LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
LUT Mechanical Engineering

Janne Jääskeläinen

VALUE STREAM OF DEMANDING CUSTOMER PROJECTS IN THE ORDER-TO-DELIVERY PROCESS

Examiner(s): Professor. D.Sc. (Tech). Harri Eskelinen
Engineering Manager. M.Eng. Paula Häkänen

TIIVISTELMÄ

Lappeenrannan teknillinen yliopisto
LUT School of Energy Systems
LUT Kone

Janne Jääskeläinen

Haastavien asiakasprojektien arvovirtaus tilaus-toimitusprosessissa

Diplomityö

2018

105 sivua, 31 kuvaa, 3 taulukkoa ja 3 liitettä

Tarkastajat: Professori. D.Sc. (Tech). Harri Eskelinen
Engineering Manager. M.Eng. Paula Häkänen

Hakusanat: Tilaussuunnittelu, Haastavat asiakasprojektit, Asiakasohjautuva tuote, Arvovirtakuvaus, Engineer-To-Order valmistus, Tilaus-toimitusketju.

Tässä tutkimuksessa keskityttiin tilaussuunnittelun lävitse kulkevaan informaatiovirtaan. Tilaussuunnittelun pääasiallinen tuote on informaatio. Se muokkaa asiakkaalta saatuun tietoon perustuen tuotteen rakenteen vastaamaan asiakkaan toivomuksia. Tutkittavan yrityksen tuote on monimuotoinen, joka mahdollistaa sen muokkaamisen vaatimuksia vastaavaksi. Kohdeyrityksen tuote on osa asiakkaan suurempaa kokonaisuutta, siihen kohdistuu paljon vaatimuksia ja sen täytyy täyttää ulkoisten luokituslaitosten asettamat vaatimukset.

Kohdeyritys toimii tiukasti kilpaillulla alalla, jossa tuotteiden vaatimus- ja suoritustasot kohoavat jatkuvasti. Kohdeyritys on pystynyt voittamaan edukseen haastavia kauppoja, joiden toteuttamisesta halutaan paras mahdollinen hyöty. Nämä tilaukset voidaan nähdä haastavina asiakkaina, vaikka juurisyy tämän tutkimuksen mukaan on kommunikaation määrässä ja projektien muutoksissa. Tilaussuunnittelulla on suuri osuus projektien hallinnasta ja asiakasräätälöidyn tuoterakenteen valmistamisesta. Tuoterakenne palvelee niin sisäistä, kun ulkoista asiakasta, sekä myös alihankkijoita. Tässä tutkimuksessa kohdeyrityksen toimitusketjua tarkasteltiin arvovirtakuvauksen avulla siten, että tilaussuunnittelu on tutkimuksen keskiössä. Arvovirtakuvauksen ympärille rakennetuissa syventävissä tutkimuksissa selvitettiin prosessiin liittyviä tekijöitä.

Tutkimuksissa pystyttiin selvittämään, että haastavat projektit liikkuvat järjestelmässä epälineaarisesti. Tiedon ja muutosten määrä kasvaa haastavissa projekteissa. Käytetyn ajan määrä kasvaa muutosten ja kommunikaation määrän kasvaessa ja tämä muodostaa hukkaa. Projektien luonteesta syntyvä tuotteen rakenteen jatkuva muuttuminen aiheuttavat projekteihin sitoutuneen ajan kasvua. Nämä tekijät johtavat siihen, että projekteista ei saada parasta mahdollista hyötyä. Tutkimuksessa luotiin ehdotus mahdollisista prosessin muutoksista ja arvioitiin sen vaikutukset ja hyödyt prosessille.

ABSTRACT

Lappeenranta University of Technology
LUT School of Energy Systems
LUT Mechanical Engineering

Janne Jääskeläinen

Value stream of demanding customer projects in the order-to-delivery process

Master’s thesis

2018

105 pages, 31 figures, 3 table and 3 appendices

Examiners: Professor. D.Sc. (Tech). Harri Eskelinen
Engineering Manager. M.Eng. Paula Häkänen

Keywords: Order-based engineering, Demanding customer projects, Customer-specific products, Value Stream Mapping, Engineer-To-Order manufacturing, Supply Chain.

The focus of this research is on the information flow that goes through the order-based engineering. The main purpose of the order-based engineering is to produce information. It will modify the product's structure based on the customer's information in the shape that matches the customer's wishes. The product of the case company is complex and enables it to be tailored to meet the customer’s requirements. The products are a part of the customers entities, so lots of the requirements relates to the product and it must fulfill the technical specification of the classification societies.

The case company is operating in a highly competitive market sector, where product requirements and performance levels are constantly rising. The case company has been able to overcome challenging projects and wishes to utilize the best possible benefit out from those deals. The projects can be dressed in the disguise of a difficult customer, but according to this research, the root cause can lie behind a huge amount of information and changes in projects. The order-based engineering has a crucial role in these projects and designing of customer-specific products. The structure of the product is serving inner and external customers, as well as subcontractors. The order-to-delivery process of the case company was studied using value stream mapping in the way that the order-based engineering is at the center of the research. Supporting studies are built around the value stream mapping to help research factors in the order-to-delivery process.

The research discovered that challenging projects are moving nonlinearly in the process. The amount of information and changes increase in challenging projects. The amount of time spent on projects increases from the influence of the increasing amount of changes and communication, and this creates waste. The changes caused by the product's nature results in more time spent on the project. These factors lead to a situation where the best possible benefits cannot be achieved in the projects. The result of the research is a proposal with potential changes for the process. The impact and benefits for the changes are evaluated.

ACKNOWLEDGEMENTS

In my life, I have been especially blessed with people around me that have believed in me and have open-handedly given me opportunities to explore my passions. I am in great debt to people around me for that. Looking back from my corner it seems that I have come a long way and I am assured that you would not hold this book (or pdf) in your hands without the people that I have the privilege to call my friends and family.

The groups mentioned above include many people from the case company, which I have had the privilege to work for. I would like to thank the case company for the opportunity, which they have given me to do this research and finish this studying period in my life for now (until further notice). I would like to express my thankfulness to the project management team and order-based engineering team and all individuals who have to helped me with my studies and with this research. Separately I would like to express my special thanks to Paula Häkänen how to create this opportunity for me and guided me through it.

I would also like to express my gratefulness to LUT-University, which has made it possible for people to develop they knowledge sensibly and flexibly alongside with fulltime work. I would like to dedicate my special gratitude to Harri Eskelinen for helping and kindly guiding me through this research project.

Finally, I would like to thank my wonderful fiancée, who has been my upmost support and confirmed believe and sense in me about the completion of this project. I own her a great deal for the completion of my studies and this master’s thesis.

This has been a great journey and great privilege.

Janne Jääskeläinen

Janne Jääskeläinen
Porvoo 3.12.2018

TABLE OF CONTENTS

TIIVISTELMÄ
ABSTRACT
ACKNOWLEDGEMENTS
TABLE OF CONTENTS
LIST OF ABBREVIATIONS
1 INTRODUCTION 8
1.1 Background 10
1.2 Research problem 11
1.3 Research questions 12
1.4 Research scope 13
1.5 Research methods 14
2 VALUE STREAM MAPPING 18
3 MANUFACTURING AND PRODUCTION PLANNING APPROACHES 25
4 CURRENT-STATE ANALYSIS OF THE ORDER-BASED ENGINEERING .. 30
4.1 Order-based engineering 31
4.2 Order handling 34
4.3 Schedule of engineering 36
4.4 Customer-specific products 38
4.5 The order and change orders 41
4.6 Customers and demanding customer projects 42
5 CURRENT-STATE MAPS OF THE ORDER-BASED ENGINEERING 44
5.1 The current-state map of the 1st target of research 47
5.2 The current-state map of the 2nd target of research 49
5.3 Summary of the current-state maps of the order-based engineering 50
6 WASTE OF THE ORDER-TO-DELIVERY PROCESS 54
6.1 Waste in the office environment 54
6.2 Demanding customer projects 56
6.3 Information flow 59
6.4 Order document and attachments 61
6.5 Change orders 63

6.6 Waste in designing process 68
6.7 Planned schedule of engineering Vs. the actual schedule of engineering........... 70
6.8 Summary of waste in the order-to-delivery process 71
7 FUTURE-STATE MAP OF THE ORDER-BASED ENGINEERING................ 76
8 ANALYSIS OF THE IMPACT AND EFFORT OF FUTURE-STATE MAP 82
9 DISCUSSION 85
9.1 Comparison and interfaces with previous research 85
9.2 Objectivity 87
9.3 Validity and reliability 88
9.4 Error and sensitivity analysis.. 89
9.5 Key findings 91
9.6 The novelty value of results 95
9.7 Generalization and utilization of the results... 96
9.8 Topics for future research 97
9.9 Closing words.. 98
10 SUMMARY 99
LIST OF REFERENCES.. 104
APPENDIX
Appendix I: The current-state map of the 1st target of research.
Appendix II: The current-state map of the 2nd target of research.
Appendix III: Future-state map of demanding customer projects.

