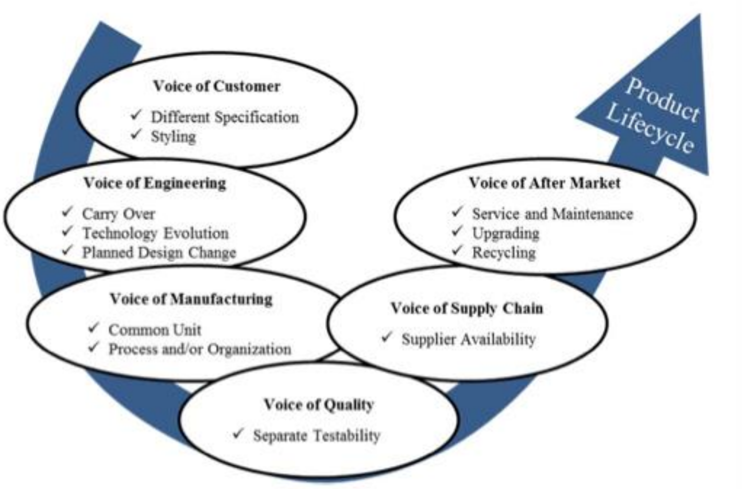


Figure 10: Modular drivers over the product lifecycle (Lange & Imsdahl, 2014).

With this in mind it is important to consider who benefits from a modular strategy and which drivers to address.

Technical specification

In order to handle customisation and product variation effectively the company should strive towards allocating as many of the different technical specifications in as few parts of the product as possible. By doing this together with a modular strategy, the product can easily be customised to satisfy the customer. The variations should then also be performed as late as possible in the production chain to improve inventory savings, customer service and to lower the overall cost. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Styling

If the product is strongly influenced by trends a good idea is to have modules that can be changed without affecting the products function. By doing this the product can easily be customised while the production still can produce the generic product. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Carry over

If a part of a product or a sub system from an old product is used in a newer product it is carried over. The part may be carried over from an earlier generation of the product to a new one or from a product family to another. Because of this it is important to review the entire company if sub systems can be carried over from other functions. It is also important to consider how carry overs can affect the company image. If a new product looks too much alike the old one some customers might get dissatisfied. To facilitate a carry over the parts must be of a modular structure so that the can fit with the new system. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Technological evolution

If a part or a sub system is likely to go through a radical technology shift during the products life cycle it is a good idea to modularise that specific part. If there is a change in the customers demand the company need to change that part in order to stay competitive. Many products are also continuously improved. In this case a modular design helps the company to retain a competitive product. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Planned design changes/product planning

One of the most important factors for a products' success or failure is the product planning and product strategy formulation. One way to improve the success rate is by using modularisation as a product strategy.

When planning design changes the product development process can be divided into primary development (new strategies, technologies, materials) and product delivery in order to facilitate the project development. This is done more easily with a modular product strategy. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Common unit

Even if there is a high degree of variation it might still be possible to find a part that is a common unit that is used throughout the entire assortment of products. These kinds of parts can be found by studying blue prints and similar. A common unit is not necessary the same thing as a carry over unit. But if these can be combined huge winnings can be made. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Process and/or organisational re-use

When manufacturing products the processes can look different depending on which part of the factory that is studied. With a modular approach equipment and skills can in simpler way be shared to improve the production. Standardised modules and processes also improves the possibility of automation. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Separate testing of functions

If the end product is divided into modules these can be separately tested and the quality ensured. By doing this defect components can be discarded earlier and the feedback loop is shortened. Shorter feedback loops enables the production to quicker fix errors. Also, with separate testing of the modules the end product does not need to be tested at all since all the correct modules guarantees a functioning end product. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Supplier offers black box

When working with a module product strategy the company is able to order complete modules from their supplier. This is called black box engineering since the buying customer does not interfere with the supplier's development process. This kind of work will also lower the purchasing cost. Fewer models also facilitates the supply chain since the number of components are reduced from all the subcomponents to one module. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Service and maintenance

With a module structure damaged modules can quickly be replaced by a functioning one. Then the damaged component can be repaired thoroughly at a workshop with the proper tools nearby and in an ergonomic and safe way. This prevents downtime which in many cases can be a significant cost for the company. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Upgrading

If the product is constructed around a modular architecture, there is a possibility to upgrade modules during the product's lifecycle. Products can also be rebuilt for new purposes to gain market advantages. A modular structure also helps the salesperson to quickly present a price for an upgraded model. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

Recycling

To satisfy the increasing demand of environmentally friendly products, modules can be design so that they consist of one or a few materials. This makes the modules and the product easier to recycle. If there should be some environmentally hostile parts they can be kept in the same module to minimize the impact on the environment. If there would be some new legislation, for example forbidding certain materials, that module can easily be substituted. (Erixon, Modular Function Depoyment - A Method for Product Modulrisation, 1998)

3.6 Integral architecture

In contrast to modularity that provides flexibility an integrated strategy strives towards stability and optimisation. The design aims to have as many functions covered with as few components as possible. This gives a high initial cost but the operational cost becomes lower, see Figure 11 (Erens, 1996). This since the number of components is much fewer than in the modular case. However, this usually requires a stable environment and is therefore more suitable for mature companies.

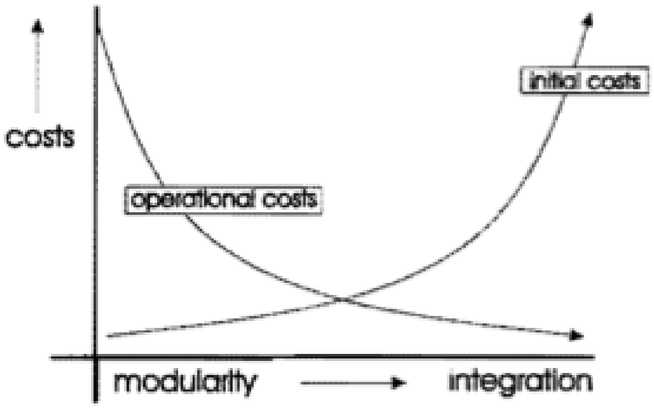


Figure 11: Cost for modularity and integration (Erens, 1996)

Ulrich and Eppinger also state that a product with an integral architecture often is designed with the highest possible performance in mind. Boundaries between the different parts can often be hard to find and sometimes even non-existent. Since many functional elements are composed down to a few physical components small adjustment in the final product often becomes expensive and might require extensive redesign (Ulrich & Eppinger, 2012, s. 186).

On the other hand an integral architecture can give benefits in form of facilitation on an holistic optimization performance. Especially those who are driven by size, shape and mass of the product (Ulrich & Eppinger, 2012, s. 189).

Integration can also be seen in a perspective with modularity and design margin. These three often stand in conflict with each other. Modularity is needed in order to increase the variety and integration improves the cost performance ratio. The design margin is the freedom in design that allows the designer to postpone critical requirements in order to meet the customer's requirements. If the design margin is reduced a more modular and integral strategy can be implemented, see Figure 12 (Erens, 1996, s. 236).

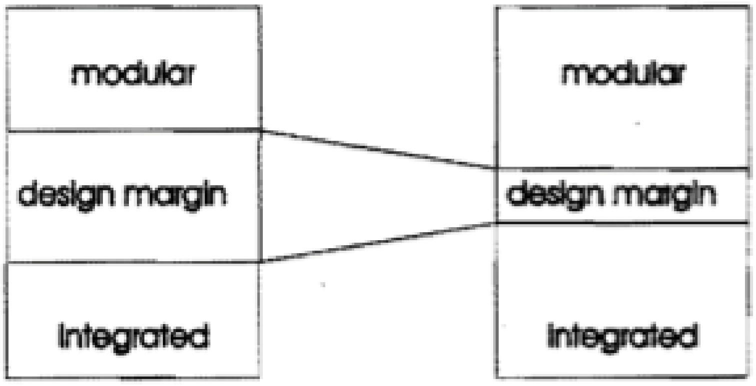


Figure 12: Modular, integrated and design margin ratio (Erens, 1996, s. 236)

3.7 Product commonality and component sharing modularity

Another product strategy is component sharing modularity were several components are used in different products. This strategy is often used to drive economies of scale. This leads to shorter lead times due to less setup time, which in the end results in lower price per unit in comparison to a component that would have been customized. If a component is produced in bigger volumes it might also attract new companies that can start to reduce costs in order to gain market shares. Larger volumes also give the company the possibility to gather more information about their product and to optimise the production even further, which also might cause lower production costs (Ulrich K. , The role of product architecture in the manufacturing firm, 1995). An illustration of component commonality compared to no commonality can be seen in Figure 13 and Figure 14.

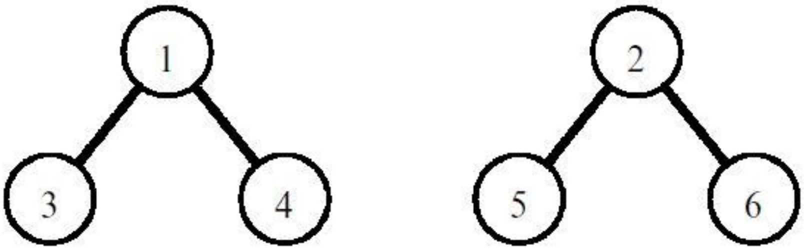


Figure 13: No commonality between products (Hillier, 1999)

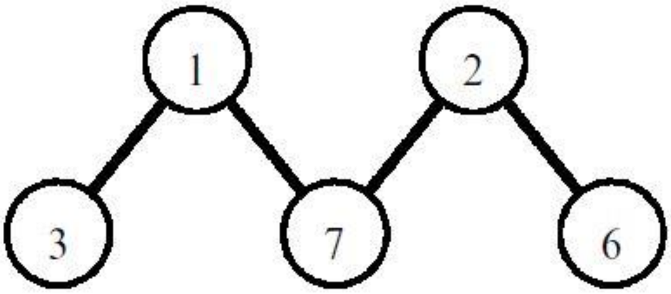


Figure 14: Commonality between products (Hillier, 1999)

It also increases the reliability of the production since the lead times are reduced. However, a commonality strategy, which this strategy also is mentioned as, can be hard to follow since different niche market may require small customizations of the product. This leads to many variations and the modules erodes (Boas & Crawley, 2011). Erens also states that if designers and engineers focus too much on an individual customer requirements they might feel that a sharing in components may jeopardise the quality. This makes them develop new products and ignoring standards instead of reusing existing material (Erens, 1996, s. 2).

Common component often has better performances, in comparison to its cost, then unique design due to the experience the company has gained from producing the previous components. However, it might prevent a company from adopting a new technology or a new component due to lack in compatibility. On the other hand it might reduce the complexity in the product leading to lowered lead times and costs. The number of uncertainties also decreases with already known components (Ulrich K. , The role of product architecture in the manufacturing firm, 1995).

3.8 Risk pooling

By using one type of components in several different products a company can reduce risk of stock outs and over stocking, if say one product sells very well and the other sells poorly. This kind of benefit is called risk pooling or inventory pooling and allows the company to carry fewer components in inventory. Several authors have discussed this phenomenon over the years and many have developed models to be used when calculating the possible benefits. Two examples of methods are, firstly the commonality index method developed by (Collier, 1982) and the single period inventory model developed by (Baker, Magazine, & Nuttle, 1986) which has been further refined by (Hillier, 1999).

3.8.1 Commonality index

Commonality index is a method where safety stock is calculated by first calculating the Degree of Commonality Index, which is basically an index for evaluating how much components that are shared between the products. The lowest possible index is one (1) and is achieved when there is no sharing of components in the finished products. The highest value is when all components are shared between all the finished products, the extreme example would be if one type component is needed for all finished products. This is then used to calculate the aggregated safety stock compared to what safety stock is needed without commonality, according to equation (1).

$$Degree\ of\ Commonality\ Index\ (C) = \frac{\sum_{j=1}^{d} \Phi_j}{d}, \quad 1 \leq C \leq \beta \qquad (1)$$

Where: Φ_j= the number of immediate parents component *j* has over a set of end-items or product structure level(s). d = total number of distinct components in the set of end-items or product structure level(s). $\beta = \sum_{j=1}^{d} \Phi_j$ which is equal to the total number of immediate parents for all distinct component parts over a set of end-items or product structure level(s). An example on how commonality index is calculated can be seen in Figure 15.

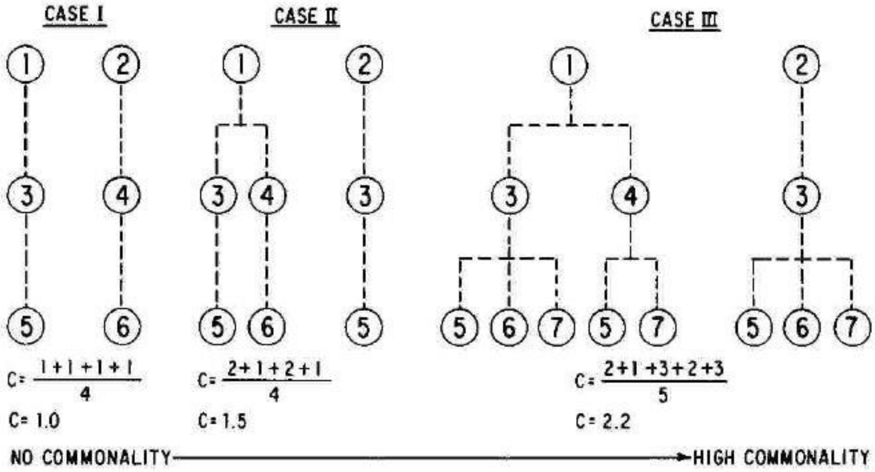


Figure 15: Example of how to calculate commonality index (Collier, 1982)

The relationship between the Degree of Commonality Index, total safety stock for j items, and the aggregate safety stock (S_c) for the common component part(s) that replaces the d items is given by equation (2).

$$S_c = \frac{1}{\sqrt{C}} * \sum_{j=1}^{d} S_j \qquad (2)$$

3.8.2 Single period inventory model

Hilliers believes that Colliers equation is way too simple and has developed a single period inventory model, where safety stock after and before commonality is compared to see what benefits that can be achieved. The idea is to minimize the area of the illustrated rectangle in Figure 16, while satisfying the service level, the grey area, but still have the smallest area as possible. This results in the linear program (P1)

$$\text{Minimize } T_{SP} = (h_3 + h_4)S_3 + (h_5 + h_6)S_6$$
subject to
$$S_3 S_6 = \beta b_1 b_2 \qquad \text{(P1)}$$
and
$$S_3 \geq 0, S_6 \geq 0.$$

In these formulas the variable is the stock level S for each component, β is the service level wanted, h is holding cost but can be considered as cost of the component since it is a single period model, and b is the demand distribution. The indices on S follow from Figure 13 and Figure 14.