LIST OF ABBREVIATIONS

ATO	Assemble-To-Order
BTO	Buy-To-Order
BOM	Bill Of Material
CODP	Customer Order Decoupling Point
DP	Decoupling Point
ETO	Engineer-To-Order
ERP	Enterprise Resource Planning
FIFO	First In First Out
GTS	Global Technical Support team
LSU	Local Sales Unit
MTO	Make-To-Order
MTS	Make-To-Stock
OBE	Order-Based Engineering
PLM	Product Lifecycle Management
STS	Ship-To-Stock
TOC	Theory Of Constraints
TQM	Total Quality Management
VSM	Value Stream Mapping

1 INTRODUCTION

A working supply chain is the foundation of any successful business. In the world where nowadays everything is happening faster, and everything is available immediately, a business must also step up and be able to respond to that challenge. The basic idea of business has not changed, fulfilling the customers need is still the driving factor behind all business, but the customers have become more aware of what they want and what they can have. Moreover, in the field of industry, the customer can tell at which time they need it. At the same time, the expectations on the product and services have increased, and the assumption on lead time has decreased. For continuous business, the supply chain needs to get more effective and accurate.

This research focus is to observe and investigate the supply chain of the case company from the point of view of the order-based engineering department. The order-based engineering department is a part of the organization of the case company. The case company is a production unit of a multinational corporation, which main products are electrical equipment. The main business area of the case company is highly customized products for customer needs.

The products are individually and highly customized and fulfill complex customer product entities. The product needs to fulfill specific customer demands and fulfill the technical specification of the classification societies. Engineering of this products begins from customer order and continues in close co-operation with the customer until manufacturing of the product is ready.

The project management department manages this co-operation, but the design of the product is the responsibility of the order-based engineering department. This research focuses on studying the supply chain in the point of view of the order-based engineering department.

The case company has been winning challenging and demanding projects from its competitors. The case company has strong knowledge and long expertise of designing and manufacturing the customer-specific products. Customer oriented thinking is one of the case company's key values, nevertheless the case company has had troubles managing so-called demanding customer projects. On some projects fulfilling the customer requests are challenging, and sometimes these projects may turn out to be challenging for the case company. It is common that on these demanding customer projects the problems and challenges are multiplied. This causes a lot of extra work, which results in direct and indirect costs for the project. In this process the order-based engineering plays a key role. It is widely recognized that the engineering phase determines a large part of the total cost of the product and effects also the cost of manufacturing (Earl, Hicks & McGovern 2000, p. 179-190; Ehrlenspiel, Hundal, Kiewert & Lindemann 2007, p. 12).

This research will focus on demanding customer projects from the point of view of the order-based engineering department. The main study is to find out how the role of the order-based engineering in the supply chain can be improved, so that it supports the all stakeholders better and can continuously improve the strengths of the department.

Already at this point, it is important to underline that demanding customer projects mean projects where the customer demands and the technical specification are very strict. It is highly important to notice that demanding customer projects do not mean that the customers are difficult or demanding.

1.1 Background

The case company of this research is a production unit of a multinational corporation, which main products are electrical equipment's. The production unit, which is studied in this research is focused on the manufacturing of electrical motors and generators. The case company is one of several production units, which together form the backbone for the previously mentioned multinational corporation's business. The business production range between these units varies, and the characteristics of the end-user can also be differently oriented. From here on this production unit of the previously mentioned multinational corporation is referred to as the case company.

The previously mentioned multinational corporation has its headquarters in Zurich, Switzerland. The global revenue in the year 2017 was 34,312 million dollars. This multinational corporation is employing approximately 147 000 people in 100 countries around the globe. The case company is one of the production units of Finland which together employ approximately 5200 people in Finland. Other production units are in the Helsinki area and Vaasa and Porvoo.

The customers of the case company are large manufacturing companies and industry in general. The main business area of the case company is highly customized products for customer's needs. The products are a part of complex customer product entities. The final assembly site may be anywhere on the globe. Main industrial fields are oil and gas, marine and mining industries.

The case company designs and delivers around 1000 customer specific tailor-made projects every year. Each order can contain 1 to 4 identical products. The total lead time including designing is between 12 and 28 weeks. The product range includes 3 main categories for products. The features between products vary, but the common feature is the possibility of high-level customization.

The production line of the case company is in the Helsinki campus area, where other production lines of other production units are also located. All main functions of the case company's supply chain, like purchase, production, order-based project managing, order-based engineering, and production planning are located at Helsinki campus area. Meaning that the communication between different departments is natural and happens on multiple levels. Also, the co-operation between other production units is possible, but all production units have their main functions, which are working separately. The sale units are spread around the globe, close to the customers.

1.2 Research problem

The competition on the market has been demanding in recent years, and only the fittest has been able to win deals. The case company has been part of this competition and has been able to win contracts. The case company has focused on demanding projects and products. The customer requirements are constantly tightening. The design of the product needs to fulfill specific customer demands and the technical specification of the classification societies. The highly customized product competes with the level of customization and delivery time along with the price and the effectiveness of the product. All of these combined from a challenging project with short delivery times. The case company has a strong knowledge of designing customer-specific products. The order-based engineering is in a key role of this process, but the case company has had troubles managing these so-called demanding customer projects.

The workload of the order-based engineering department is well controlled. New projects can begin at short notice, but demanding customer projects are creating large workload for the department and affect the whole order-to-delivery processes. Demanding customer projects are hard to see in advance, and their identification may be too late when the design of the product is finished, and the production has begun.

Under high customization and a tight schedule, a simple product can become challenging, and the problems and the challenges can multiply. Unclear and constantly changing projects are creating challenges for remaining on the schedule. Changes in the structure of the product cause extra work and material losses.

This research aims to increase the understanding of the role of the order-based engineering department in demanding customer projects. The demanding customer projects are a well-known issue in the case company, but actual studies and findings are rare. All actions and the information amount and flow have not been studied before. The case company carries out many studies which are related to the supply chain and the stakeholders of the case company's order-to-delivery process, but these studies are not made from the point of view of the order-based engineering department. This research focuses on finding out how the role of order-based engineering can be improved and how the order-based engineering team can support the other stakeholders better, especially in demanding customer projects. This subject is less studied in the case company, and it is a fascinating topic for the case company.

A good management of the demanding customer projects is the responsibility of all stakeholders in the supply chain and is a prerequisite for all profitable business. This research will focus on increasing the understanding of the challenges of these projects from the point of view of order-based engineering. This research aims to meet the research questions which are presented in chapter 1.3 and which are based on the previously described research problem.

1.3 Research questions

In this chapter, the research questions of this research are presented. This research focuses on one main research question and three secondary research questions. The main research question will answer the previously described research problem and tries to explain the contextual behind the research problem. Three secondary research questions ensure that the main research question can be addressed. The main and secondary research questions are tightly linked to each other. The secondary research questions try to point out the root causes behind the core issue of the research problem.

The main research question of this research is:

- "Why demanding customer projects of the case company requires lots of effort and time from the order-based engineering?"

The secondary research questions are:

- "What are the key factors which create a negative impact(drag) to the flow of the process?"
- "What is the waste which is formed from these challenges?"

- "Is it possible to reorganize process steps of order-based engineering in way that it will decrease the amount of challenges in demanding customer projects and how could this arrangement be achieved?"

1.4 Research scope

In this research, we are mainly focusing on the process of the order-based engineering department. The research scope is limited to a specific period in the supply chain. That specific period is after the customer order decoupling point, and before manufacturing starting point, i.e., this research is focused on orders when they arrive into the factory and the factory takes the leading role on order handling. At this point, the order becomes a project for the case company. The scope of this research ends when the office part of order handling is over, and the order moves on to the production line.

This research focuses on the role of the order-based engineering department. The effective supply chain requires good co-operation between the stakeholders of the order-to-delivery process. In the case company's order-to-delivery process the order-based engineering plays a key role and is in close co-operation with other stakeholders of the process. This expands the research area to cover almost the whole supply chain, but this research is only dealing with relationships between order-based engineering and stakeholders of the order-to-delivery process. The research scope is highlighted in figure 1. The stakeholders of the research scope are illustrated on the list on the low left corner of figure 1.

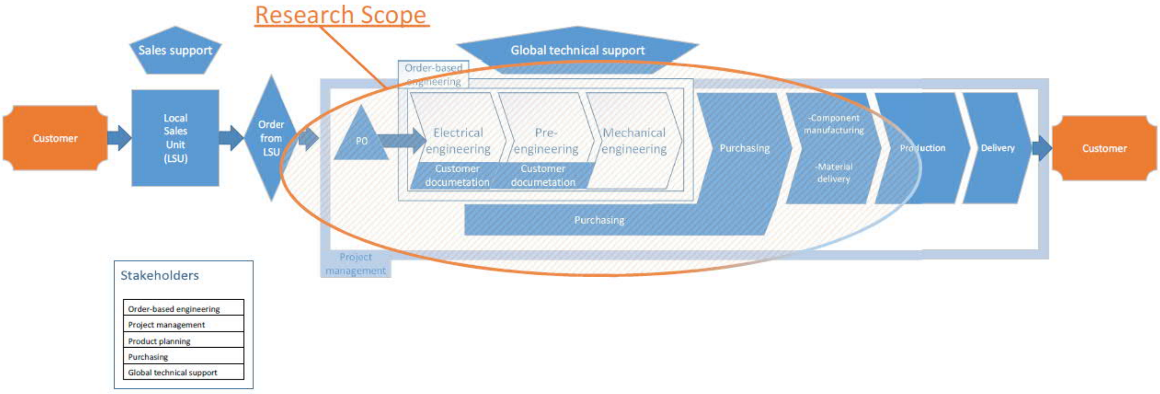


Figure 1. Order-to-delivery process and highlighted research scope. The stakeholders of the research scope are illustrated on the list in the lower left corner.

1.5 Research methods

The study of this research is divided into 6 main steps. Each step contains several inputs. The primary input is from the previous step, and additional input is from the independent resource or literature study. The main core of the research design of this research can be seen in figure 2.

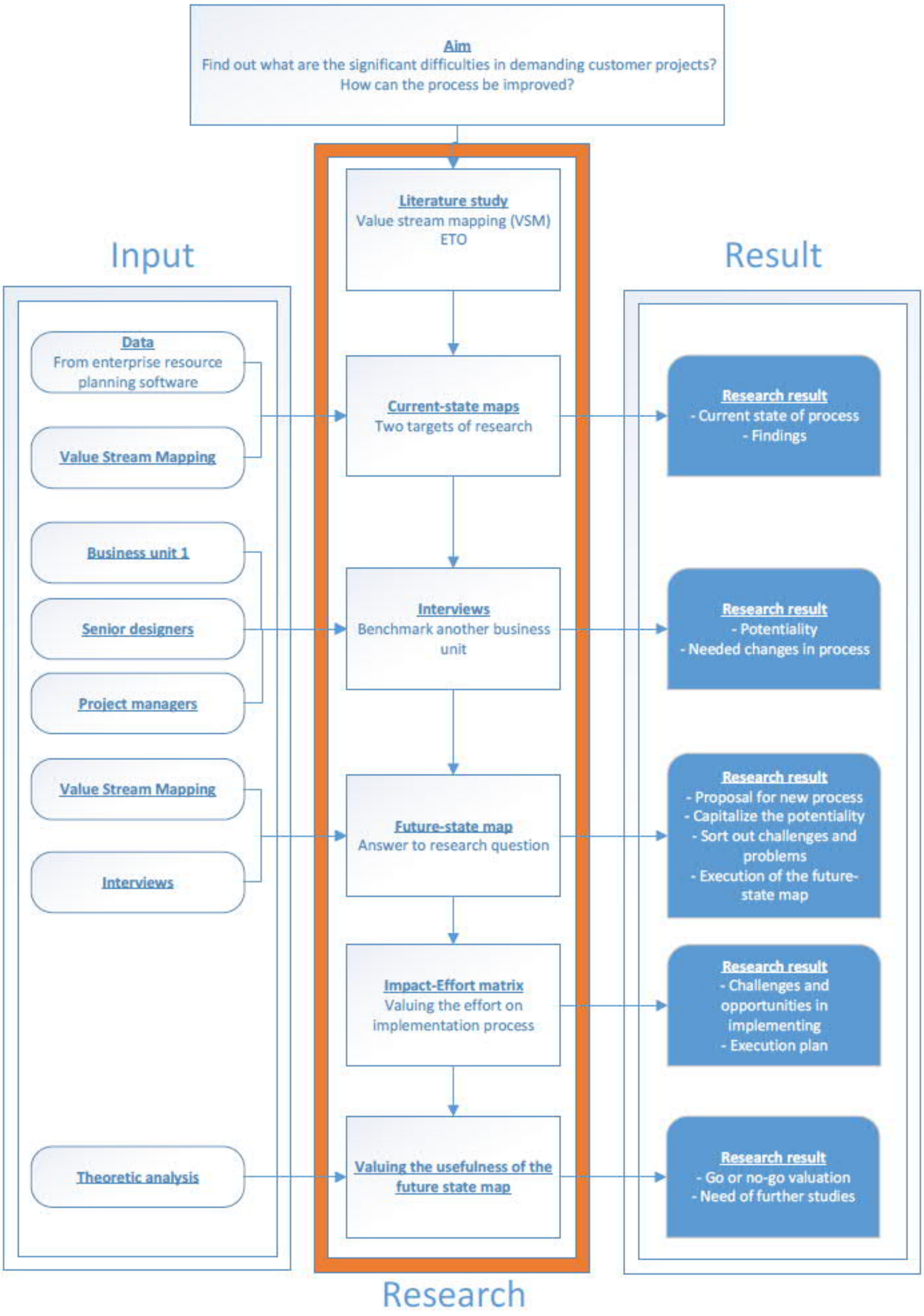


Figure 2. The main core of the research design, the use of input, and the results of the research.

The backbone of this study is the research process in the middle column of figure 2. The primary input is on the left column, which will be gather from the organization's systems and literature. Also, parts of the results of the earlier stake research process can used as the input of the next research process. The output i.e. results of research can be found in the right column.

The main research steps of this research are:

- Literature study.
- Current-state mapping using value stream mapping methods.
- Interviews with another business unit and stakeholders.
- Future-state mapping using value stream mapping methods.
- Impact-effort matrix.
- Theoretical analysis.

The study of this research is based on literature studies and case studies. Chapters 2 and 3 will introduce the literature discoveries of this research. In chapter 2, the value stream mapping tool is introduced. A part of chapter 2 is an evaluation of the usefulness of the value stream mapping tool. Chapter 3 will introduce the core manufacturing process of the case company and underline the critical features of engineer-to-order process and -products. Chapter 4 will tie them together with findings from current-state of order-based engineering of the case company. Chapter 4 will introduce the order-based engineering department and other stakeholders of the order-to-delivery process of the case company.

Chapter 5 will introduce the current-state maps. Current-state maps will be drawn for two different projects. Both projects can be classified as demanding customer projects, but the nature of these projects are different from each other, but still, the degree of difficult, and structures are similar enough that the comparing and inspection can be carried out.

Current-state maps are a part of the value stream mapping methods, which is one of the Lean-tools. However, in this research, the Lean and Lean-tools are not in the scope of the study. Lean is a useful tool for all business and is in widespread use in the case company, but Lean is better for mass production. In this research, we try to focus on a highly customized products, and in these cases the volume of delivered products is low.

Besides of Lean the theory of constraints (TOC) could be an interesting approach for research questions of this research, but TOC is assuming that there is a flawless flow. At this point it seems that the business model of the case company is not capable of flawless flow and the business model is not based on that either. Especially when this research is covering the part of supply chain before purchasing and assembly. TOC may be easier to target on those functions although it has been successfully used on sales, engineering and project management in another business unit. The case company’s focus is in highly customized products and this may require interaction with a customer, which may last from sales over engineering and purchasing and even over assembly phases.

Valuable information about the production phases can be found in the case company’s enterprise resource planning (ERP) software. This information is used when the current-state maps are created. This information will be refined by the necessary Office tools. The researcher draws current-state and future-state maps. Basic Office programs will be used for drawing the maps. No special program is used for this purpose. The progress of the project can be maintained through ERP-software. All stages of design and manufacture processes are recorded to ERP-software. Also, all changes are recorded to that software.

The case company is just one production unit in a large corporation. That gives us an opportunity to also study and benchmark another business unit. Another business unit is selected in way that the features and natures of the product are similar to the product of the case company. The study from another business unit will be carried out as interviews.

To support these findings stakeholders of the order-to-delivery process will be interviewed. The interview groups were senior designers, project managers, and engineering manager of another production unit. The interviews are made in separate group interviews and the interviews will be carried out as open interviews where the researcher will take part in the discussions. The pre-made list of topics has been sent to interviewers in advance, and the researcher makes sure that topics will be reviewed and that everyone has the opportunity to make their own opinion on the topics.

The 7th chapter of this study will be a future-state map. In this phase, the previous steps are combined to one future-state map, which will illustrate the optimal process for the order-based engineering department. This chapter will combine the found knowledge from the literature study and the interviews with the findings from the current-state maps.

Finally, the impact-effort matrix gives us an idea of how much work it would take to put the improvements brought by the future-state map into use. In this phase, the theoretic analysis of the usefulness of this change will take place.

This chapter is good to end with an introduction of the researcher. The researcher has worked for the order-based engineering department of the case company for the last six years. The researcher has worked as a mechanical designer with close co-operation with electrical designers, project managers, purchasers and people from the production. The researcher himself designs the targets of research, which this research will examine. The first two months of the research period, the researcher spent working as a part of the order clearing processes, examining the front end of the supply chain of the case company.

2 VALUE STREAM MAPPING

This chapter points out what are the benefits of Value Stream Mapping (VSM). The primary purpose of this chapter is to show how VSM is used and what it will reveal about the process. The VSM tool is generally used to illustrate the value streams of shop floor of factory or production line, but it can also be used for an office process and administrative process. The value streams of the office process are significantly different from the value streams of the shop floor, but in both cases, the principle is the same.

The use of VSM for office processes is not as common as it is for the shop floor process. In office process, the value adding actions and non-value adding action are harder to identify. The first section of this chapter introduces the VSM process in general. The end of this chapter underlines the unique features of VSM in the office process.

This chapter also evaluate the usefulness of VSM for the case company's office processes. This evaluation give responses if the VSM can give answers for the research problem and the research question of this study. The evaluation also reveals whether there are questions that cannot be answered using VSM tools.

The evaluation is based on the researcher's own experiences of VSM and literary findings. The evaluation method to use for VSM is like the method which is used for evaluation on risk in the work environment. The technique is based on BS 8800, and it has been customized to fit better for this research.