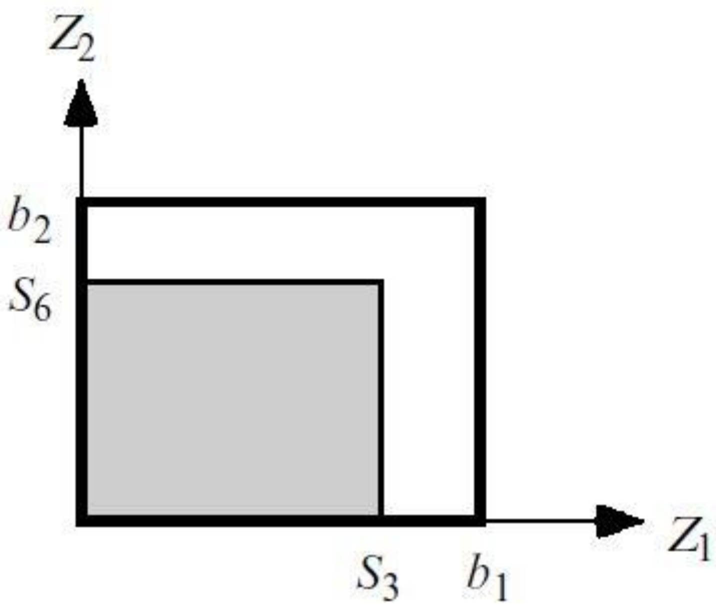


Figure 16: Grey area is the needed stock level to be able to satisfy service level (Hillier, 1999)

However, when the commonality of components is introduced, the constraint and the equation changes according to introducing a straight line that cuts of one corner of the rectangle. The service level is still needed to be achieved however not as much area is needed, which can be seen in Figure 17. This results in the linear program (P2). The same notation in P2 as in P1.

$$\text{Minimize } T_{SP} = h_3 S_3 + h_6 S_6 + h_7 S_7$$
subject to
$$2S_3 S_6 - (S_3 + S_6 - S_7)^2 = 2\beta b_1 b_2 \qquad \text{(P2)}$$
and
$$S_3 \geq 0, S_6 \geq 0, S_7 \geq 0.$$

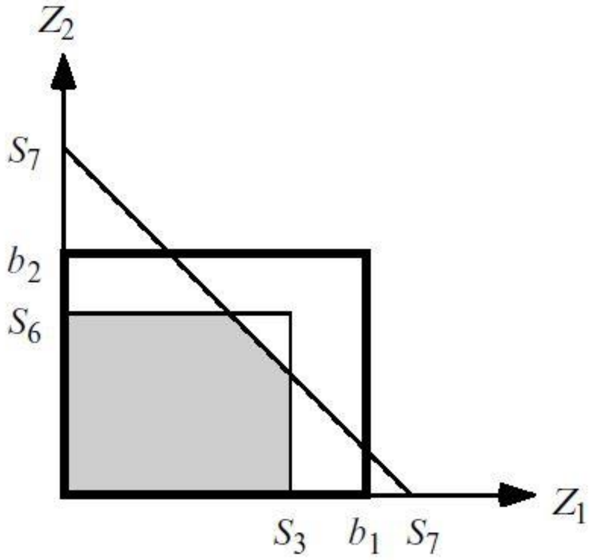


Figure 17: The grey represent needed stock to reach certain service level (Hillier, 1999)

3.9 Modular clustering methods

When deciding on how to modularise a product usually some sort of clustering method is often used. There are several possible methods to use when clustering components into modules. Some of the more frequently used methods are the Modular function deployment, Design structure matrix, Product decomposition and various heuristic methods (Erixon, 1998), (Hölttä-Otto, 2005) (Pimmler & Eppinger, 1994), (Stone, Wood, & Crawford, 2000)

The goal of the methods is to systematically divide a product into modules. The methods differ slightly among each other. In some of the methods, as in the modular function deployment, the modules are derived from the customer's requirements while the product decomposition method is more about breaking down an already existing product, finding the interactions and then clustering the elements into chunks (Erixon, 1998), (Pimmler & Eppinger, 1994). However, the main goal is to decompose a product into modules using a structured method.

3.10 Clustering method used in this master thesis

The method used to derive to the suggested modularised product architecture is a slightly modified version of the product decomposition method suggested by Pimmler and Eppinger (1994).

In Pimmler and Eppingers article from 1994 they present a three-step method to define architectural chunks or team chunks ready for resource allocation and detail design. The three steps in this method decompose the system into elements, document the interactions between elements and cluster the element into chunks and will further be described below (Pimmler & Eppinger, 1994).

The first step of this analysis requires specification of the overall product concept in terms of physical and functional elements. The main challenge of this step is how to divide the elements. It is also suggested for the elements to be specified one level further than the desired product architecture level, see figure 18. When doing this decomposition both functional and physical elements may be used (Pimmler & Eppinger, 1994).

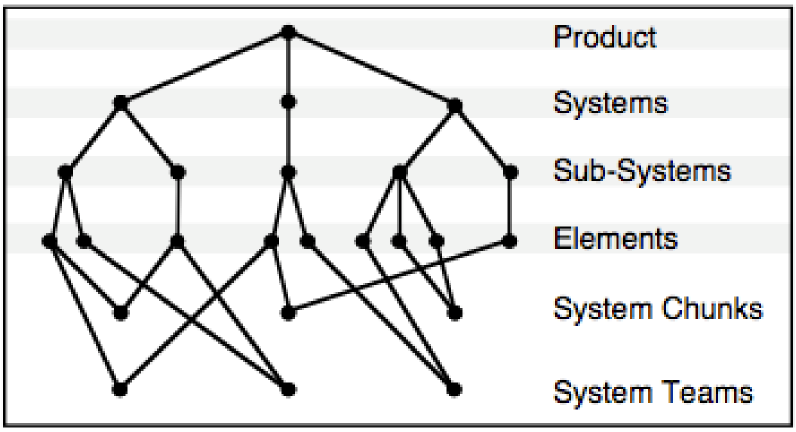


Figure 18: Example of product decomposition (Pimmler & Eppinger, 1994)

In this step it is determined how the developed elements might interact. Documentation of these interactions is important since it allows understanding of the needs for coordination required in the later stages, and how the coordination requirements depend upon the clustering of elements. To schematically identify and describing interactions for generic interaction types are defined (Pimmler & Eppinger, 1994).

- Spatial: identifies the needs for adjacency or orientation between elements.
- Energy: Identifies needs for energy transfer between two elements.
- Information.
- Material.

When the interactions have been quantified the next step is to cluster them into chunks. This can both define the physical architecture and the product development team structure. This might be done merely on interaction alone, or other architectural and resource criteria may be considered.

In this project the products were decomposed into smaller systems, sub-systems, and components. The components were then evaluated based on which type of component it was and what properties it had regarding, measures, and quality. For example, the Hemnes chest of drawers (COD) is a range of bureaus with different number of drawers. That firstly was decomposed in to five different types of systems, which was then further decomposed into different components, where the evaluated ones were constructed by glueboards.

Secondly these components were then clustered in to comparable components. The criteria used to cluster the components were, dimensions, quality, and function. With these three criteria it were possible to compare similar components in the different types of bureaus, to be able to make decisions on where the same component could be used. For example it were possible with minor changes to use the same top panel in both the Hemnes COD 3 and COD 6. All components in the series were evaluated and the possible changes were made. After the changes a new bill of material were developed to be able to see the changes and establish how many components that could be combined into a module.

In this master thesis no modules are created within the products, as suggested by Pimmler and Eppinger. The decomposed components have instead been compared to other decomposed products in the Hemnes COD range to see if some products could be merged into a common unit.

One of the reasons why this combination of models was used was because that some of the previous mentioned models required a great deal of background information about the products and the drivers that affects the customer. To be able to use a standard model and especially Erixons modular function deployment model further investigation about modular drivers, company specific drivers and customer requirements are needed. In this project it is assumed that the product assortment already is set which makes this out of scope.

It is also out of scope for this project to change IKEA's product development process. Some of the methods discussed in the theory interact more with the product development phase making it very hard to estimate the monetary effects and savings from such a change. Nevertheless, it is important to understand the connection between product development and modularisation. To fully get the benefits from a modularisation it must be implemented at the development stage. The development can also benefit from a modularisation in form of shorter lead times due to for example carry over of old modules.

3.11 Operational parameters

During this master thesis operational efficiency, production cost, and lead times will be investigated. In order to get a better understanding of which parameters that affect the production a short description of some manufacturing theories will be presented.

3.11.1 Result parameters

Firstly, manufacturing of consumable products can be divided into several parameters. To get a more efficient production system basic knowledge of the entire system is often required even though it often is plausible to focus on one or a few of aspects of the entire production process. Ståhl categorises production efficiency in to seven groups which are (Ståhl, Development of Manufacturing Systems– The link between technology and economics , 2015, s. 19):

- Tools and tooling systems
- Workpiece and workpiece materials
- Process and process data
- Personnel and organisation
- Maintenance and service
- Special factors
- Peripheral factors

In this paper mostly the process and process data will be examined with focus on set-up times and lead-times. When discussing result parameters three factors are usually mentioned as extra crucial, see Figure 19 (Ståhl, Development of Manufacturing Systems– The link between technology and economics , 2015, s. 17)

- Quality
- Production time
- Cost

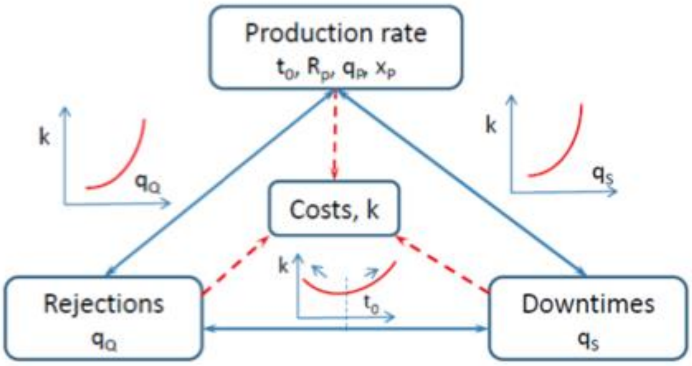


Figure 19: Relationships between production rate, quality disturbances, downtimes, and production costs (Ståhl, 2015)

These parameters can often be presented in absolute numerical terms and are often divided into three groups (Ståhl, Development of Manufacturing Systems– The link between technology and economics , 2015, s. 17).

- Quality parameters, concerning dimensional requirements, surfaces, functionality and performance. Losses in quality can be described in form of the rejection ratio q_Q.
- Downtime parameters, concerning downtime caused by process related events. The downtime ratio can be described in form of the downtime ratio q_S.
- Production or processing rate parameters, in terms of number or products produced during a given period. The change in production rate is often mentioned as q_P.

Another important aspect to take into consideration is also

- Environmental and recycling parameters, factors such as tools, equipment, energy requirement, and scrap recycling.

With this in mind a company should, to get a good result in from production perspective, focus on these parameters and these factors. Small adjustment might always be necessary but this can serve as a foundation when choosing focus area for production improvements (Ståhl, Development of Manufacturing Systems– The link between technology and economics , 2015, s. 18).

3.11.2 Work in progress

Work in progress is the products that not yet have ben finished and can be defined as lead times multiplied with the throughput (Lee & Johnson, 2009). Since the work in progress or WIP is a major key performance indicator (KPI) this will be further examined. To lower to WIP either the throughput or the lead times needs to be reduced, see equation (3). In this case the throughput needs to remain on the same level in order to meet the service levels at the stores. This will in the end lead to decreased lead times in order to achieve a lower WIP.

$$WIP = Throughput * Lead\ time \qquad (3)$$

3.11.3 Operational efficiency

When discussing operations and operational efficiency it is important to define what to measure. According to Lee and Johnsson operational efficiency can be defined in several ways (Lee & Johnson, 2009).

Firstly, there is absolute operational efficiency (AOE).

$$AOE = \frac{actual\ throughput}{ideal\ throughput} \tag{4}$$

The actual throughput is often lower than the ideal due to for example varying skill levels of operators or due to scheduling.

Secondly, there is a relative operational efficiency (ROE).

$$ROE = \frac{actual\ throughput}{best\ observed\ throughput} \tag{5}$$

In this case relative benchmarks are often used since comparable machines with similar process parameters often can be found. The best observed throughput is often determined by historical data.

In today's world when resources are limited a company that wants to provide a product as an output must consume input resources. The ratio between the output and the input level can be described as the productivity.

$$Productivity = \frac{Output}{Input} \tag{6}$$

De Ron and Rooda defines Operational efficiency (OE) as

$$OE = \frac{production\ time}{equipment\ uptime} \tag{7}$$

where the composition of the total time can be seen in Figure 20.

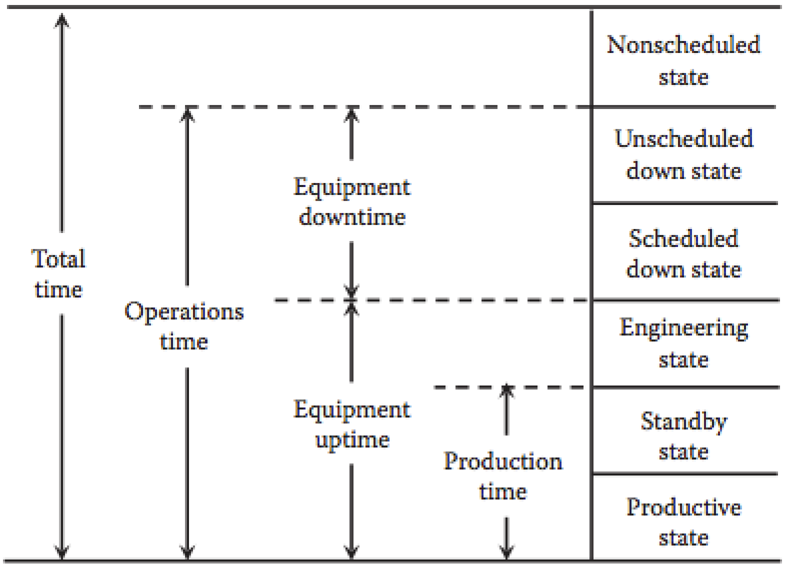


Figure 20: Composition of total time (de Ron & Rooda, 2005)

- The non-scheduled state is described as equipment that is not scheduled to be utilized in the production. Examples of such time are unworked shifts, weekends, and holidays.

- The unscheduled down state is the state that includes maintenance delays, repairs, and changes in the equipment that is not scheduled.
- The scheduled down state is the state when the equipment is not available due to planned downtime. This can include production test, preventive maintenance, and setup.
- The engineering state is when the equipment is able to perform its intended function but is operated to conduct engineering experiments. This state can include activities such as process engineering, equipment engineering, and software engineering.
- The stand by state includes the time where the equipment is able to perform its intended function but is not operated. This can depend on no available operators, no available items or due to lack of support.
- The productive state is when the equipment is performing its intended function. This state includes regular production, but also work for third parties, and rework.

Previously a few examples of how to calculate operational efficiency were presented. However, it is often connected to either the time, like in equation 7 or the throughput, as in equation 4. In both examples it is the uptime or the actual amount of produced products that gets divided by the ideal case. It can also be seen that none of these equations include the total time. To get a good value on the operational efficiency the main goal should therefore be to have as little downtime as possible when producing the product. What happens between batches or when there is no scheduled production does not affect these KPIs. It can also clearly be seen in that the operational efficiency only covers a small part of the total time.

3.11.4 Overall equipment effectiveness (OEE)

Another KPI that can be examined is the OEE of a company. Lee and Johnsson defines OEE as

$$OEE = \frac{Theoretical\ production\ time\ for\ effective\ units}{Total\ time} \tag{8}$$

OEE can also be described as

$$OEE = AE * (OE * RE) * QE = Availability * Performance * Quality \tag{9}$$

Where the different components consists of

$$Availability = AE = \frac{Equipment\ uptime}{Total\ time} \tag{10}$$

$$Performance = OE * RE \tag{11}$$

$$RE = \frac{Theoretical\ production\ time\ for\ actual\ units}{Production\ time} \tag{12}$$

$$Quality = QE = \frac{Theoretical\ production\ time\ for\ effective\ units}{Theoretical\ production\ time\ for\ actual\ units} \tag{13}$$

The OEE KPI can therefore be broken down into sub system where bottlenecks more easily can be identified (de Ron & Rooda, 2005). This KPI compared to the operational efficiency carries more information. Since information about availability, performance and quality can be derived from this KPI it can be highly useful and gives a good overall value over the production. However, it can be hard to directly from the OEE identify were the problems are located in the production. It might also differ between manufacturing sites if the manufacturing methods are changed. Whit this in mind it is important to know why the KPI is used and more to use it as a way to track the change internally in a production facility over time then to compare facilities between each other.