Talking about the VSM as a method or technique for improving the production process, people like Jim Womack, Dan Jones, Mike Rother, and John Shook cannot be ignored. Jim Womack and Dan Jones set the first rhythms for the VSM on their book *Lean Thinking* in 1996. Mike Rother and John Shook launched their tool book, *Learning to See* in 1998. Of course, Taiichi Ohno and others Toyota pioneers had their influence on the development of VSM.

VSM is all about improving the flow, eliminates waste and identifying value. Value stream means all the step of the process which shapes the raw materials into finished products for the customer (Rother & Shook 2003, p. 3). Features and functions of product (or service) which meet the customers' expectations can be considered as a value (Duggan 2002, p. 3). Rother and Shook (2003, p. 3) introduce steps as actions in their book *Learning to See* and separates them into the value adding actions and non-value adding actions. There is also a third action type: necessary but non-value adding (McManus 2005, p. 33, 49). Of course, all production wants to focus only on value adding actions and reduce the amount of non-value adding actions. The non-value adding actions do not increase the value of the product (or service). The non-value adding actions can be considered as pure waste (Duggan 2002, p. 3). Customers are not interested in the ratio between value adding and non-value adding actions in the manufacturer's inner processes. Customers are only willing to pay of quality, effective lead time and service. (Rother et al. 2003, p. 6.) The production flow contains also information and material flow (Rother et al. 2003, p. 5).

VSM is a two-step process, and it begins from analyzing and mapping the current-state of the process and lead, to designing the best possible future-state for the process (Duggan 2002, p. 3; Rother et al. 2003, p. 9; Keyte & Locher 2004, p. 7). These two phases are called current-state mapping and future-state mapping. When the value adding and non-value adding actions has been identified, and material and information flow between actions has been discovered on the current-state map, the waste elimination process can be started, and this is done creating the future-state map. This research is going to focus mainly on these steps and especially in an office environment and administrative process.

VSM can be used to illustrate the holistic view from the suppliers to end users. That total value stream includes several firms and lots of functions. In many cases it is more useful to divide the process into smaller pieces which are more accessible to maintain and understand. The VSM can be subjected to one product or one product family. (Rother et al. 2003, p. 3; Keyte et al. 2004, p. 6-7).

This research is going to subject the VSM on particular types of projects. VSM illustrates all functions in the process. To collect and present the value adding and non-value adding steps from that process and give more knowledge from the information and material flows. VSM is a visual way to illustrate the holistic view of the process (Keyte et al. 2004, p.1,5 & Rother et al. 2003, p. 3). A simple illustration of a current-state map is represented in figure 3.

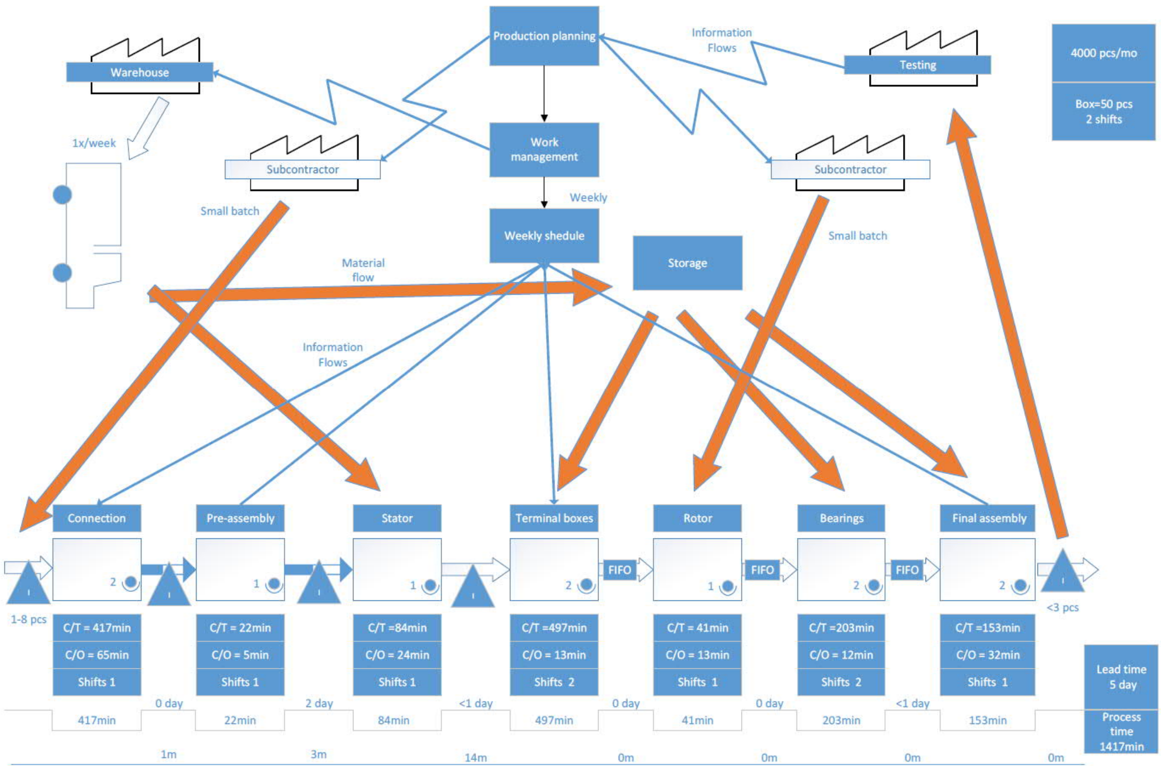


Figure 3. Example of current-state map (Mod. Duggan 2002, p. 9).

Like it has been mentioned, production flow contains information and material flow. The material flow is to from raw materials into finished products for the customer. These two flows are generally considered to be the most critical flows in the production and together they cover almost the entire flow at the production. The direction of the material flow is from suppliers through production to the customer, and generally, it is thought that the information flow is in the opposite direction. (Rother et al. 2003, p. 5). However, in the office process, it is not necessarily so that the information flow is the opposite direction from the material flow.

Nonproduction and administrative processes, i.e., office processes are considered as a harder subject for VSM (Keyte et al. 2004, p. 1, 5; Chiarini 2013, p. 33). The mapping of the office processes is difficult because fact that the office process not contain any material flow, the value stream of office process consists of data and information. (Chiarini 2013, p. 33). Also, the knowledge should be considered as a part of the office process value stream (McManus 2005, p. 24).

In the office process, it is maybe easier to centralize on what the customer needs. However, it can be harder to note which processes at the office level really are value adding and which are non-value adding (Keyte et al. 2004, p. 1, 15-16). Also, it is clear that the office process has more necessary, but non-value adding actions than the manufacturing process. The workload and the balance of the workload may be harder to detect, and the office process flow can be more fragmented than on the shop floor. (McManus 2005, p. 10, 71; Keyte et al. 2004, p. 68-70; Rother et al. 2003, p. 72).

The main focus of VSM in this research is to be used in office environment to identify the customers (inner and external) needs and to discover the value adding steps on administrative processes before and during the actual manufacturing phase. This is covered on the current-state mapping and the future-state mapping of the office process of the case company.

Within the framework of this research, there will be made two current-state maps of the process of two separate projects. These current-state maps illustrate the steps and phases of each project in the order-to-delivery process of the case company. Both projects are delivered. The structures are similar, and the degree of difficulty is the same. The researcher himself has made the mechanical engineering. Also, the level of customization is very close to each other.

Because both projects are delivered, the few facts about the projects is known in beginning of this study. The project, that is examined at the first, is delivered without significant challenges. For this reason, it is an excellent subject of the study. The project, that is examined second, was a far more challenging project for the case company. At this point, it can be stated that the projects which are selected for this research represent very different projects in demanding customer project category.

Searching and studying projects which have different characteristics on project management level, but are similar on the structural level. This research is aiming to find successes and challenges of both projects. Based on these findings, the future-state map is made. Future-state map will be a combination for the current-state maps of both projects, but the focus is on comparing the maps.

It is a important to note that the main idea behind VSM is not a drawn map of the map, but to create a holistic view of the actions and activities across the organization which points out the non-value adding actions and development targets.

A part of this research is evaluating if the VSM tool is suitable for studying office process in the same way it can used for revealing value streams on shop floor processes. At the same time, it is studied whether the VSM will also provide answers to the research problem and the research questions. For this evaluation, the same method has been chosen, which is often used to estimate the risks on the work environment. The technique is based on BS 8800, and it has been customized to fit better to this research questions.

Figure 4 presents a 9-level table. In the left-hand column of the table there is presented the probability of instance and the upper row of the table shows the effect of the instance. Sectors are divided as follows:

- 1-Very low risk
- 2-Low risk
- 3-Medium risk
- 4-High risk
- 5-Very high risk

It is important to note that no research method does not match the research questions indisputably or directly solve the research problem. All method needs to assist of the researcher. If evaluating of suitable is on level 1, the risk is low, and the method is acceptable. In other words, the method answer the research questions, and the significance of the answer is high. If the evaluating is on level 2, the method is answering the research questions partly, or answers is partly significant. Level 2 is still acceptable. On level 3 or 4, the risk is real, and the method does not necessarily answer directly to the research questions.

On these levels, the method can be used, but the results should be treated with carefulness and other methods are needed to find answers to research questions and the research problem. If the evaluating ends up at the level 5, that means that the method does not answer to the research questions.

The literature findings show that the VSM can be used for evaluating the office and administrative processes. Keyte and Locher (2004, p.1) underlines that mapping the office and administrative processes may need a more creative approach then mapping the material flow on the shop floor. VSM is as useful for office that it is for shop floor (Keyte et al. 2004, p.1). VSM will be the most significant research tool in this research. The aim is that VSM will reveal the value stream and potential development targets of the order-based engineering process.

VSM visualizes the office process as good as it visualizes the shop floor process. It also points out the problems in the process. (Keyte et al. 2004, p.5.) Mapping the office process is still different and challenging. Value adding processes can be hard to identify at the office process where the value flow is more focused on information flow then material flow. (Keyte et al. 2004, p.5.)

This research involves one main research question and three secondary research questions. If the VSM answers to these research questions is estimated as follows. The main research question, of this research gets an evaluation of 2-low risk. Based on current-state maps and the future-state map the answer to the main research question can be formed. It is evaluated that are combination of the current-state maps, and the future-state map cannot fully and directly answer the main research question, but an answer will be partial. The weight of this answer is evaluated to be significant. Although VSM does not respond directly to the main research question, the final answer can be formed using the secondary research questions as support.

The first secondary research question gets an evaluation of 1-very low risk. Current-state map will reveal the problems and challenges in the process. The approach can be adjusted so that the map is made from the point of view of the order-based engineering and then it will be focusing on the needs of this department. Meaning that the current-state map answer, the first secondary research question and the weight of this response is significant.

The second secondary research question gets an evaluation of 3-medium risk. The current-state map will reveal the problems, but it may not directly reveal the root causes behind these problems. Solving the root causes is often difficult. However, solving them is very important, so that development can be achieved. For this reason, it has been evaluated that the current-state map will not answer the secondary research question, but the answer is critical for this. Because this secondary research question cannot be ignored in this research, this question will be solved using interviews and supporting studies.

The third secondary research question gets an evaluation of 1-very low risk. The purpose of the future-state map is to illustrate the best solution and organization for the office process, so there is only value adding actions, and information flow is effortless and efficient. For this reason, it is evaluated that the future-state map answer the third research question. Also, it is evaluated that the weight of this result is significant for this research.

Based on this evaluation made by the researcher and findings in the literature research, it can be concluded that the VSM is a useful tool for solving the research questions and finding the answer to the research problem. The validity of the VSM can be considered reliable, because the process that has been studied has been familiar for the researcher. The placement of risk evaluating table is presented in figure 4.

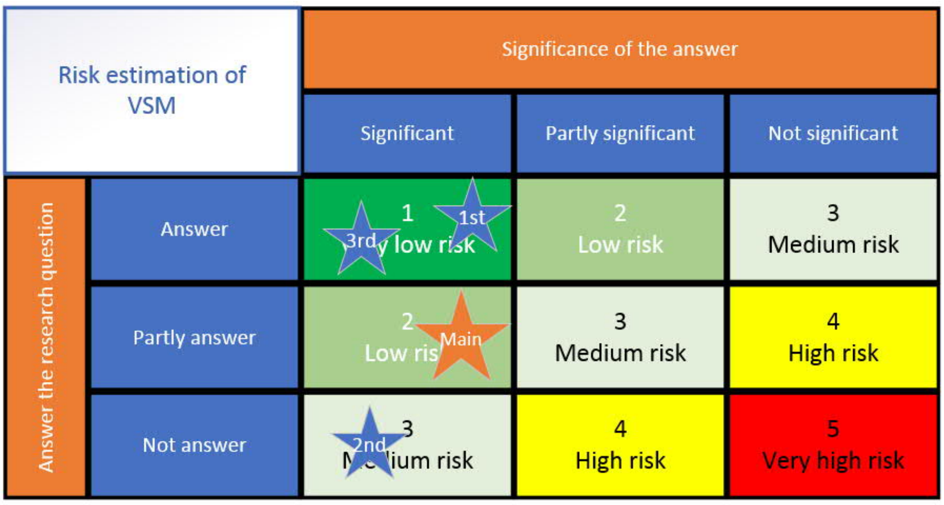


Figure 4. Research questions in the risk evaluating table.

3 MANUFACTURING AND PRODUCTION PLANNING APPROACHES

Manufacturing and production planning are vital for all supply chains. Product designing and project management can be one phase of production planning. This depends on the business area and core business of the company. This research studies a company which core business is highly customized product for customer's needs.

This research chapter will point out what is the production planning approach of the case company. The selected production planning approach must support the core business of the company. Manufacturing systems and carefully done production planning gives a competitive edge to the company and for this reason understanding the critical points of the manufacturing system and production planning is very valuable to the company.

For manufacturing systems and production planning, there are several leading approaches. The production planning and manufacturing systems can be classified bases on their relationships with the market. (Caron & Fiore 1995, p. 313–319.) The best-known categories are buy-to-order (BTO), make-to-stock (MTS), ship-to-stock (STS), assemble-to-order (ATO), make-to-order (MTO), and engineer-to-order (ETO). (Berry, Jacobs, Vollmann & Whybark 2011, p. 35, 37–38; Caron et al. 1995, p. 313–319.) The last two are considerably more interesting for the point of view of this research, but this research will be focused mainly on ETO-manufacturing.

In this chapter, the research focus is on ETO-manufacturing. We also quickly go through the characteristics of the MTO-manufacturing system, because the philosophy behind this manufacturing system increases our understanding of individual characteristics of the ETO-manufacturing. Others previously mentioned manufacturing systems like MTS-, STS-, ATO-manufacturing includes the common feature that the manufacturing process includes a high rate of stock and low ability of modification of the products. These manufacturing approaches do not support the market field of the case company.

MTO-, and ETO-manufacturing systems are different from those previously mentioned systems in such a way that in MTO-, and ETO-manufacturing the production starts after the company has received the order (Caron et al. 1995, p. 313–319). MTO-manufacturing is based on catalog products (Caron et al. 1995, p. 313–319). The catalog products are pre-engineered, and because of that, the production can start right after the order has arrived. That gives the MTO-manufacturing system the opportunity to have a short lead time. MTO-manufacturing give the customer smaller opportunity to modify the products. That means that customer-specific products are hard to achieve. Other manufacturing systems have a hard time to compete with the ETO-products on the level of customization. ETO-products are often low volume products, which have a complex structure (Earl et al. 2000, p. 179-190).

When using the ETO-manufacturing system, the company re-engineer the product or part of the product after the company has received the order. In the framework of this research, the engineering and design is defined as the same or a similar process. The designing phase of the product can include different types of designing. Types of designing can be electrical designing, mechanical designing or hydraulics designing. The production can only start when the new design of the product is complete. (Little, Rollins, Peck and Porter 2000, p. 545-554; Caron et al. 1995, p. 313–319.) The ETO-manufacturing system can achieve complex products with specialized customer requirements (Caron et al. 1995, p. 313-319; Little et al. 2000, p. 545-554). The designing phase of the products can take more time than the manufacturing or the assembly phase, and the changes to the product during the production are not unusual (Little et al. 2000, p. 545-554).

One of the critical features of the manufacturing system and the supply chain is the decoupling point (DP) or customer order decoupling point (CODP) (Yang & Burns 2003, p. 2075–2090). In this research, the CODP is used from now on. CODP is also a critical point in case company’s supply chain. CODP is the point which separates the forecast and order driven activities on the supply chain. CODP is that exact moment where the customer order is penetrated in the supply chain, and the material is tied to that specific customer order. At that point, the customer order process starts. (Yang et al. 2003, p. 2075–2090; Olhager 2010, p. 863–868.)

Like it has been said, CODP has a significant effect on manufacturing systems. In figure 5 the CODP-line is going diagonally across the material flow chart dividing it in two. Functions on the left side of the CODP-line, on so-called upstream, are forecast-driven actions on the material flow and functions right side of the CODP-line, on so-called downstream are customer order-driven actions on the material flow.

Figure 5 illustrates that the all manufacturing and production planning systems are clear and straightforward. The order comes to the factory or production plant in CODP, and the process steps after that point begin, and the product flows through the other steps in the process to the end customer. In some cases, the steps after CODP are not that simple. The size of the boxes in figure 5 are not in scale, because the designing phase of the products can take more time than the manufacturing or assembly (Little et al. 2000, p. 545-554).