4 Empirical study

This chapter presents the information collected from factory observations, interviews, and data gathered at IKEA. This will be followed by some comments about the collected information.

4.1 Situation analysis

To truly understand why a modular product strategy could be beneficial the current situation at IKEA needs to be further described. First the observations from the factory in Wielbark, Poland will be described followed by findings from interviews and the given product data.

4.1.1 Manufacturing description

To describe IKEA's supply chain it is of ease to start from the end customer and work backwards through the supply chain. The customers can either buy IKEA's products online or at their local IKEA store. Both of these channels have been supplied from IKEA's distribution centres (DC) around the world, which in turn have been supplied by a vast number of suppliers. In the case with solid wood furniture one of these suppliers is IKEA Industry. However, they are not alone of supplying these types of furniture, there are other suppliers that are competing of supplying the DC's. This puts IKEA Industry in a peculiar situation, where they are not guaranteed orders even though they are a part of IKEA. In the solid wood value chain the closest supplier to the DC's are a so called furniture factory, which is supplied by a number of different supplier, supplying different types of components. Some of which are IKEA subsidiaries, saw mills owned by IKEA Industry, and IKEA components. IKEA components supply the furniture factory with hinges, knobs, plugs, and so on. The IKEA owned saw mills supply both IKEA owned furniture factories, 3rd party furniture factories, as well as other customers that need to use chips, boards, or planks. A forestry company supplies the sawmill. A graphical representation of the supply chain can be viewed in Figure 21. In this master thesis the focus has been on the two steps in the red circle.

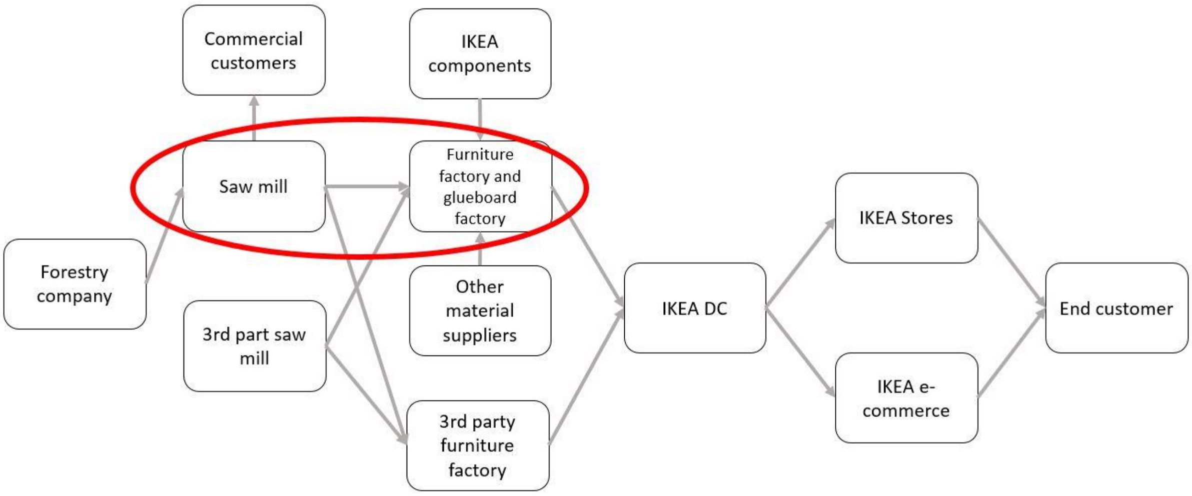


Figure 21: IKEA Industry supply chain mapping

Breaking down the IKEA Industry part of the supply chain a bit further will show how the production of solid wood furniture is done. The three main steps of producing wooden furniture is the saw mill, the glueboard factory, and lastly the furniture factory. Each of these will be described later on. The observed factory in Wielbark, Poland did contain all three steps. However, not all factories contain all three steps. It is common that there is no integrated saw mill at the production site and in this case the production is supplied either with material from IKEA's own saw mills or from a 3rd party supplier.

Most of the information regarding the supply chain's structure was gathered through observations on site in Wielbark, Poland the 18th of February 2016. All this have been checked through interviews and input from engineers at IKEA Industry in Malmö.

During the visit it was clear that some processes on the production site was more demanding than expected. For instance the quality control and repairing was mainly done manually and some sorting was also needed to be done by hand. These labour intensive activities required a large number of employees to ensure the needed throughput.

4.1.2 The saw mill

There are five basic steps in the sawmill, which can be seen in Figure 22. The raw material is tree logs. These logs are then sorted according to which diameter the logs have. The logs are scanned for shrapnel from World War Two as well, to make sure the saws are not destroyed. After sorting the logs are transported from the log yard to the saw line. In the saw line the logs are cut to 50 mm thick planks and a couple of smaller boards. The length of the cut material is set by the length of the log, the width depends largely on how big the logs are but it is tried to be kept to industry standards. This to be able to sell unused material to a 3rd party. After cutting the planks they are sorted according to width and they are then packed. The last step in the saw mill is the drying tunnels and the drying chambers. The wood needs to be dried before it is used in any type of furniture and the drying of the wood needs to be done in a controlled environment. This due to the fact that wood is a living material and every piece will shrink differently and there is a risk of wood splitting if it is dried to fast. The different shrinkage would create problems if components to the furniture are produced before the wood is dried properly, the glue boards could split. This creates a constraint that wood needs to be in drying for at least 8 days before it can be moved in to the incutting warehouse.

As mentioned some of the planks and boards are sold to a 3rd party. However, the technical yield is only 45%, so there is a lot of material that are removed from the logs. This scrap material does not go to waste. The chips that are created from the cutting of the logs are sold to other companies as well and to IKEA Industry's own board production. Lastly some of the bark is used in the factories own heating pans to keep the factories as self-sustaining as possible.

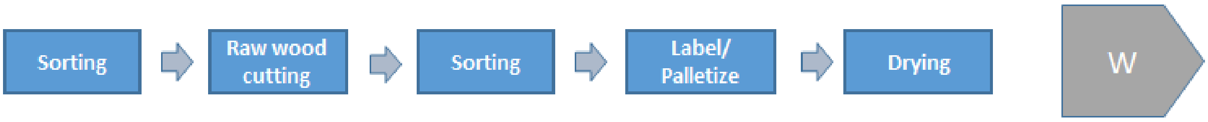


Figure 22: The saw mill process

4.1.3 Glueboard factory

The first thing that happens in the glueboard factory is that the planks and boards are cut in to lamellas, with a width of 50 millimetres. The thickness depends on in what component the lamella is planned to be used. The lamellas are basically smaller planks. These lamellas are then scanned by a scanner and cut in to shorter pieces, due to that the quality of the wood can change along the lamella. Some of the components have a need for finer wood, hence these components uses only high quality parts of the lamella. The lamella pieces are sorted according to quality. The pieces that are too short is sent to a finger jointer and is joint together so they reach a long enough length to be used in the glueboard. This to reduce the level of scrapped material. The lamellas are then glued together in to a larger board, called a glueboard. This is either done in a one by one press or in a continuous process where the boards are cut to the right length. After the gluing process the glueboards are inspected and the defects are marked. The larger defects are then plugged by the use of tree plugs or so called boats, which are plugs formed as the hull of a boat. The smaller defects are fixed by a thin layer of transparent spackling paste that is applied to the board. The boards do now have a completely smooth surface, the surface is nevertheless sanded so the paint which will be applied later sticks to the surface. Lastly the boards are stored in the intermittent storage between the glue board factory and the furniture factory. The glueboard process can also be viewed in Figure 23.

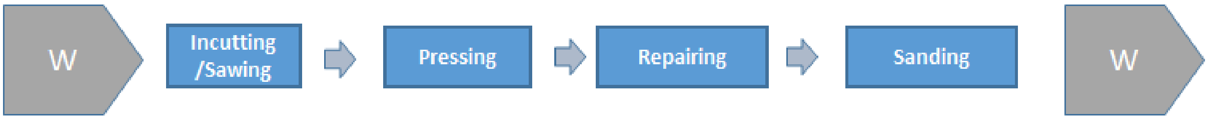


Figure 23: The glueboard process

4.1.4 Furniture factory

The two previous parts of the production are much more of a line production and the products follow a more or less determined path. The difference is that there may be additional needs for repairing. The furniture factory on the other hand is much more like a job shop where every product does not need to be at all of the workstations. The first stations are for formatting of the glue board, getting it to the right dimensions and having the right edge profiles. After the formatting holes are drilled to make it possible for customers to assemble the products easier. After all holes are drilled and the right dimensions are achieved it is time to apply the paint. Firstly the edges are sprayed on several of the same components at the same time. When the edges have dried it is time for lacquering of the plane sides of the component, the paint is hardened by an UV-light. After this it is time for another inspection of all components. This process is done by hand and this is the most labour intensive process in the whole production. When the components are approved, some goes to an assembly line where harder assembly is performed, the rest goes directly to packing. The packing is done manually on a moving belt and is very efficient. When the products are packed they are stored in the finished goods warehouse before they are sent to a distribution centre. The furniture factory process can also be viewed in Figure 24.

Figure 24: The furniture factory process

4.2 Work in progress

Today there is a high work in progress throughout the production in Wielbark, Poland. Some weeks the WIP is almost 100 days of stock, which is very high compared to the average transactions per day, the average is calculated from the last 90 days of transactions. In Figure 25 and Table 5 some values can be seen regarding the total on hand value, the transaction value and the stock days WIP.

These values can be seen as relatively high which indicates that it might be a potential to reduce costs and to reduce the lead times.

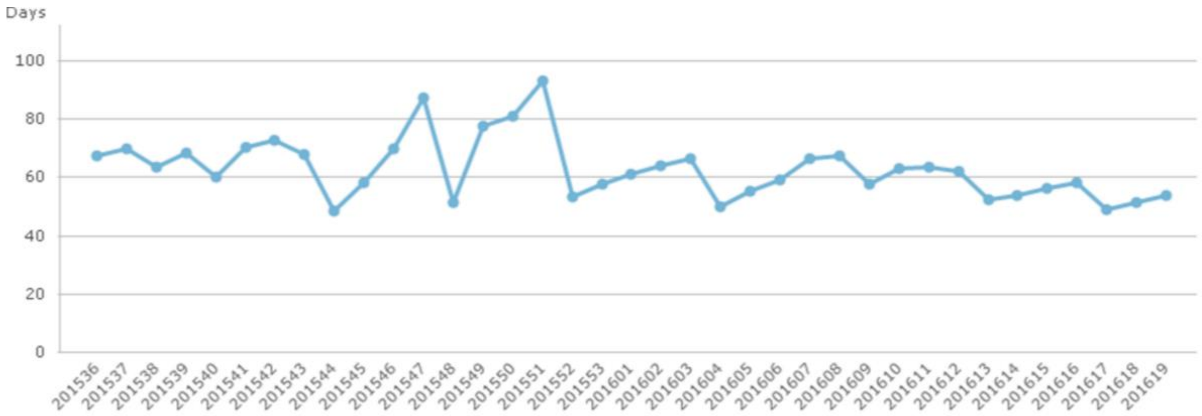
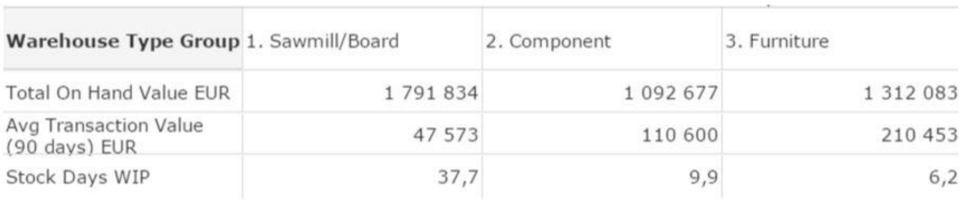


Figure 25: Days WIP, Wielbark, Poland factory (Engvall, 2016)

Table 5: On hand value Wielbark, Poland factory (Engvall, 2016)



Warehouse Type Group	1. Sawmill/Board	2. Component	3. Furniture
Total On Hand Value EUR	1 791 834	1 092 677	1 312 083
Avg Transaction Value (90 days) EUR	47 573	110 600	210 453
Stock Days WIP	37,7	9,9	6,2

4.3 Interviews

To get a thorough understanding of the benefits and drawbacks with a modular strategy several interviews were held with employees at IKEA. To get a complement to the production data collected from IKEA semi-structured interviews were held in order to both get concrete answers, but also to get a deeper understanding of the challenges within IKEA and how modularisation can be a solution for these challenges.

The persons interviewed together with date, duration, and interview format can be seen in Appendix A. The interview guide used for the semi structured interviews can also be found in Appendix B.

The main takeaways from the conducted interviews are that the definition of what modularisation stands for varies among the employees at IKEA. One of the employees did define modularisation as that "*I can build a product based on different modules that can be customised to solve different problems*". Another employee did on the other hand define a module as a part that can be used in different products. This is similar to the ambiguity that the researcher faces, where the definitions also are similar but not exactly the same.

Otherwise the common voice of the interviewees was that modularity could be a good tool for simplifying the supply chain and to get a more efficient production unit. But it is also emphasised the real problem starts when trying to implement the changes. There have been many projects before this project and all of them have faced the issue of institutionalise the solution. Furthermore it is common that they developed modules or standards in a specific project that do not reach outside the project. This problem comes from no clear data base regarding standards for the whole IKEA. Each project often does not have the time to look up if someone has done something similar before meaning that there has been no consistency between projects regarding modularity.

During 2013 IKEA Industry executed a project in order to modularise some of their products. They then observed several benefits with a modular strategy. The benefits are listed below.

- Reduction of items in production
- Shorter lead time
- Easier planning
- Smaller stocks
- Better yield – which is the relation between materials in each furniture compared to how much material goes in to the saw mill.
- Less set ups of machines
- Shorter time for new products to reach customer
- Less risks for mistakes

Other possible benefit mentioned by the interviewed employees was the possibility to avoid parts that are hard to produce. For example, the 7mm board is relatively hard to produce since twigs and other defects have a great impact. Due to the low thickness it is hard to get an A- and a B-quality side. Making the quality higher than requested from the product developers.

From the interviews a common belief is that the complexity on the factory floor level can be reduced by minimising the number of components in the manufacturing flow.

According to one of the interviewed employees the main benefits from a modular product strategy could be the reduction of lead times within the solid wood segment. The fluctuation in the warehouses can be monitored more easily and the internal stocks can be reduced.

The main drawback with a modular strategy is that the designers could feel that their artistic degree of freedom can be reduced. Otherwise the most important aspect is that it does not become an engineered product but that it also can be sold to the customers.

One more interesting fact that has come up during the interviews is that sometimes furniture is designed by one designer when they are first released. Then when the decision of extending the family of products it can be a new designer that designs the new products in the family, which can create some differences between the new and old furniture in the same product family. This makes it even harder to actually be able to keep some kind of continuity in the dimensions.