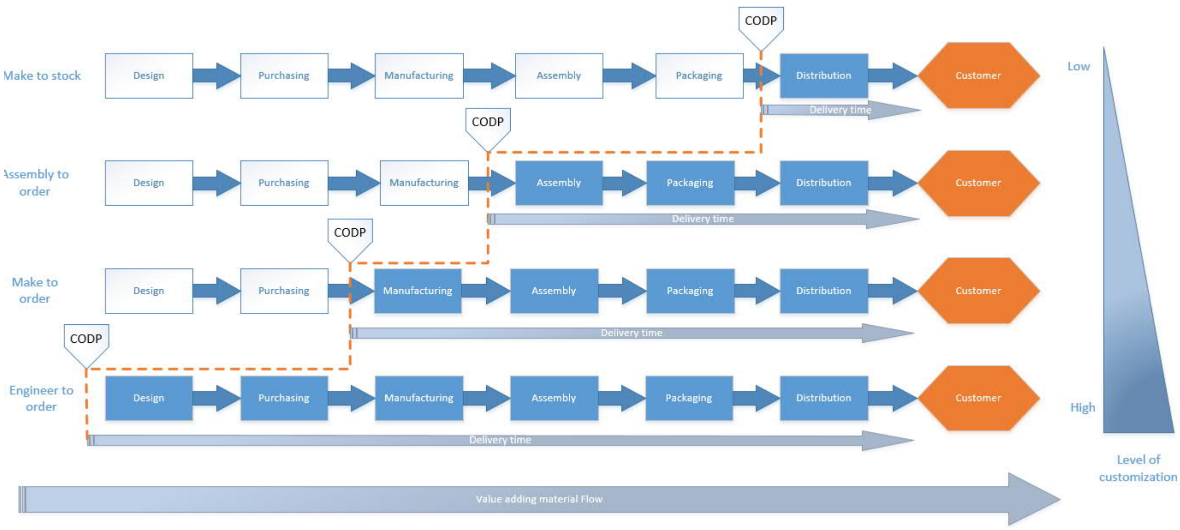


Figure 5. The location of CODP in different manufacturing systems. (Mod. Lampel & Mintzberg 1996, p. 21-30; Kundu Mckay & de Pennington 2008, p. 1529-1549)

Figure 5 illustrates that the lead time of the products also varies between manufacturing systems. The lead time starts from the CODP when the order comes to the factory. In the ETO-process the lead time starts at designing step (Hummingbird & Tersine 1995, p. 8-18). In framework of this research terms: engineering and design are considered as the same step between customer and production.

In the ETO-process, the lead time also contains the lead time of components and parts of the product. In MTO-, ATO-, and MTS-processes the lead time of the parts which can be obtained from suppliers or manufactured in-house are not included in the delivery time of the product. (Hummingbird et al. 1995, p. 8-18.)

In ETO-projects the schedule of delivery, is often already decided at the beginning of the project. This schedule defines the whole internal scheduling of the project. All functions must be able to fulfill their mission on time. The nature of the ETO-projects are also that of the customer may change the scope of the product during the engineering or manufacturing or in fact, during any phase of the supply chain. These changes are very challenging for the whole supply chain. Staying in the original timetable can become an insurmountable challenge. (Little et al. 2000, p. 545-554.)

The ETO-manufacturing is a constant balance between the short lead time and the customer specifications. It is evident, that it is easier to have shorter lead time for products that have been ready-made in the stock than products that need to be assembled. In the same way it is evident, that products which components must be manufactured, has a longer lead time than products which require only assembly.

Engineered products cannot ever compete with the lead time of stock products, and stock products cannot ever fully answer the customer's specific requirements. In figure 6 the relationship between customer's specification and lead time is shown. ETO-, MTO-, ATO-, and MTS-manufacturing has been placed on the diagonal axel. High level of customization is achieved on the expense of short lead time and the price of short lead time is a low level of customization. However, the customers are often willing to make that sacrifice.

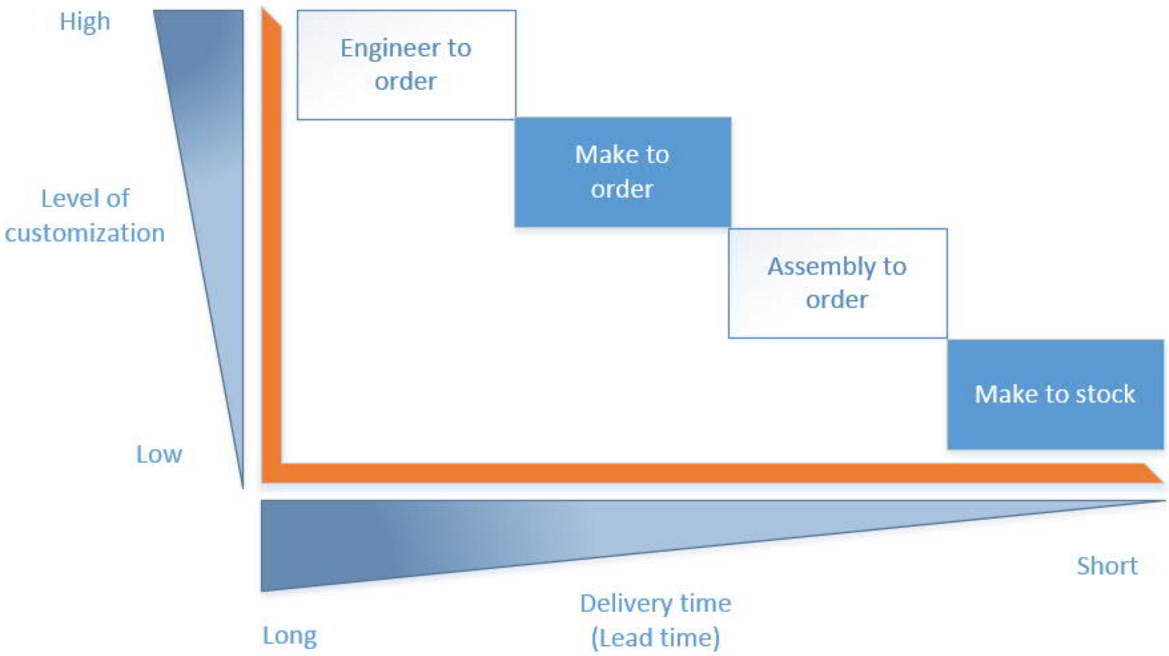


Figure 6. Delivery time Vs. level of customization (Mod. Steger-Jensen ja Svensson 2004, p. 83-103).

The attributes of ETO-manufacturing can be summed as follows. In ETO-manufacturing the customer contact will be made at an early stage of the project. The product volumes are low compared to other production methods like MTO-, or MTS-manufacturing. However, ETO-products are mass-produced products, even if the size of the series are just a few products. The features of the product can be unique and vary between the series. Typical for this manufacturing is also the fact that stocks of components are often low. This refers to the material stocks. Challenge of ETO-manufacturing is longer delivery times than other production methods. The changes also play a large role in the ETO-manufacturing. All factors above can also be seen in the case company’s manufacturing process.

4 CURRENT-STATE ANALYSIS OF THE ORDER-BASED ENGINEERING

This chapter introduces the role of order-based engineering as a part of the case company's organization. This chapter also briefly introduces other stakeholders and how they are linked to each other. The purpose of this chapter is to familiarize the reader with the case company's order-to-delivery process and give the reader background information about the order-based engineering, the product of the case company and the holistic view of the projects handling process, so the understanding and interpretation of the VSM is possible.

In many cases, when the holistic view of the supply chain is presented, the engineering is only one block between the customer and production. It is needless to say that engineering is not just simple step, which transfers the needs of customer to the form which serves the needs of production in the best way, so the customer will end up with the product that they were willing to pay for in the first place. The classic process view illustrates all functions of the supply chain as functional silos. Figure 7 illustrates the traditional supply chain of any company.

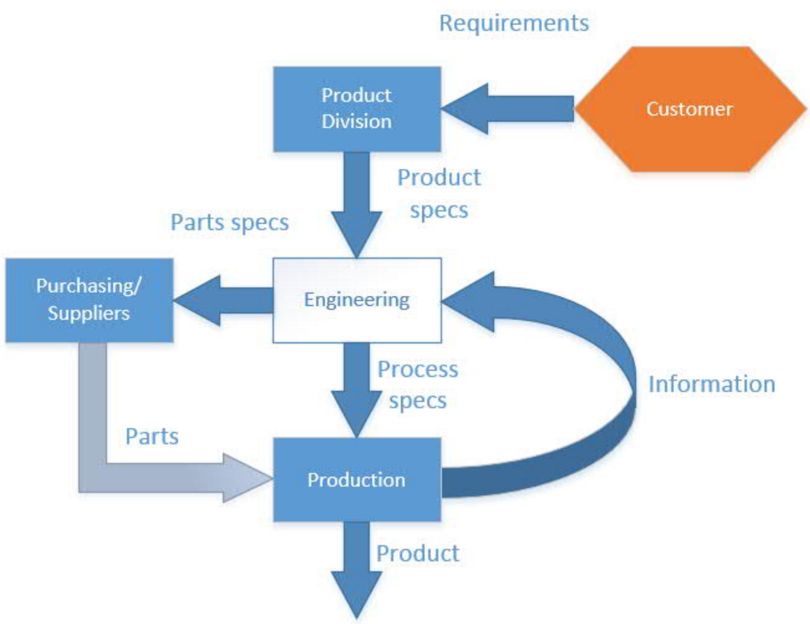


Figure 7. Traditional supply chain, where the engineering is one block in the process diagram (Mod. Caron et al. 1995, p. 313–319).

The supply chain of the case company is different from the traditional supply chain. The supply chain of the case company includes several steps before the customer's needs, and requests are implemented into the product. The supply chain will include individual characteristics, which are clarified in this chapter.

The case company will mainly use the ETO-manufacturing approach. Some projects of the case company will fulfill the descriptions of the MTO-process. In these cases, the order is clear, and the modification level of the product is low. The projects which fulfill the descriptions of the ETO-process have a higher degree of customization, meaning that the components or parts of the structure are designed to meet customers specifications.