4.4 Product architecture

In this master thesis it was chosen to study Hemnes chest of drawers. This since it is one of the most prominent product families in the solid wood range with a volume of roughly 1.2 million bureaus sold per year. A Hemnes chest of drawers consists of a top panel, four legs, side panel fillings on the sides and on the back, and a number of drawers separated by rails. A Hemnes chest of drawers 3 can be seen in Picture 3 from chapter 1. In this picture the different components can clearly be seen.

In Table 6 the different number of components in Hemnes COD today can be seen. With five different variants of bureaus this number of total unique components can be seen as pretty large.

Table 6: Number of components in Hemnes COD today

Type	Number today
Top panel	5
Drawer fronts	10
Drawer backs	12
Drawer sides	7

Legs	3
Filling/side panel	5
Total	**42**

When looking at the number of unique stock keeping units (SKUs) throughout the supply chain, it is possible to see that the number of SKUs is quite low in the early stages of the production. Between the glueboard factory and the furniture factory the number of SKU's increases dramatically, to once again be quite few in the finished goods warehouse. This makes the production more complex than if the number of SKUs could be kept to a minimum. In the graph below the case for all different Hemnes chest of drawers is shown, where it goes from almost 50 glue boards to over 350 different SKUs in the furniture factory, see Figure 26. In the Hemnes COD case bureaus are produced in different colours. Today a white and a black top panel are classified as different components even if the measures are the same. This leads to far more components than presented in Table 6.

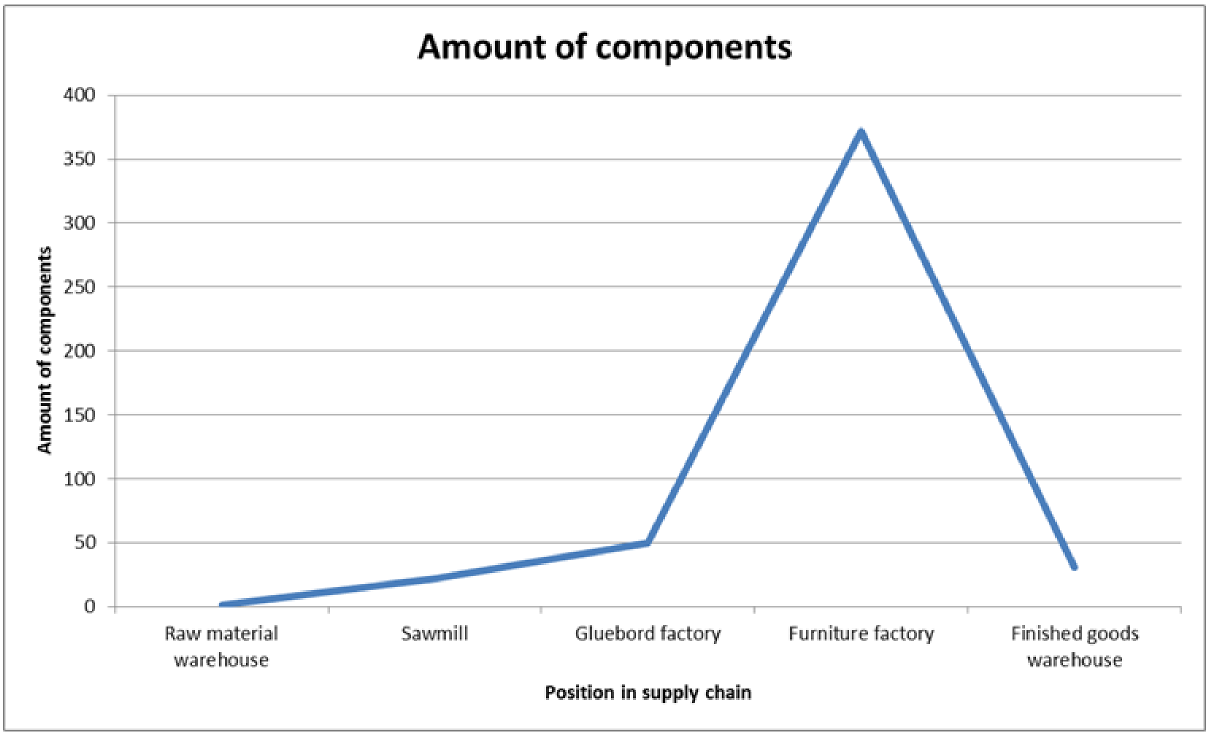


Figure 26: Amount of components in Hemnes COD

It can also be seen that the value increases further downstream in the production process. If looking at Figure 27.

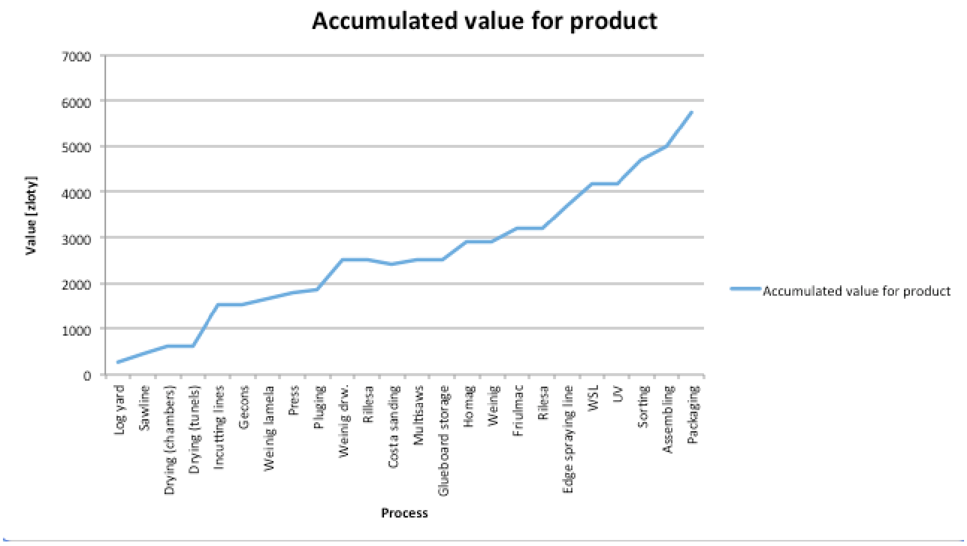


Figure 27: Accumulated value for products in the factory in Wielbark, Poland

The accumulated value of the products are for all products in the factory in Wielbark, Poland. This means that it might not be exactly accurate for the Hemnes chest of drawers, but a clear pattern that the products increases in value the closer to a finished product it become is obvious.

5 Analysis

This chapter aims to present the analysed material collected from the empirical studies and the collected information. The results will then be compared to existing literature.

To be able to leave a recommendation to IKEA several aspects of the production will be analysed. One of the goals is to reduce the lead time, if the throughput shall remain unchanged this will lead to reduced WIP. In the next section mainly the setup times and the amount of defect products will be considered. In the following case the savings are calculated for different levels of component reduction. However, it is important to keep in mind that these graphs should be used with a critical mind set since some values become unrealistic near the boundary values, for example, is it difficult to reduce the number of components by 100% without affecting the number of sold products.

5.1 Component reduction

From the observation of finished products and analysis of data it can clearly be seen that today's range of furniture is developed with focus on form and design rather than producibility. The focus on design can clearly be seen if looking at the wide number of components needed the produce the furniture. Many of the components are also very similar but not identical making the production of the furniture more complex than needed. This is both in line with IKEAs strategy and not in line with IKEAs strategy. This according to strategy when considering the needs of the customer, but do not follow strategy regarding low cost products which comes from a low cost production. One example is the Hemnes chest of drawers that have many different drawer sizes and dimensions, which is not optimal for production but may be optimal for the customer. This results in an explosion of number of unique components inside the production, which can be seen in Figure 26.

From the data regarding the number of components per product it indicates that there are numerous different dimensions of the components on similar products. One prominent example is the top panels of the Hemnes chest of drawers where the five different variants have five different top panels even though it is possible to use the same top panel on a two chested drawer variant and a five chested drawer variant as well as on a three chested drawer and a six chested drawer variant. The differences in dimensions are today very small and sometimes as small as a few millimetres, this however creates more SKUs than needed. This does not only drive cost it also creates an unnecessary complicated manufacturing process. Both cost and complexity are mentioned as aspects that IKEA want to decrease according to their goals in IKEA 2020, which makes it preferable to reduce the number of individual components in IKEA's supply chain.

It is also important to understand that IKEA Industry in the solid wood segment mainly mass produces their products. This can be seen in the high volumes and few variants in their product range. To be successful with such a strategy it is important to focus on an efficient production and to keep cost as low as possible.

The method used to derive the suggested modularised product architecture is a slightly modified version of the product decomposition method suggested by Pimmler and Eppinger (1994). The method is further described in section 3.10 in the theory chapter.

The finding that the number of components can be reduced by 21% will in the following sections serve as a foundation for the calculated savings.

In the Hemnes chest of drawers case it can be seen that there is a potential to reduce the complexity of the production by reducing the number of components needed to satisfy the need of five different chest of drawers. The suggested change would, in this case, decrease the number of different components by 21%, with only minor changes to the current design, see Table 7. For a more detailed description of which components that has been reduced see Appendix C.

The reduction of number of components will be a benefit for the ease of planning of both material, stock levels, purchasing and capacity needed. The actual benefit for just planning is hard to evaluate. This is a typical example of so called component sharing modularity, discussed by Pine II (Mass Customizaion, 1999).

Table 7: Amount of components before and after reduction

Type	**Number today**	**Number suggestion**	**Reduction %**
Top panel	5	3	40%
Drawer fronts	10	9	10%
Drawer backs	12	8	33%
Drawer sides	7	6	14%
Legs	3	3	0%
Filling/side panel	5	4	20%
Total	**42**	**33**	**21%**

All components are produced from logs and are refined until they end up as a flat package containing the requested furniture. There can be lamellas that are not produced in the own sawmill but they are not increasing the number of unique components. After the saw mill the number of unique components have risen. The next step shown is the amount of components in the glueboard factory. The fourth step is the number of unique components in the furniture factory, which are needed to produce the five chest of drawers presented in the final stage. The amount of components before and after the reduction can be seen in Figure 28.

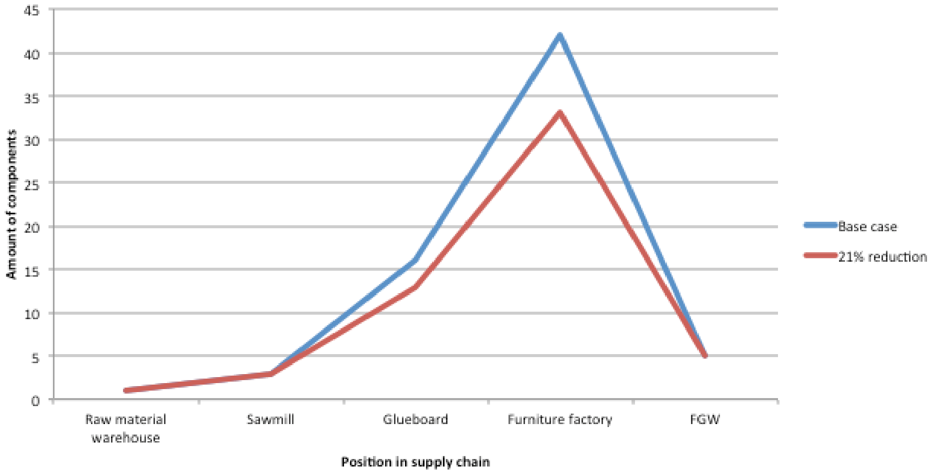


Figure 28: Amount of components before and after reduction

5.2 Changeover

With a modular product architecture products can share components which will result in fewer setups and a shorter overall setup time. This can be done by modularising some of the parts to avoid unnecessary changeovers. If the drawers, for example, can be converted into a common component module, the total number of components produced in the factory will reduce. The total amount of set up time will also be reduced due to shared components.

If looking at Figure 29 it can be shown from the calculations performed in this master thesis how the production cost decreases if the setup time is decreased. The calculations are based on data from the archive analysis and have then been modified to suit the new conditions. It is also assumed that the workers operating the machines can get their working time reduced. This in order to reduce the manufacturing cost connected to the employees. For further information about the calculations and which formulas that has been used se Appendix D.

The setup cost can be broken down into the setup times multiplied with the wages for the operators multiplied with the numbers of operators. Then to get the savings the setup times are changed.

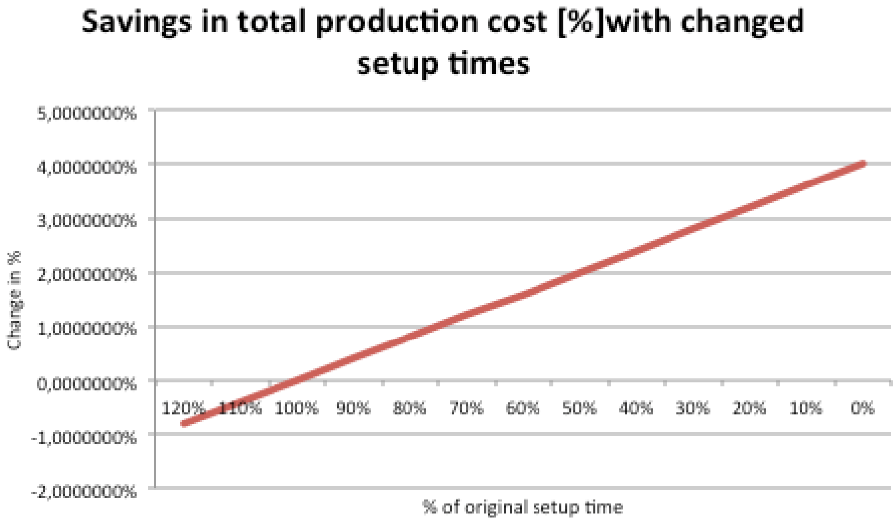


Figure 29: Savings in total production cost with changes in setup times in percent, positive values indicates a reduction in production cost

In Figure 29 the amount of the original setup times decreases along the x-axis. When the set up time decreases it can also be seen that the cost connected to the production decreases. The y-axis represents the change in percent, where the positive values indicate a reduction in production cost. So if the change is positive then the production cost has been lowered. If the set up times were removed completely and some sort of continuous dedicated lines were introduced then the maximal savings should be approximately 4%. However, in this case batch production is still performed, which will lead to smaller savings then if a continuous production had been used. In the batch production case the company will on the other hand get more flexible.

In this graph all the set up times have been decreased equally, in percent. This to get an overview of the effects that can be gained with this kind of component sharing modularity. However, in reality it can be difficult to reduce the setup times equally over the entire product range. But this gives, as previously stated, a good overview of the potential effects.

In Figure 30 the same graph as the one in Figure 29 can be seen but instead of the savings in percentage the savings can be seen in zloty.

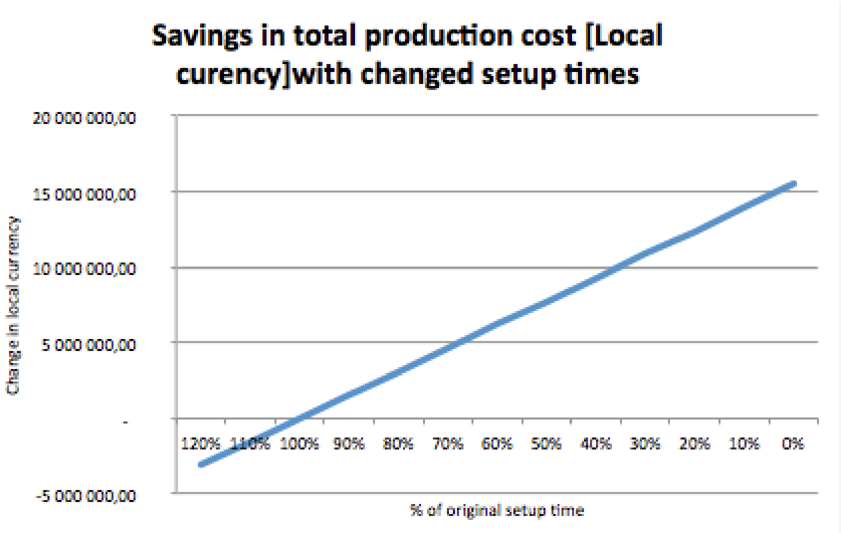


Figure 30: Savings in total production cost with changed setup times in zloty, positive values indicates a reduction in production cost

In this case it is only calculated that the furniture factory reduces their setup times. This since the machine and production data only covers that part of the production. This is important to keep in mind when analysing the savings since it would be possible to gain some savings from the glueboard factory and from the sawmill.

One of the major benefits with a modular strategy and common units is that it drives scale for the remaining components, which will lead to fewer changeovers. This will reduce the amount of setup time, and reduce setup cost. A reduction in setup cost then leads to a reduction in the total production cost.

Previously it was presented that if a component sharing modularity would be implemented 21% of the components could be reduced. If it then is assumed that the amount of changeovers are directly correlated to the amount of components, the amount of changeovers should be reduced by 21%. In this and the following sections it will be assumed that the changeovers are reduced equally among the entire range of components. This can be seen as a simplification but in order to draw some general conclusions this seemed to be a reasonable approach.

If all parameters are left unchanged and the setup times are reduced with 21% then IKEA could, from all factories that produce Hemnes chest of drawers save 3 379 111 zloty per year. If comparing to the total cost the saving corresponds to 0,81% of the total cost for the Hemnes COD range. If looking at the production cost the reduction in changeovers reduces the cost connected to the manufacturing process with 2,87% for the Hemnes COD range.

Another benefit that could be derived from a reduced amount of changeovers are the freed capacity that occurs. In this case a reduction of the changeovers by 21% result in 1 947 freed hours. This can also be presented as a freed capacity of 16 181 bureaus per year, which equals an 1,32% improvement in capacity. For an overview of the results see Table 8. Formulas used to calculate the values can be seen in Appendix E.

Table 8: Potential savings from changeovers after reduction of components

Activity	**Savings/ year**
Monetary savings [zloty]	3 379 111
Monetary savings [%]	0,81
Savings operations [%]	2,87
Freed capacity [Hours]	1947
Freed capacity [Products]	16 181

5.3 Defects

Except the previously mentioned benefits connected to modularity there are several other aspects that can contribute to a better and more efficient production, however some of these are hard to quantify. One of the benefits that might occur is a reduced amount of scrap during the manufacturing process. If the available capacity is increased due to less changeovers this can lead to fewer scrapped products. This since many of the machines might need some adjustments to properly meet the new products required measurements and tolerances (Ståhl, 2012, s. 270). This kind of savings is hard to quantify but if looking at Figure 31 and Figure 32 it can be shown that a reduced number of scrap gives a lower total production cost. This due to whenever defects occur it increases cost through reworking of the part, deviation from production plan, etc. This result decreases both labour costs and work-in-progress. The reduced cost can be seen in Appendix F how reduced scrap affects the direct material cost. It can then be seen in Appendix D how direct material affects the total cost.

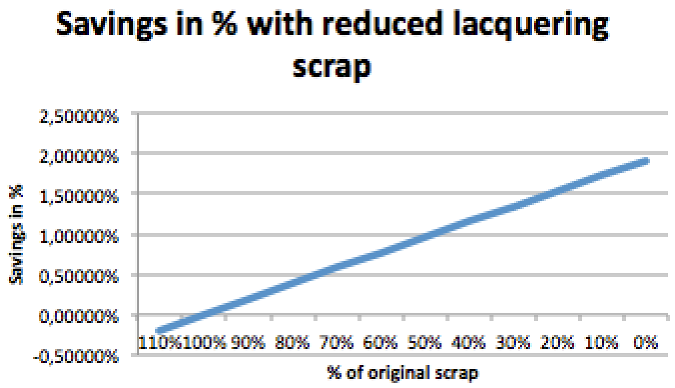


Figure 31: Savings in % with reduced lacquering scrap

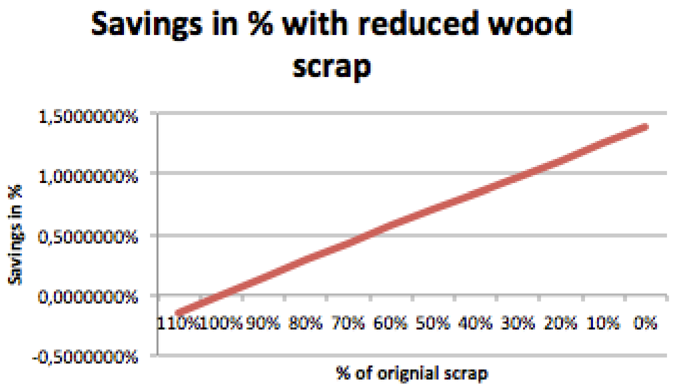


Figure 32: Savings in percent with reduced wood scrap

In both Figure 31 and Figure 32 the savings are presented on the x-axis and the percent of original scrap is presented on the y-axis. If the amount of scrapped products are reduced there would be a decrease in cost. Consequently a positive value on the x-axis means a lower total production cost

IKEA originally has a given scrap frequency for their components. The percent of the scrapped products varies depending on the machine and the quality of the component. To get the final scrap cost the percent of scrapped products gets multiplied with the scrapped pine volume. The pine volume also varies depending on the quality. Some components that require a higher quality gives a higher scrap cost if the component is defect. To get the final value of the scrap cost the percent of scrapped products are changed to its new value. This way of calculating the scrap cost is used for the scrapped wood components. When calculating the cost for the lacquering scrap the lacquered area is calculated instead of the volume of the scrapped wood. Otherwise it works in the same way.

Since the material cost for IKEAs solid wood products often represents a majority of the product cost a reduction in scrapped products become even more crucial. If a larger share of the material can be utilized it will affect the total cost. The scrapped products and especially the products that get scrapped in the lacquering process get useless quite late in the production process. If these defect product can be avoided capacity will be freed in all previous steps in the production. It can also be seen in Figure 27 that the products value increases throughout the production. This means that if a product is scrapped later on in the production it has a higher accumulated value, which will lead to a higher scrap cost for the company.

In the previous section the amount of components where reduced by 21%. It could then be assumed that the setup times also could be reduced by 21%. It has also been stated that the concentration of defects are larger in connection to changeovers. It is assumed that 50% of the defects occur when changing the machines. If this is combined with the previous statement that the amount of changeovers are reduced by 21% it can be derived that the amount of scrapped products can be reduced with 10,5%.

In this case the scrap can be divided into two sections. One part can be derived to the wood scrap and the other part from the defect connected to the lacquering process. The savings from the wood scrap sums up to a total of 637 015 zloty per year and the savings from the reduction in scrap from the lacquering is 863 105 zloty per year. This gives a total saving of 1 496 793 zloty per year connected to the reduction in scrap for the Hemens chest of drawers. Looking at the total cost in per cent the reduced costs sum up to 0,36%.

If looking at data received from IKEA the scrap is connected to the usage of material and the material cost. This leads to the fact that the scrap does not lead to any savings in the production cost or that it leads to any freed capacity. However, when reducing scrap the batch sizes should logically be reduced otherwise the company produces more products than before.

For an overview of the savings from the reduction in scrapped products see Table 9.

Table 9: Potential monetary savings from scrapped products after reduction of components

Activity	Savings/year
Savings wood scrap [zloty]	637 015
Savings lacquering scrap [zloty]	863 105
Total savings scrap [zloty]	1 496 793
Total savings scrap [%]	0,36
Savings operational cost	0

5.4 Inventory

When considering how inventory is changing in relation to a reduction of components, the two ways of calculating this are discussed in section 3.8. The two results are presented below and are then compared to each other.

The risk pooling effect of commonality depends largely on the relative cost between the common component and the unique components that it replaces. However, the benefits could still be significant even if the common component is more expensive. In this case with Hemnes COD the replacing component is cheaper or exactly the same compared to the component it replaces.

5.4.1 Commonality index

The commonality index for the suggested case is calculated according to formula (1). This gives a commonality index of 1.56. Which gives according to formula (2) a reduction of needed safety stock by 20 percent. But without clear figures regarding the current safety stock at all of the production sites it is impossible to calculate the monetary benefits from this result.

5.4.2 Colliers single period model

A general assumption of a uniform demand has been made and the yearly demand has been split up to monthly demand, and calculated in a single period model. This has resulted in a decrease of inventory by between 4 and 9 percent. Savings in money is in zloty and the savings calculated from Colliers single period model can be located in tied up capital, which can be seen in Table 10.

Table 10: Potential monetary savings if introducing inventory pooling after reduction of components. The numbers at line "Hemnes COD" represents the numbers of drawers.

	Without commonality	**Without commonality**	**With commonality**	**With commonality**
Hemnes COD	2 and 5	3 and 6	2 and 5	3 and 6
Cost [zloty]	1,460,023	7,621,573	1,331,490	7,308,586
Savings [zloty]	-	-	128,523	312,987
Savings [%]	0	0	8.8	4.1

5.4.3 Comparison

Both of the models show benefits when introducing component sharing modularity. There is however a difference between them when the first one shows a benefit in safety stock while the other shows a benefit in cycle stock during one period.

5.5 Material

After interviews with employees at IKEA many interesting aspects of how the production could benefit from a modularisation was presented. One of the most economical benefits came from an interview with a project leader at IKEA who previously had been in charge for a modularisation project called Next generation pine. During his investigations he found a possibility to reduce the required material with 5%. However he believed that there could be an additional 10% saving in material[3]. If this would be feasible then IKEA could save 50 682 274 zloty per year in reduced material cost. This is equal to 12,16% of the total cost and 4,33% of the manufacturing cost for Hemnes COD range. However, the reduction is only based on the information received during the interview. Further research is needed in this field. The main takeaway from this should be the size of the economic impact that the material has on the total cost.

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[3] Interview with Stefan Månsson, IKEA Industry (2016-02-29).

An overview of the savings can be seen in Table 11.

Table 11: Potential monetary savings from material usage after reduction of components

Activity	Savings/year
Monetary savings [zloty]	50 682 274 zloty
Monetary savings [%]	12,16%
Operational savings [%]	4,33%

5.6 Component reduction according to new amount of unique components

In the previous sections it has been assumed that the reduction in components affects the changeovers equally among the component range. However, this case is based on the actual component reductions from section 5.1.

In this case if two components are merged together into one new component the two original components are affected equally. The savings in setup time are then equally distributed to the two components. If a machine produced two component the set up time was reduced by 50% for component 1 and 50% for component 2 if they were combined into one component. If the machine produced more than one product the set up time was weighted to compensate for that.

In this case some material are also removed in order to form the new dimensions on the components affected by the changes. In order not to make the changes too drastic the material has been reduced by roughly 0,05%.

These changes gives a total saving of 853 628 zloty per year where approximately 400 000 zloty or 47% comes from the reduction in material and 450 000 zloty from the reduction in changeovers. If looking at the total savings in percent of the cost the saving adds up to 0,20%. If looking at the production excluding material cost this changes saves 0,48% of that cost.

The reduction in changeover and setup time also results in some freed capacity. The freed capacity counted in machine hours are 449 per year and this can be translated to 4 320 bureaus per year.

In this case it is calculated that the amount of scrap stays unchanged. This even though it is implied that the frequency of defects are higher after changeovers. Additional testing and confirmation of the values and a more exact number of the amount of scraps are needed. In section 5.3 it is merely assumed that 50% of the scrap occurs in connection to changeovers.

An overview over the savings can be seen in Table 13: Benefits and drawbacks with modularity at IKEA.

Table 12: Potential total monetary savings in the comparison case

Activity	Savings/year
Monetary savings [zloty]	853 628
Monetary savings [%]	0,20
Operational savings [%]	0,48
Freed capacity [machine hour]	449
Freed capacity [bureaus]	4 320

5.7 Benefits and drawbacks with modularisation

There are other aspects that both IKEA and literature have been pointing out as possible benefits from a modular product architecture. In Table 13 the benefits and drawbacks with modularisation identified at IKEA are presented. In cases were the findings differs from theory the text is in bold and italic.

Table 13: Benefits and drawbacks with modularity at IKEA

Benefits	Drawback
Less material needed	***Reduced design freedom***
Easier planning	***Modularity gets defined differently in the company***
Shorter time for products to reach customer	Risk of losing sight of customer needs which leads to reduced sales
Shorter lead times	Increased initial cost
Economies of scale	Difficult to institutionalise a modular strategy
Increased number of variants that can be offered to customer	
Components that are difficult to produce can be replaced with simpler components	
Risk reduction connected to ramp up	
Environmental benefits	

When looking at Table 13 and comparing to benefits and drawbacks with modularisation identified from the theory in Table 4 it can be seen that not all aspects were mentioned during the interviews and that some aspects have been added. There is a possibility that additional aspects can be added to Table 13 if additional employees at IKEA could be interviewed. However, with the limited time frame a core of the most important aspects have been identified.

However, there are some aspects that IKEA emphasizes that are not mentioned in the related theory. First is the better yield aspect, which from IKEAs point of view is that there is a possibility that less material needs to be removed from each log of timber to be able to produce the same amount of furniture. Other benefits could be that components that are hard to manufacture could be replaced by components that are simpler to produce.

Another benefit with a commonality strategy and if the component already is being produced can be seen as a risk reduction. This since the company can be sure that it actually is possible to produce the product. When introducing an entirely new product there is always a risk that the producer will not be able to produce as agreed. But this can be avoided with this product strategy. Then there is always a risk connected to the ramp up. But the risk can be lowered if not ramping up from zero or close to zero.

Lastly, many of these improvements also have a positive environmental aspect. Both less used material in the products and less scraped material lowers the amount of raw material needed. With a more efficient production process less resources are consumed, which benefits the customer, the environment and IKEA.

The drawbacks and challenges identified at IKEA shows that some of the same risks that are identified in literature are present in this case. The main identified drawbacks are the risk of lost sales, the reduced design freedom, and risk of the products becoming too expensive due to overdesign. One of the other largest identified challenges at IKEA is the problem to make sure that everyone follows a modular strategy, exactly this is not mentioned in literature. However, literature mentions that if the strategy is not followed, the small changes in design will erode the strategy and the benefits will reduce.

When analysing the mentioned benefits and drawbacks at IKEA a clear conflict between the manufacturing unit and the product development unit can be identified. This can especially be seen in the identified drawbacks where the risk of reduced design freedom is mentioned. The risk of upsetting the product designers were mentioned repeatedly by the employees at IKEA Industry. This can also be connected to the difficulties to align the entire company along one definition of modularisation. If looking at IKEA 2020 and the goals that were stated there it should be possible to align the entire company to one single company philosophy. If the designers and production engineers do not work together IKEA will have a hard time fulfilling their goals.