Regardless of which manufacturing approach is chosen, the essential characteristics of the products remain the same, i.e. the product platform is the same for all projects and the base of all customization. The product platform is defined by the Research and Development-department(R&D). The case company's product range includes several types of products. The customization remains the responsibility of the order-based engineering team.

4.1 Order-based engineering

The order-based engineering team is the department which handles all projects in case company. The order-based engineering team consists of electrical engineers and mechanical engineers. The team is responsible for all design and modifications of products.

The hierarchy of the order-based engineering team is very light and can be seen in figure 8. Directly under the Engineering Manager, work the senior designers and team leaders. The organization has two team leaders, who are mainly responsible for the order clearing meetings and work schedules of order-based engineering. The senior designers mainly take care of the more demanding orders. The group of senior designers includes both mechanical designers and electrical designers.

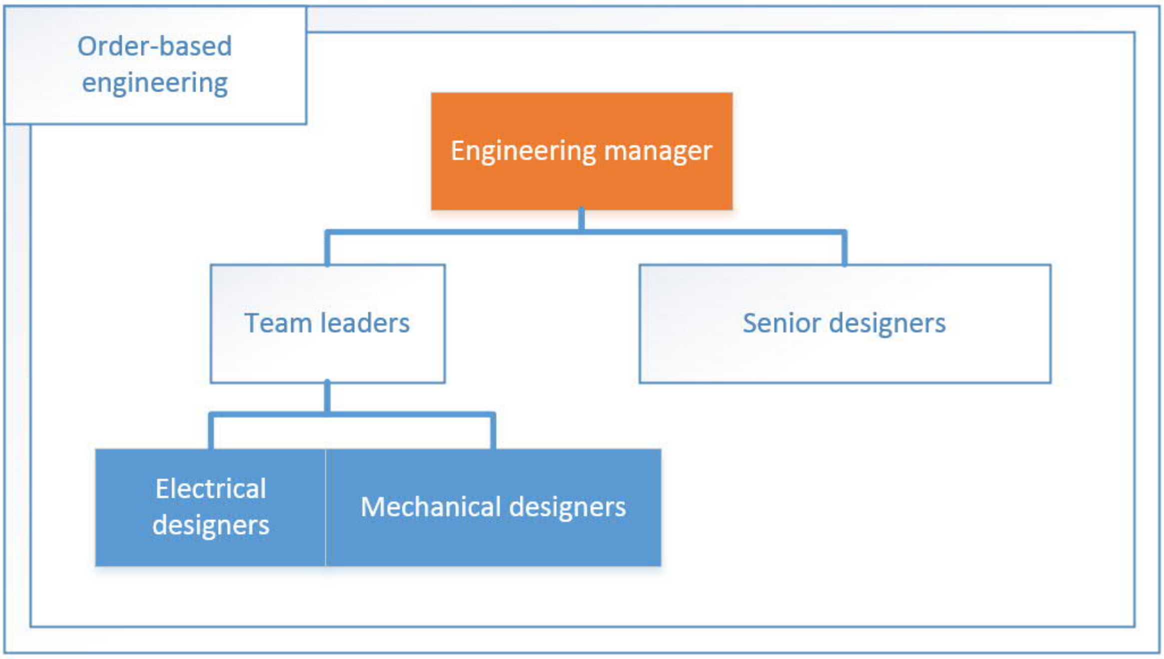


Figure 8. The structure of the order-based engineering team.

The products of the case company requests two types of designing. The total design of the product consists of electrical and mechanical design and the work is shared between electrical designers and mechanical designers. The electrical designers are responsible for the electrical design of the product and make sure that it fulfills the needs of the customer. The mechanical designers are responsible for the structure of the product, and make sure that it fulfills all customer requirements.

The order-based engineering process is a three-phase process, which includes electrical engineering and mechanical engineering. The process flow is illustrated in figure 9. The designing process starts from the electrical engineering of the product and after that transferred to the mechanical engineering phase. The mechanical engineering part is divided into two separate phases, to pre-engineering and mechanical engineering. In the pre-engineering phase, the customer documentation is made and long lead time components are ordered. On the mechanical engineering phase, the structure of the product is finished. All three steps use the information from the earlier stage and refine it further. After every step there, is a phase where the design of the product is inspected. The electrical design is checked by other electrical designer, and the mechanical design is checked by the other mechanical designer.

It is very common for that one electrical designer takes care of the whole electrical design of a customer specific product. Often all steps of mechanical engineering are done by one mechanical designer, but the steps can also be shared between two mechanical designers in such a way that the other mechanical designer is takes care of the pre-engineering phase and another mechanical designer continues with the mechanical engineering phase.

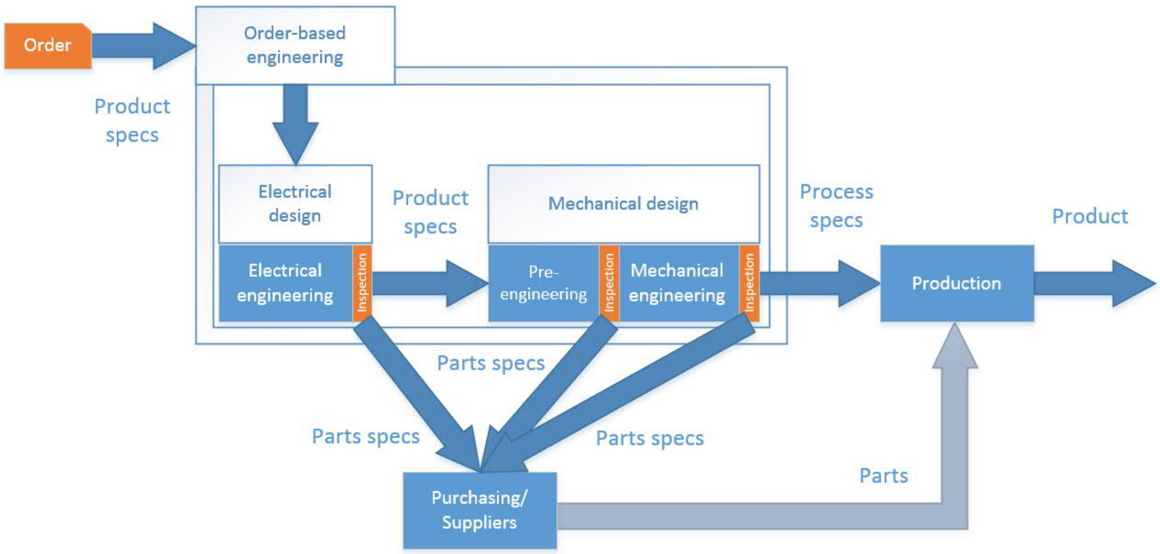


Figure 9. The phases of order-based engineering as a part of the order-to-delivery process.

Every step of the engineering process requires a large number of smaller actions which will transfer the design of the product forward. The electrical design of the product is finished after the electrical engineering, but the mechanical design is a two-phase process which is finished after both the pre- and mechanical engineering phases. Without electrical engineering, the mechanical designer cannot start the mechanical designing. The electrical engineering needs to be completed before pre-engineering can start. The pre-engineering needs to be completed before the mechanical engineering.

It is crucial at this point to note, that the order-based engineering team is mainly working with information. The order-based engineering team gets the input about the product and customer requirements from the project management team. The project management team is working in close co-operation with the customer and the local sales unit. It is their responsibility to take care of the progress of the project and the project timetable. The project management team delivers customer requirements to the order-based engineering team using the change order tool. The order-based engineering team makes these requests part of the structure of the product and provide the necessary information to the stakeholders. In the matter of fact, the information is the only thing that the order-based engineering team is producing.

4.2 Order handling

ETO-manufacturing gives the customer ability to customize the features of the product before ordering. That also means that all customs requirements need to be known and incorporated into the product before the subcontracting and the manufacturing processes can begin. In ETO-manufacturing the engineering and the modification of the product is the critical phase of the whole supply chain. The core business of the case company is individually a highly customized product, and for that reason, the ETO-manufacturing is the primary manufacturing system and production planning approach of the case company.

The orders do not come directly from the customers. The sales unit is handling the customer contact. All orders go through the local sales unit and the local sales unit works as a link between the customer and production unit. Orders will be transferred from the sales unit to the production unit. At this point the order changes into a project. The scope of the project is checked in order clearing meeting which is specifically designed for this purpose.

The team leaders of order-based engineering are in closest co-operation with the project management team. Project managers book all orders which come from the local sales unit. The project goes through the local sales unit and the project management team. Team leaders of the order-based engineering assist the project manager and salesperson with technical questions related to the product and manufacturing. However, the team leaders or the order-based engineering team are not responsible for the schedule of the project. That’s lying on the shoulders of the project management team and production planning team.

At this so-called P0-meeting, the team leaders from the order-based engineering, project manager from the project management, a representative person from the production planning and the sale person are gathered together. The team leaders of order-based engineering assist the project manager and salesperson with technical questions related to the product and manufacturing. Together they go through the customer's requirements and plan a timetable for the production of the project. The order-to-delivery process is described in figure 10, and the order clearing meeting is illustrated with a red triangle.