5.8 Changes in operational efficiency

In this section one of the initial research question about the possibility to increase the operational efficiency will be analysed. As previously mentioned in the theory chapter the operational efficiency can be identified as the production time divided to the equipment uptime for the component. In this case the only known times in the production are the setup times and the total production time. The setup time are usually categorised as scheduled downtime under equipment downtime. To see the relationship between the different states see Figure 20. This means that a reduction in the setup times does not improve the operational efficiency in a theoretical meaning, see equation 7.

Usually the defect products are compensated for and if the number of defect products can be reduced then the time they consumed can be freed. Then the scheduled down time can be reduced. However, this does not affect the operational efficiency if looking at the same definition as before, see equation 7.

In Figure 33 it can be shown what states are affected by the different reduction caused by a modularisation. As can be seen in Figure 33 the states that affect the operational efficiency are not affected.

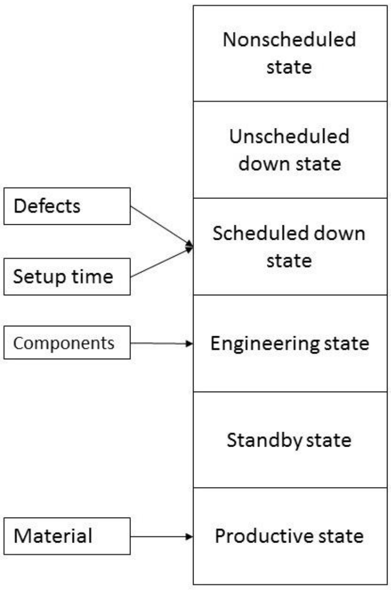

Figure 33: Affected production states at IKEA, inspired by (de Ron & Rooda, 2005)

If to improve the operational efficiency the parameters that can be changed are the times in the productive state, standby state and the engineering state. When using this as a key performance indicator it is important to keep in mind that the output value easily can be manipulated to look better than the actual result. For example, the cycle time per component can be increased. This increases the productive state. This will increase both the production time and the equipment uptime making the relation between these two states smaller. This gives a higher operational efficiency value. However, the production cost will rise and the output will decrease due to the increased cycle time per component. In the same time the standby state can be made proportionally large which will make the total OE value to look very good. This even though no or very few products are being produced.

In order to really improve the production the focus should be on the entire system. If looking at the WIP, throughput, lead time and the total cost a more fair description of the production can be presented. It might be tempting to reduce the equipment downtime in order to increase the uptime. But without looking at the bigger picture this might affect the company in a negative way. Sometimes downtime is required, for example when changing tools in a machine, but from a general perspective it is not a good idea to have idle machines.

If reducing the number of unique components logically the engineering state should be possible to be reduced. This since all new components needs to be tested in the machines. If there are fewer unique components occupying machine time in the engineering state then the OE should increase. However, in this case it has not been possible to collect any data regarding the engineering state, which means that further research to validate this is required.

Lastly, a reduced amount of material in the components should lead to a shorter productive state. If there is less material to remove the time it takes to format the product would probably be reduced. Either this will lead to an increase in standby state equally to the reduction in productive state or only a reduction in the productive state and an increase in the non-scheduled state. In the first case the OE will remain the same and in the second case the OE will reduce. However, from a monetary point of view it would in this case be preferred to increase the non-scheduled time since employees in this state can be let off.

6 Discussion

In this chapter the different findings from the analysis are discussed. The results, challenges with the analysis, limitations, and drawbacks are discussed. Important to remember is that this report focuses on the product assortment Hemnes chest of drawers.

6.1 Components

One of the main challenges when the products were decomposed into components and then merged together was how much material to remove or add. In this case the component with the smallest dimensions were primarily chosen. In order not to change the furniture's design impression more than necessary a decision not to change the components dimensions further then to the nearest adjacent dimension was taken.

The most obvious implication of a modular strategy should for IKEA be the reduction in components. With this in mind the amount of unique components could serve as a good KPI if implementing a component sharing modularity strategy. If observing the results from chapter 5 it can be seen that there is a strong correlation between a lowered number of unique components and savings connected to both setup-times and defect products. The quantity of the remaining components would also increase which hopefully can lead to a stronger negotiation position and lower purchasing prices.

If reducing the amount of unique components in the Hemnes chest of drawers range, the time spent in the engineering state could be reduced. This since fewer components will need less experiments and testing in order to get the end components to be correct. Fewer unique components also reduce the complexity in the production process and the engineering time also reduces. This will free up time, which can be allocated elsewhere. If implementing a modular strategy one of the main benefits is except from a more efficient production freed capacity in the production. If looking at equation 3 about WIP it can be seen that if the engineering time is reduced the WIP can be reduced since the total lead time will be reduced. However, the lead time will not directly affect the Hemnes COD. But if the entire factory can produce the requested components faster the total WIP in the factory will be reduced.

A reduction in components also contributes to a simpler production system. The simplification of the production process depends on a variety of reasons. Firstly the inventory can be streamlined and reduced leading to less inventory cost and hopefully a revelation of other problems within the production process. It also reduces the number of changeovers making it possible to produce larger batches. This makes it possible to reallocate resources from the changeover process and focus on other tasks. Fewer components also allow the workers to specialize on these components making it easier to produce with a high consistent quality. If looking at IKEA 2020 and their goal of simplifying IKEA a reduction of components definitely aligns with that strategy.

6.2 Changeover

Changeover is a parameter that to a high extent is correlated to the amount of unique components in the system. If the components were reduced to only one then no changeovers would be needed. In this case it is assumed that number of components and the changeovers are direct correlated. However, testing and validations of this assumption is of course needed.

Another aspect that needs to be noticed is that a reduction in changeovers leads to freed time in the machines which can be used either for an increased capacity, training of the workforce or to reduce the number of employees.

Excluding the savings from a reduction in material the savings from changeovers is the major one. It is nearly twice as large as the savings derived from the scrapped products. This makes it important to work with the changeovers and to keep them as short as possible.

Regarding the changeovers it is also important to keep in mind that the data collected only covers the furniture factory and not the glueboard factory and the sawmill. To get the total savings for the entire chain further research is needed. It can also be seen as a buffer in case the reduction in changeovers would be lower than expected.

Lastly, it must also be considered that the scheduling must be changed in order to reach a 21% reduction in changeovers. If the planning is not optimised some of the benefits from commonality might be lost. If the merged components are not produced directly after each other the amount of changeovers and the setup time may not be reduced. Therefore it can be seen as a little bit aggressive to state that a reduction of components by 21% reduces the number of changeovers with 21%. However, if planned perfectly it should, in theory, be possible.

The literature connected to changeovers often discusses lean where the main focus usually is to reduce the time it takes to perform a changeover. In this case the changeovers are connected to fewer components and not by improving the processes connected to the changeover. However, if looking at the literature it should be possible to further reduce the changeover process times by for example implementing a lean philosophy.

6.3 Defects

The scrap can as seen in the previous chapter be divided into two different categories. These two categories are then together summed up to the final scrap savings. In this section there are several uncertainties. First the reductions in changeovers are assumed to be 21% for all components, which is a simplification. Then the following assumption is based on that the first simplification is true. Secondly, the next assumption is based on interview findings and literature. The number 50% is estimated based on interviews, however it has also been stated in literature that defects often are connected to changeovers. This leads to that the final result must be examined very carefully.

Another flaw with the model is that the result it is derived from does not take into account the changed amount of produced products. If there is a reduction of scrapped products it would logically mean that the company either produces smaller batches or that they get more products that they can sell in the end. In this report the forecasted demand is set and this would therefore in this case lead to a reduction in the total batch size needed to deliver the requested amount of products.

In literature it can be seen that defects can be connected to changeovers. However, the exact correlation varies between different cases and it also depends on the products. To be able to make the assumption more accurate employees at IKEA were interviewed and about the correlation.

6.4 Inventory

There is a possibility to decrease the inventory levels if introducing a component sharing modularity. How big this saving can be is hard to calculate and different methods give different answers. Some methods only consider safety stock other consider service level and total stock. The simpler method with commonality index indicates that the reduction of safety stock can be as large as 20%. However, this is a theoretical value and to ensure that it is possible to achieve in practice additional testing and validation is needed.

Colliers method that considers the service level as well indicates a possible saving of between four and nine percent. This seems like a more viable result that will not risking to reduce the stock too much. This method however does consider the total stock needed during a single period and a simplification is made that the whole stock is available during the whole period. In other words the real stock can be smaller and replenished more frequently during the period, which would give a different result.

If lowering the inventory levels the WIP will be reduced. If looking at equation 3 regarding WIP it can be seen that either the lead times or the throughput needs to be affected if the WIP are reduced. In this case the throughput is assumed to stay unchanged which leads to a reduction in lead times. With this in mind the incentive to reduce the inventory levels become clear when both the WIP and the lead times are reduced. Another benefit with reducing inventory is that it reveals hidden problems that are not visible thanks to large inventory levels.

The reduction of inventory levels when decreasing the number of unique components can clearly be connected to theory. Both Collier and Hilliers models shows that a decrease of unique components leads to less inventory. It can therefore be stated the support from literature is strong in the inventory case.

6.5 Material

When analysing the potential savings from the reduction in material there are mainly three aspects that needs to be covered.

Firstly, the potential saving from material is very large compared to the other calculated savings. Almost 30 times the savings from scrapped products and almost 15 times more than the savings connected to the reduced setups. With this in mind it is important for the designers at IKEA to design the furniture so that they consume as little material as possible. If possible new and more efficient machines that have a higher material yield could also be a potential investment for IKEA. However, it can be hard to reduce the amount of material without major changes in the design. But in the cases where it is possible a reduction of material should be considered. Another thing to keep in mind is that changes in design could be dangerous since it might lead to reduction of sales due to that customer may value the esthetical feeling a more material intensive product gives.

The second aspect is that the calculated reduction in material usage is based on findings from an interview. It has not been further investigated in this report where this 10% in material reduction could be reduced. Therefore this result should also be seen as highly hypothetical. Nevertheless, the total savings from even just a reduction in material with 1% should result in significant savings. With this in mind it is also important to understand that an increase of the material usage will diminish the savings achieved from modularity.

Lastly, the reduction in material is not directly connected to a component sharing modularity. This means that the savings connected to the reduction in material could be achieved without introducing a modular strategy. Further research in this field is needed but if it is possible to reduce the usage of material with 10% as implicated this could heavily affect the final cost. If the largest saving can be achieved without introducing a modularisation then it might be a better idea to first focus on a material reduction program then on a modularisation program.

The reduction in material has been derived from interviews at IKEA and has therefore not been previously discussed in the literature. The modules on the other hand can have a tendency to get overdesigned in order to fit into more products. If that is the case more material might be required. In this report the decrease in material are calculated in order to show the potential in the material presented by IKEA.

6.6 Component reduction according to new amount of unique components

The savings in this case differ significantly from the savings calculated in the first case. The total saving in this case is just over 850 000 zloty. If only looking at the reduced changeover case the saving should exceed 3,3 million zloty. In this case some material saving are also included so the total saving should be even larger. One explanation to this is that the merged components do not affect the total setup time as much as the average product. This can also be stated when looking at the machine data where some machine has up to ten times longer setup time then another machine in the factory.

With this in mind it can be implied that some components with relatively long setup times are more important to modularise. This gives a good hint on where to start and among which components it is extra crucial to search for common units.

It also shows that this question is far more complicated than this report might have given the appearance of. All components do not affect the final result equally. To find and eliminate these bottlenecks in the production further research is needed. If a component sharing modularity is implemented and all components actually can be reduced with 21% major savings can be obtained.

However, it is somehow alarming that the savings from the reduction in changeover, in this case, only represents roughly 14% of the assumed potential saving. When looking at the details and the components that actually got merged in this case it can be seen that several of the components with a combination potential are not produced in the same IKEA factory, at least no production data regarding these components can be found among the received data. In some cases the same product is produced in several factories.

The reduction in unique components must however occur somewhere in the supply chain. So even if IKEA cannot benefit from it themselves in their own factories some of their suppliers should be able to obtain that saving. If so then IKEA can pay less for the component while the subcontractor retain its margin. Since one of IKEA Industries main goals is to show the suppliers that their products can be produced to a lower cost, the most important thing is that the saving occurs somewhere in the supply chain. If the total cost for the products can be lowered then IKEA has a better chance to stay competitive in the home furnishing business.

6.7 Key findings

A reduction of components seems to lead to a reduction in setup. However, if not modularising the entire product range there is a risk that a component that only affects a small part of the total cost gets modularised. In only one or a few of the product ranges are modularised there is a risk that the modularisation does not attain savings proportional to the effort. This leads too much smaller savings than what should be possible. Also some of the component consolidation might occur at a supplier level leading to lower purchasing costs instead of lowered manufacturing costs. This shows the importance of, if implemented, modules throughout the entire company.

Another key finding is that a majority of the cost comes from the usage of material. The usage of material is not connected directly to a modular strategy and a material reduction program could be initialised without a modularisation program. Due to the large part of the total cost that the material usage stands for it could be a good idea to consider such a reduction program. However, this may not be a viable solution since the perceived quality of the product will decrease if all components are made thinner, it is believed that the other dimensions are kept the same to keep the form of the furniture. This could potentially lead to reduced sales.

It should also be kept in mind that the savings directly connected to a modular strategy discussed in this report, could be achieved by implementing other strategies. The amounts of changeover and setup time are often discussed in Lean literature. Defected products and how to increase quality is also a subject on its own. A modular strategy can improve these areas but it is also important to understand that they can be improved in different ways. To get a more thorough understanding on how other strategies can be used to reach the same savings further research is needed.

The difference between component sharing modularity and standardisation is not always clear, depending on which definition that is used. In this report component sharing modularity have been used since the components that have been made the same is not for the whole range of furniture. It would have been a case of standardisation if exactly the same component had been used in all of the chest of drawers, but this is not the case for the suggestion. One example of a standardisation would be that the same kind of screws are used in all of the furniture.

7 Conclusion and recommendation

In the following chapter answers to the research questions, recommendations to IKEA, research implications, limitations, and possibilities for future research are presented.

7.1 Conclusions associated to the purpose

The purpose of this master thesis was to evaluate modularisation as a method to decrease IKEA Industry's complexity and cost associated with their manufacturing. In this master thesis theories, archive data and empirical material have been analysed in order to form an opinion whether IKEA should implement a modular strategy or if they should desist. The basis of the recommendations consists of a short term and a long term suggestion on how to further pursue a modular product strategy. As well as calculations of possible savings throughout the production.

Further one of the most significant products for IKEA Industry have acted as a base when designing the improvement suggestions.

7.2 Answer to research questions

In the next section answers to the research questions from section 1.3.1 are presented.

Research question 1

- Is there any way to modularise the products in the solid wood segment, which enables an improvement in operational efficiency, which in this case refers to the relationship between production states?

After analysing IKEAs production and especially the production of the Hemnes chest of drawers category it can be found that a modular strategy will not directly improve the operational efficiency at IKEA. This since operational efficiency according to theory consists of production time divided by the equipment uptime. The changeover is defined as scheduled downtime, which do not affect the operational efficiency. To improve the operational efficiency mainly the productive, stand by and engineering state time should be improved.

However, if looking at other benefits connected to modularity it can be seen that operational efficiency could be affected. If a component sharing modularity should be implemented and the number of unique components reduced this should lead to less time in the engineering state and an increased operational efficiency.

Reduced production time connected to less formatting as a result of less material in the components might also affect the operational efficiency. As previously stated in chapter 5 this could affect the operational efficiency in a negative way. If the components are produced faster without increasing the batches or in some other way producing additional components the operational efficiency is reduced.

It can be difficult to calculate the exact changes in operational efficiency from both the reduction in the engineering state due to less components and the changes due to less formatting connected to less material in the components. To be able to analyse the exact benefits and to develop an operational efficiency for IKEA several measurements in the factory are needed. Due to the limited time frame this was not included in the report. However, additional research and measurements are recommended in order to completely map the production.

This discussion about operational efficiency raises the question about which KPIs that should be used in a company and how they are used. Operational efficiency can be a good measurement if it is understood properly and used in a correct way. If the company's problem is that the engineering state takes an unproportioned part of the total time and of the equipment uptime then it can be used. If the wrong KPI is used the company might focus their resources on the wrong activities, this can lead to lower earnings. As an example reduced formatting time can lead to a lower operational efficiency even tough shorter lead times are preferable.

In this case KPIs as, for example, WIP, lead times and production cost can be better to use. It is also important to look at the KPIs in a wider spectrum in order to avoid sub optimisation. In the different functions the right things need to be measured. It is also hard to know what to improve if the base case is unknown. Looking at the case with reduced formatting time a reduction in operational efficiency will occur. But since the lead times also are reduced the WIP will be reduced. This is one of the reasons to measure several parameters and to understand why it is measured. If doing like this the positive contributions to the production can be clarified.

With this in mind it is important to understand what benefits a possible modular strategy can have on IKEA's solid wood segment. In this study mainly the scheduled downtime has been analysed in form of setup times, defects in form of scrapped products and inventory cost. In order to get a full understanding on the benefits KPIs concerning these parameters need to be further measured.

Research question 2

- Would such modularity yield any reduction in production costs and decrease in lead time?

When analysing the benefits from a component sharing modular strategy it can clearly be shown that both the production cost and the lead times can be reduced for the different products. This since modularisation reduces the amount of changeover. A reduced amount of changeover decreases the setup time. The setup cost, which is a part of the total production cost, depends on the setup time, the depreciation of the machine, the number of employees required to operate that machine, and the employees' wages. If the setup time decreases the setup cost will also decrease. The setup time is also a part of the total lead time. This means that a reduction in setup time also reduces the total lead time.

The reduction of changeovers also reduces the number of defect products which will reduce the production cost. This might also help reduce the lead times since a fewer number of products need to be produced in order to meet the desired service level.

At the same time there is a possibility to reduce the total stock on hand by utilising risk pooling when using a component sharing modularity strategy. This would decrease the average WIP at the factory and as long as the throughput is kept the same, the lead time will decrease. In this case both component commonality index and Colliers single period model indicated an inventory reduction.

In addition to these savings several other savings are possible. For example the time to market can be reduced and planning facilitated. Additional benefits identified both from theory and from interviews should be possible. Some of its gains are harder to quantify but will probably help reduce the production cost. Some example of such gains are less material needed and a reduced number of difficult tasks in the production. With this in mind a modular strategy should be able to reduce costs in the production that are not directly connected to a certain production step. This cost on the other hand would affect the overhead cost of the company and lead to savings. However, some of these cost are hard to quantify and therefore further research is required.

7.3 Recommendations

To further improve the production performance and to lower the production cost it is recommended for IKEA Industry to in the future implement a modular strategy. However, there might be other projects that need to be prioritised before.

It is also recommended that IKEA carefully evaluate new products before launching them to the market to make sure that it in an efficient way can be integrated in the existing product range. This in order to keep the setup times as low as possible. If an already existing component can be used in the newly launched product the total number of components in stock can also be reduced by using inventory pooling, which will result in lower inventory costs for the product.

A reduced number of components also reduce the changeovers and the total setup time. It is also indicated that the scrap from defect products will decrease. A decrease in scrapped products has many advantages and the major one is lowered costs due to fewer produced total units required to reach the requested service level. It is also better from an environmental point of view since the raw material do not need to be produced in the first place. The different processing steps also require energy, which in this case also can be avoided.

Even though it will not be recommended to exceed the modularisation rules it might be needed to keep a diversified product range with many different designs. This since the designers need to be creative and too strict design rules can inhibit this. But it shall be complicated for the designer in order to prevent not pre-set dimensions, this is also suggested by the conducted interviews. It is important to emphasize that a modularisation also can help the designers to bring their product faster to the market. This since they do not have to spend time designing already designed components. Then they can spend more time on the characteristic components for their product, making it unique and producible.

7.4 Research implications

This case study aims to answer questions about how a modular strategy can make the production at IKEA more efficient. In literature both the car and electronic industry have been well studied. However, companies with other preconditions have not been studied as thoroughly. Hopefully, this paper will add some knowledge about how a company like IKEA is affected by a modular strategy.

This study does not in detail tell how IKEA would implement a modular strategy. It merely shows the benefits that could be obtained with such a strategy. The results from this project may give the decision makers at IKEA Industry some support for the possibility to further investigate and to implement a modular strategy. To be able to take well-founded decisions a problem need to be investigated from several angels. Hopefully this will contribute to a more theoretical approach to the modularisation strategy problem.

This case study alone might not give all the answers needed to decide if a modular strategy is a possible strategy for IKEA. But it hopefully raises the awareness about the importance of a unified product strategy and the potential benefits connected to a more modularised strategy. This report also illuminates the possible benefits and drawbacks connected to a modular strategy, once again raising the awareness and the importance of a correct handling around these issues.

7.5 Limitations

The main limitations in this master thesis have been the ability to gather reliable data from IKEA's production facilities. The products are not always manufactured in the same way in the different factories. This makes it hard to compare the costs directly between the factories. The measurement also varies among the different data sources making the effects of a modular strategy varying. In some cases the data also is questionable, for example in one case the percentages of scraped components are equal for all products, and while there in most cases varies according to shapes and quality. This discrepant in information from IKEA make it hard to validate the result in this report.

In the beginning of this project the goal was to investigate the entire solid wood product assortment, further on the scope was narrowed to the Hemnes family and finally Hemnes chest of drawers. This since the time for the project was limited. However, Hemnes and especially the Hemnes chest of drawers product family are one of the bestselling products and therefore has a major impact on IKEA Industry's final result. It also shows the potential benefits with modularisation that are possible when introducing new product families. But of course, further research is needed in this area to secure all possible gains from a modular strategy, especially in the case when it is possible to modularise over multiple product families.

On the negative side there is also a possibility that the solution is a sub optimisation of the problem. In the report the best solution for the Hemnes chest of drawers is presented. But since no further notice has been taken on how this affects other products in IKEAs assortment it is hard to validate if it is the best solution for IKEA Industry as an entity. Once again the time limits the scope.

7.6 Future research

This study has in many aspects been focusing on the production of the Hemnes chest of drawers. To get a more holistic view over the entire solid wood segment further analysis of product families and the interactions between them are required. If larger monetary savings can be found an implementation plan for how to execute the changes needs to be composed.

The scope of this project starts from the in cutting line and ends when the product reaches the finished goods warehouse. An example for future research can therefore be how the changes among the components affect the distribution and the sold volumes. In the calculations performed in this report it is assumed that the demand will stay unchanged. It could therefore be interesting to analyse how this affects the demand. The changes in demand can heavily affect the entire supply chain. If it rises it can cause trouble producing the wanted quantities and if it reduces the inventory cost might reduce the profit margin.

Another aspect that IKEA need to work on is how they develop and introduce products to the market. Today many of the products have been designed without considering the production. By integrating these two disciplines it would be possible to produce products to an even lower cost. Through, for example, reducing setup times in the production. A way to do this is to develop a modular strategy, similar to Next generation pine, resulting in fewer dimensions. This can also shorten the time to market since every part does not need to be designed from scratch. But to ensure these benefits further research is required.

In general many of the benefits are only investigated superficially, therefore many of the different areas would need a more thorough investigation. However, with the implications given around the different areas it would hopefully be easier for IKEA to prioritise and to choose the most value adding project for their business.

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9 Appendix

9.1 Appendix A

nterview nbr.	Person Interviewed	Date	Duration	nterview format
1	Robert Henriksson, Process engineer, IKEA Industry, Wilbark, Poland	18/2-16	2 h	Semi-structured
2	Peter Mowitz, Supply chain manager, IKEA Industry solid wood	25/2-16	1h	Semi-structured
3	Stefan Månsson, Project leader, North IKEA industry	29/2-16	45 min	Semi-structured
4	Ola Petersson, Development manager storage, IKEA of Sweden	3/3-16	1 h	Presentation followed by a short discussion
5	Tony Cederqvist, Product development engineer, IKEA of Sweden and Börje Lindgren, Product developer, IKEA of Sweden	3/3-16	1 h	Unstructured
6	Henrik Norberg, Technology development manager, IKEA Industry solid wood	7/3-16	1 h	Semi-structured
7	Peter Becker, Project leader, IKEA of Sweden	11/3-16	2 h	Presentation ollowed by short discussion
8	Petra Carlberg, Category manager, IKEA of Sweden	18/4-16	45 min	Semi-structured

9.2 Appendix B

General information

Date:

Name:

Position:

Questions about today

Please describe your work at IKEA?

Is there any challenges for IKEA today? (From your point of view)

Specific for production

Can you describe the process in production for Solid woods?

Is there any specific problems or issues regarding todays production?

Specific for product development

Can you describe the general product development process for IKEA?

Is there any problems with that process today?

Design for manufacturing, is that something that is done today?

If *not* what do you design for?

How early do you involve suppliers if they are at all involved in the NPD process?

Questions regarding coordination

How does the coordination between product development and production work today?

Is the production integrated in product development?

Questions regarding modularity

Can you know describe what modularity (modulindelning) means to you?

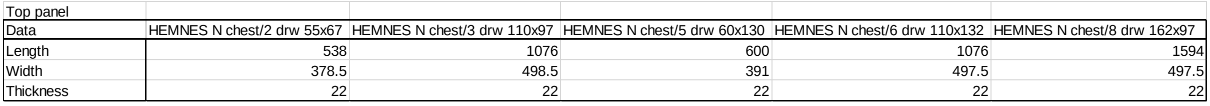
What benefits do you expect to get from introduce a modular product architecture? (From your point of view)

Do you see any drawbacks of introducing a modular product architecture? (From your point of view)

Do you see any potential benefits or drawbacks in other functions at IKEA of introducing a modular product architecture?

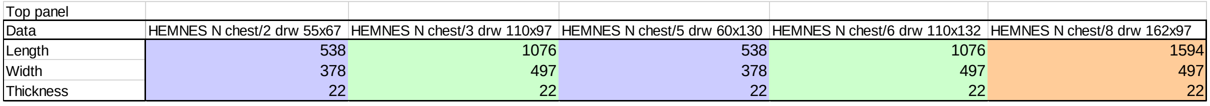
Modularity requires collaboration between functions. Do IKEA have any clear procedures regarding cross functional collaborations? If *yes* please describe how this procedure works.

9.3 Appendix C



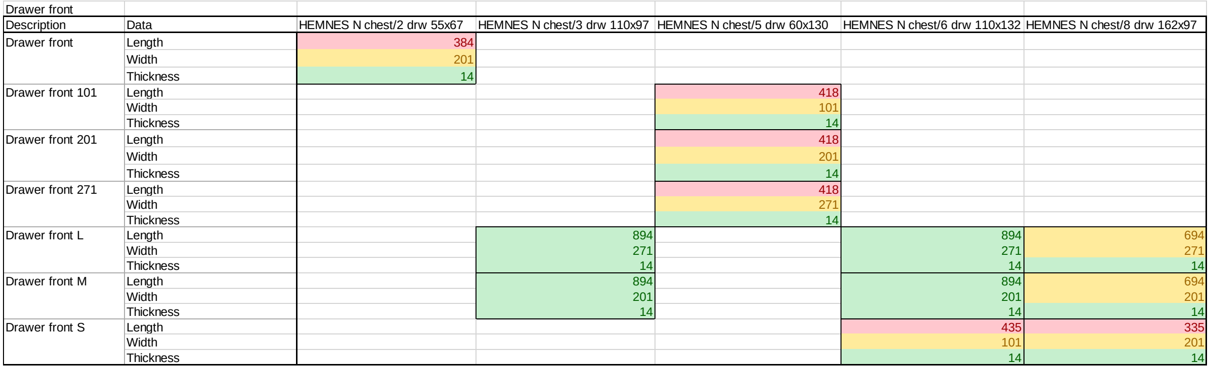
Top panel					
Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
Length	538	1076	600	1076	1594
Width	378.5	498.5	391	497.5	497.5
Thickness	22	22	22	22	22

Figure 34: Old dimensions top panels



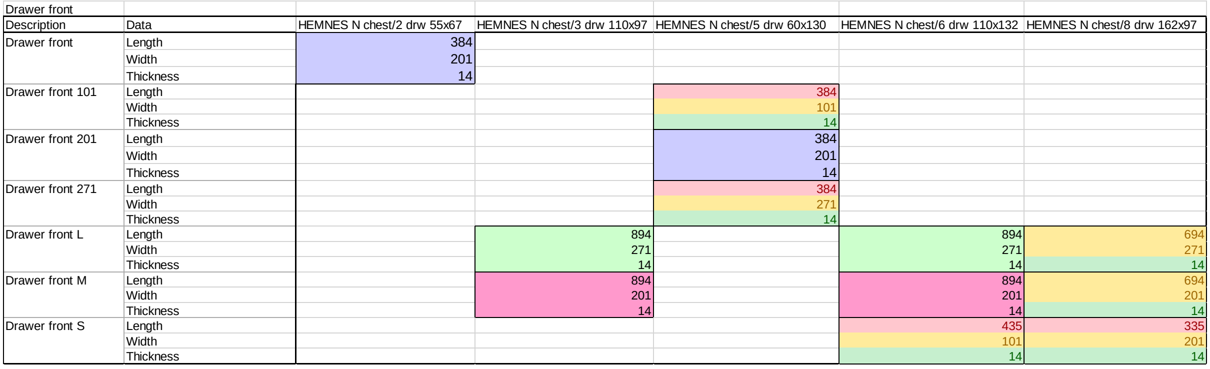
Top panel					
Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
Length	538	1076	538	1076	1594
Width	378	497	378	497	497
Thickness	22	22	22	22	22

Figure 35: New dimensions top panels



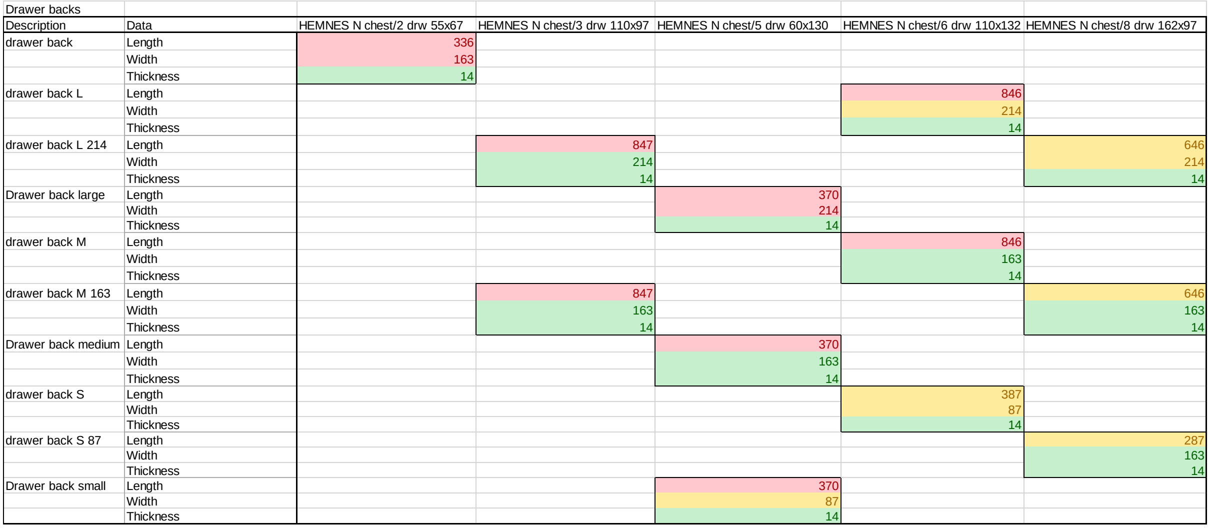
Drawer front						
Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
Drawer front	Length	384				
	Width	201				
	Thickness	14				
Drawer front 101	Length			418		
	Width			101		
	Thickness			14		
Drawer front 201	Length			418		
	Width			201		
	Thickness			14		
Drawer front 271	Length			418		
	Width			271		
	Thickness			14		
Drawer front L	Length		894		894	694
	Width		271		271	271
	Thickness		14		14	14
Drawer front M	Length		894		894	694
	Width		201		201	201
	Thickness		14		14	14
Drawer front S	Length				435	335
	Width				101	201
	Thickness				14	14

Figure 36: Old dimensions drawer front



Drawer front						
Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
Drawer front	Length	384				
	Width	201				
	Thickness	14				
Drawer front 101	Length			384		
	Width			101		
	Thickness			14		
Drawer front 201	Length			384		
	Width			201		
	Thickness			14		
Drawer front 271	Length			384		
	Width			271		
	Thickness			14		
Drawer front L	Length		894		894	694
	Width		271		271	271
	Thickness		14		14	14
Drawer front M	Length		894		894	694
	Width		201		201	201
	Thickness		14		14	14
Drawer front S	Length				435	335
	Width				101	201
	Thickness				14	14

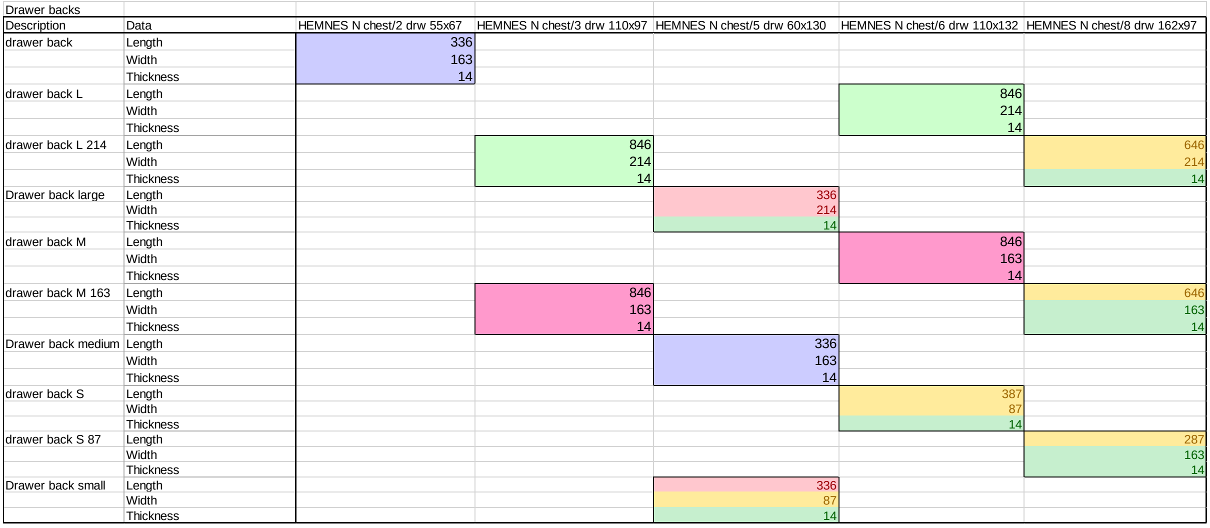
Figure 37: New dimensions drawer front



Drawer backs

Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
drawer back	Length	336				
	Width	163				
	Thickness	14				
drawer back L	Length				846	
	Width				214	
	Thickness				14	
drawer back L 214	Length		847			646
	Width		214			214
	Thickness		14			14
Drawer back large	Length			370		
	Width			214		
	Thickness			14		
drawer back M	Length				846	
	Width				163	
	Thickness				14	
drawer back M 163	Length		847			646
	Width		163			163
	Thickness		14			14
Drawer back medium	Length			370		
	Width			163		
	Thickness			14		
drawer back S	Length				387	
	Width				87	
	Thickness				14	
drawer back S 87	Length					287
	Width					163
	Thickness					14
Drawer back small	Length			370		
	Width			87		
	Thickness			14		

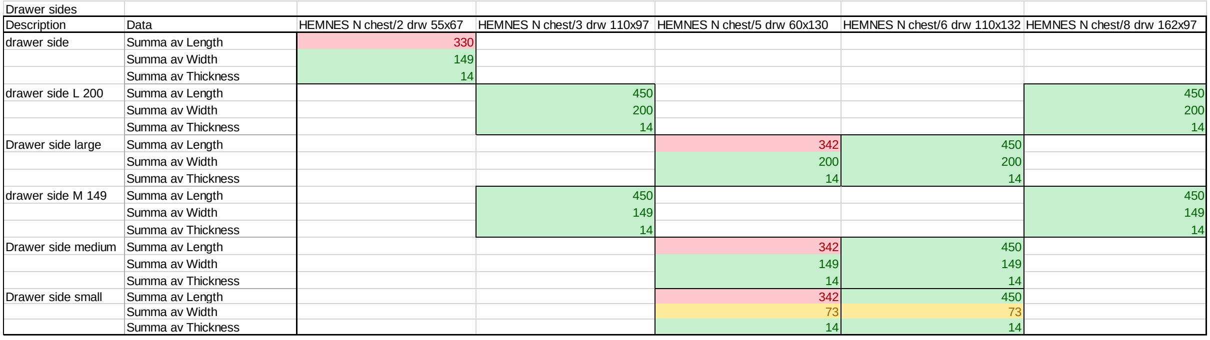
Figure 38: Old dimensions drawer backs



Drawer backs

Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
drawer back	Length	336				
	Width	163				
	Thickness	14				
drawer back L	Length				846	
	Width				214	
	Thickness				14	
drawer back L 214	Length		846			646
	Width		214			214
	Thickness		14			14
Drawer back large	Length			336		
	Width			214		
	Thickness			14		
drawer back M	Length				846	
	Width				163	
	Thickness				14	
drawer back M 163	Length		846			646
	Width		163			163
	Thickness		14			14
Drawer back medium	Length			336		
	Width			163		
	Thickness			14		
drawer back S	Length				387	
	Width				87	
	Thickness				14	
drawer back S 87	Length					287
	Width					163
	Thickness					14
Drawer back small	Length			336		
	Width			87		
	Thickness			14		

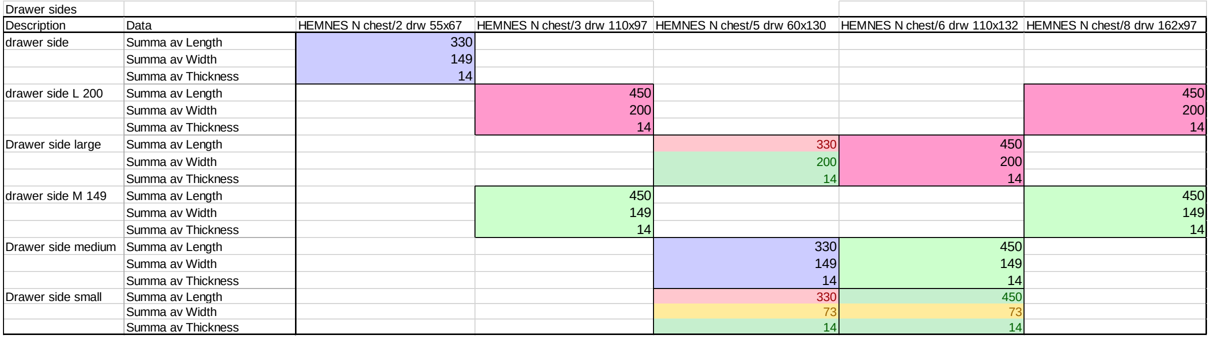
Figure 39: New dimensions drawer backs



Drawer sides

Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
drawer side	Summa av Length	330				
	Summa av Width	149				
	Summa av Thickness	14				
drawer side L 200	Summa av Length		450			450
	Summa av Width		200			200
	Summa av Thickness		14			14
Drawer side large	Summa av Length			342	450	
	Summa av Width			200	200	
	Summa av Thickness			14	14	
drawer side M 149	Summa av Length		450			450
	Summa av Width		149			149
	Summa av Thickness		14			14
Drawer side medium	Summa av Length			342	450	
	Summa av Width			149	149	
	Summa av Thickness			14	14	
Drawer side small	Summa av Length			342	450	
	Summa av Width			73	73	
	Summa av Thickness			14	14	

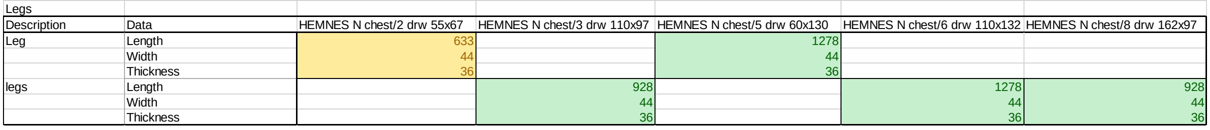
Figure 40: Old dimensions drawer backs



Drawer sides

Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
drawer side	Summa av Length	330				
	Summa av Width	149				
	Summa av Thickness	14				
drawer side L 200	Summa av Length		450			450
	Summa av Width		200			200
	Summa av Thickness		14			14
Drawer side large	Summa av Length			330	450	
	Summa av Width			200	200	
	Summa av Thickness			14	14	
drawer side M 149	Summa av Length		450			450
	Summa av Width		149			149
	Summa av Thickness		14			14
Drawer side medium	Summa av Length			330	450	
	Summa av Width			149	149	
	Summa av Thickness			14	14	
Drawer side small	Summa av Length			330	450	
	Summa av Width			73	73	
	Summa av Thickness			14	14	

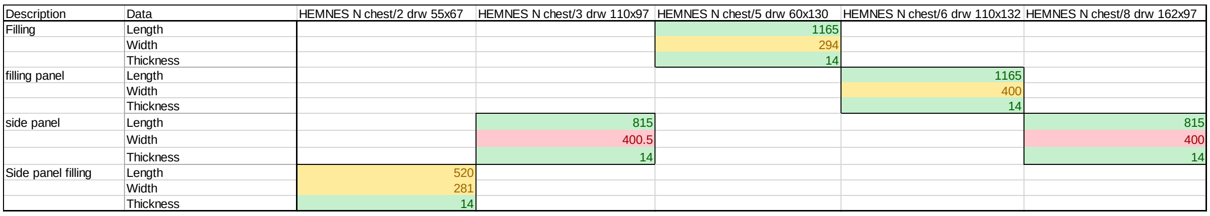
Figure 41: New dimensions drawer backs



Legs

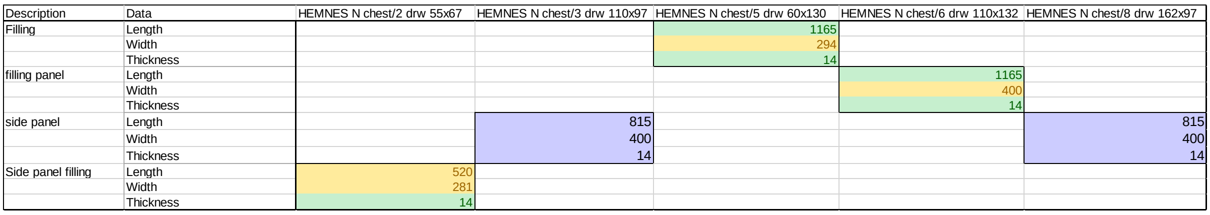
Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
Leg	Length	633		1278		
	Width	44		44		
	Thickness	36		36		
legs	Length		928		1278	928
	Width		44		44	44
	Thickness		36		36	36

Figure 42: Legs no change in dimensions



Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
Filling	Length			1165		
	Width			294		
	Thickness			14		
filling panel	Length				1165	
	Width				400	
	Thickness				14	
side panel	Length		815			815
	Width		400.5			400
	Thickness		14			14
Side panel filling	Length	520				
	Width	281				
	Thickness	14				

Figure 43: Old dimensions fillings



Description	Data	HEMNES N chest/2 drw 55x67	HEMNES N chest/3 drw 110x97	HEMNES N chest/5 drw 60x130	HEMNES N chest/6 drw 110x132	HEMNES N chest/8 drw 162x97
Filling	Length			1165		
	Width			294		
	Thickness			14		
filling panel	Length				1165	
	Width				400	
	Thickness				14	
side panel	Length		815			815
	Width		400			400
	Thickness		14			14
Side panel filling	Length	520				
	Width	281				
	Thickness	14				

Figure 44: New dimensions fillings

9.5 Appendix D

$$Production\ cost = Total\ manufacturing\ cost + G\&A\ cost + Capital\ cost\ (ROCE)$$

$$Total\ manufacturing\ cost$$
$$= DM + DL + ODC + Indirect\ production\ cost + Depreciation$$

$$DL = Operations\ cost\ per\ element * pcs\ or\ running\ meters + setup\ cost\ per\ elements$$

$$Setup\ cost\ per\ element = \frac{total\ setup\ cost}{Batch\ size * pcs}$$

$$Total\ setup\ cost = setup\ time\ in\ minutes * \left(\frac{wages * number\ of\ operators}{60}\right)$$

9.6 Appendix E

$$Monetary\ savings\ (zloty) = Savings\ per\ unit * Forecast\ Hemnes\ COD\ X =$$

$$(Suggested\ sales\ price\ before - suggested\ sales\ price\ after)$$

$$* Forecast\ Hemnes\ COD\ X$$

$$Suggested\ sales\ price =$$

$$Total\ manufacturing\ cost + G\&A\ cost + Capital\ cost\ (ROCE)$$

$$Total\ manufacturing\ cost =$$

$$DM + DL + ODC + Indirect\ production\ cost + deprecation$$

$$Monetary\ savings\ (\%) = 1 - \frac{Total\ production\ cost\ after\ changes}{Total\ production\ cost\ before\ changes}$$

$$Savings\ operations\ (\%) = 1 - \frac{operation\ cost\ per\ article\ after\ changes}{operations\ cost\ per\ article\ before\ changes} =$$

$$\frac{DL\ after\ cahnges}{DL\ before\ changes}$$

$$Freed\ capacity\ (hours) =$$

$$\frac{(Setup\ time\ per\ article\ before\ change - Setup\ time\ per\ article\ after\ change\ ) * Forecasted\ demand\ for\ Hemnes\ COD\ X}{3600}$$

$$Freed\ capacity\ (products) =$$

$$\left(\frac{Setup\ time\ per\ article\ before\ change - Setup\ time\ per\ article\ after\ change}{Total\ production\ time\ per\ article}\right) *$$

$$Forecasted\ demand\ for\ Hemnes\ COD\ X$$

9.7 Appendix F

$$DM = \frac{wood\ price * volume * Quality\ index}{(1 - lacquering\ scrap\ cost) * (1 - wood\ scrap\ cost)}$$