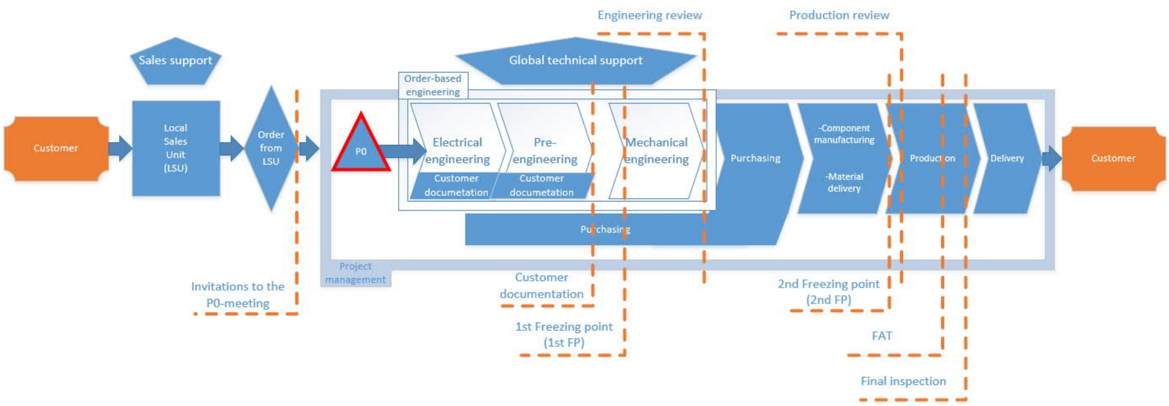


Figure 10. The phases of the order-to-delivery process.

At the order clearing meeting, the request dates for the customer documentation is settled. Based on request dates for the customer documentation and delivery date of the product the manufacturing schedule is created. The team leaders of the order-based engineering plan the engineering schedule according to this request dates of the customer documentation.

The case company has two order-to-delivery models. The first one is more used. In this model, the scheduling starts from the customer requested delivery date, and the phases of production, including the designing part, are determined according to this. The only exception is electrical engineering and the pre-engineering, which are scheduled according to the customers documentation request dates. This model sets the timetable for the engineering. It means that the pre-engineering follows immediately after electrical engineering and the time gap between pre-engineering and mechanical engineering is as short as possible.

In the second model, the two-phased delivery process, the electrical and the pre-engineering is carried out like the first model, but between pre-engineering and mechanical engineering there is a time gap which is individually defined for each project. This time gap has been agreed with the customer and affects the delivery time of the project. The purpose of this time gap is that the customer has time to check and comment all customer documentation. When the customer has approved the structure of the product and has given the final comments for documentation then the mechanical engineering starts.

Both delivery models have their advantages. The first one gives the customer an exact delivery date, but the customer changes and modification of the product can cause problems and delays for the production and that way also for the delivery. The two-phased delivery does not give an exact delivery date. The delivery time depends on the time which the customer spends approving the structure of the product and the documentation. This delivery time seeks to ensure smooth manufacturing of the product without any changes or modifications. The basic principle of the delivery models is illustrated in figure 11.

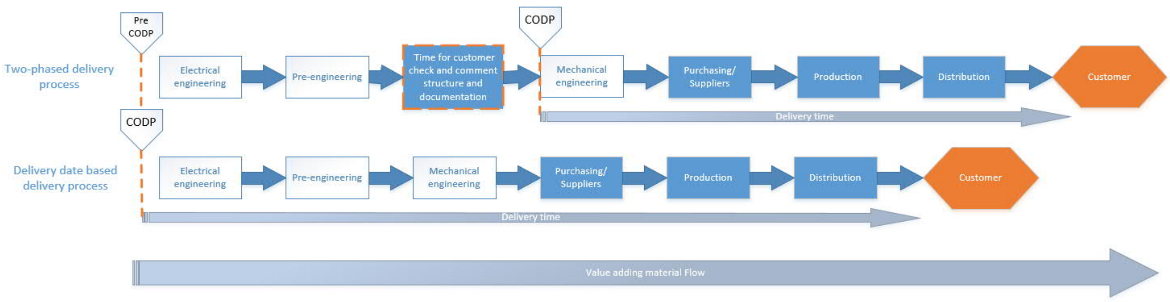


Figure 11. The order-to-delivery models of the case company.

4.3 Schedule of engineering

The engineering phases have a timetable. Electrical engineering, pre- and mechanical engineering have an individual timetable. Regardless of which one of the two order-to-delivery models is used. To keep up with the timetable, the work phases must be put into the work queue.

Electrical designers have their own work queue, which includes only electrical engineering steps. Mechanical engineers have a divided work queue, which contains pre-engineering steps, mechanical engineering steps, and change orders steps. Both work queues are the responsibility of the team leaders of the order-based engineering. The work queue of the electrical engineering is handled on the ERP-software. The electrical work queue primarily works on first in first out (FIFO) principle. The mechanical work queue is controlled on excel-form.

The work queue is color coded. The working hour needed to finish the mechanical steps is an estimation made by team leaders of the order-based engineering. The work queue also includes the change orders, but the scheduling of those actions are estimations and not so strictly controlled as the pre-engineering, and the mechanical engineering steps are. Figure 12 illustrates the principle behind the work queue of mechanical engineering. Yellow boxes are pre-engineering, purple boxes are mechanical engineering, and the blue boxes are change orders. Pre-engineering and mechanical engineering steps are linked together, but the change order steps are more random in the working queue of the mechanical engineering.

The working queue is strictly controlled, but the order of the projects and the responsibility for design are placed relatively randomly. The work queue must be able to answer the demands of all stakeholders, where the timetable of the customer documents and the whole project are the significant factors together with difficulty class and the current load of the order-based engineering department.

	Week					Week				
	Workday	Workday	Workday	Workday	Workday	Workday	Workday	Workday	Workday	Workday
Designer 1	Mechanical engineering	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date	Mechanical engineering	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date
Designer 2	Change order	Pre-engineering	Pre-engineering	Pre-engineering	Target date	Pre-engineering	Pre-engineering	Pre-engineering	Pre-engineering	Target date
Designer 3	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date	Pre-engineering	Pre-engineering	Pre-engineering	Pre-engineering	Target date	Change order
Designer 4	Mechanical engineering	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date	Pre-engineering	Pre-engineering	Target date	Mechanical engineering	Mechanical engineering
Designer 5	Pre-engineering	Pre-engineering	Pre-engineering	Target date	Change order	Mechanical engineering	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date
Designer 6	Pre-engineering	Pre-engineering	Target date	Mechanical engineering	Mechanical engineering	Target date	Pre-engineering	Pre-engineering	Pre-engineering	Target date
Designer 7	Pre-engineering	Pre-engineering	Pre-engineering	Target date	Change order	Mechanical engineering	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date
Designer 8	Change order	Pre-engineering	Pre-engineering	Target date	Change order	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date	Mechanical engineering
Designer 9	Pre-engineering	Pre-engineering	Pre-engineering	Target date	Change order	Mechanical engineering	Mechanical engineering	Mechanical engineering	Mechanical engineering	Mechanical engineering
Designer 10	Target date	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date	Mechanical engineering	Change order	Change order	Change order	Change order
Designer 11	Mechanical engineering	Mechanical engineering	Target date	Pre-engineering	Pre-engineering	Mechanical engineering	Mechanical engineering	Change order	Change order	Pre-engineering
Designer 12	Change order	Pre-engineering	Pre-engineering	Target date	Pre-engineering	Pre-engineering	Target date	Mechanical engineering	Target date	Change order
Designer 13	Target date	Pre-engineering	Pre-engineering	Target date	Pre-engineering	Pre-engineering	Target date	Mechanical engineering	Mechanical engineering	Mechanical engineering
Designer 14	Mechanical engineering	Mechanical engineering	Target date	Pre-engineering	Pre-engineering	Pre-engineering	Pre-engineering	Target date	Mechanical engineering	Target date
Designer 15	Pre-engineering	Pre-engineering	Pre-engineering	Pre-engineering	Target date	Mechanical engineering	Mechanical engineering	Mechanical engineering	Target date	Change order

Figure 12. Indicative modeling of work queue of the mechanical engineering.

4.4 Customer-specific products

The products of the case company are highly customizable. As previously mentioned, the R&D-department defines the product platform. The R&D-department is in individual department and works separately from the order-based engineering team. The customization remains the responsibility of the order-based engineering team. The frame design of R&D limits all the choices made by the order-based engineering.

The basic design of the products of the case company consists of broadly speaking 7 main sub-assemblies. These sub-assemblies are the main component entities of the product, which consist of parts, and together they create a functional entity with an individual purpose. Main sub-assemblies are:

- Main terminal boxes
- Monitoring (auxiliary terminal boxes)
- Frame (mounting)
- Stator
- Rotor
- Bearings
- Heat exchanging

The needs of the customer can modify every main sub-assembly. The reason for modification can be related to the product's performance requirements, or they can be related to the space requirements of the customers site. It is needless to say that all main sub-assemblies need to be assembled as a single functional product.

Some of the components of the case company’s product are stock items and some components needs to be ordered from the sub-contractors and suppliers. All customer-specific and the customer base modified components need to be ordered from the sub-contractors and suppliers. These components also request specific designing, so they fit the product and fulfill the customer defined purpose.

Figure 13 illustrates the customization options in one of the case company's products and the main sub-assemblies are highlighted. The customers have an opportunity to demand more customization of the product, so it fits in their product entities and fulfill the technical specification of the classification societies.

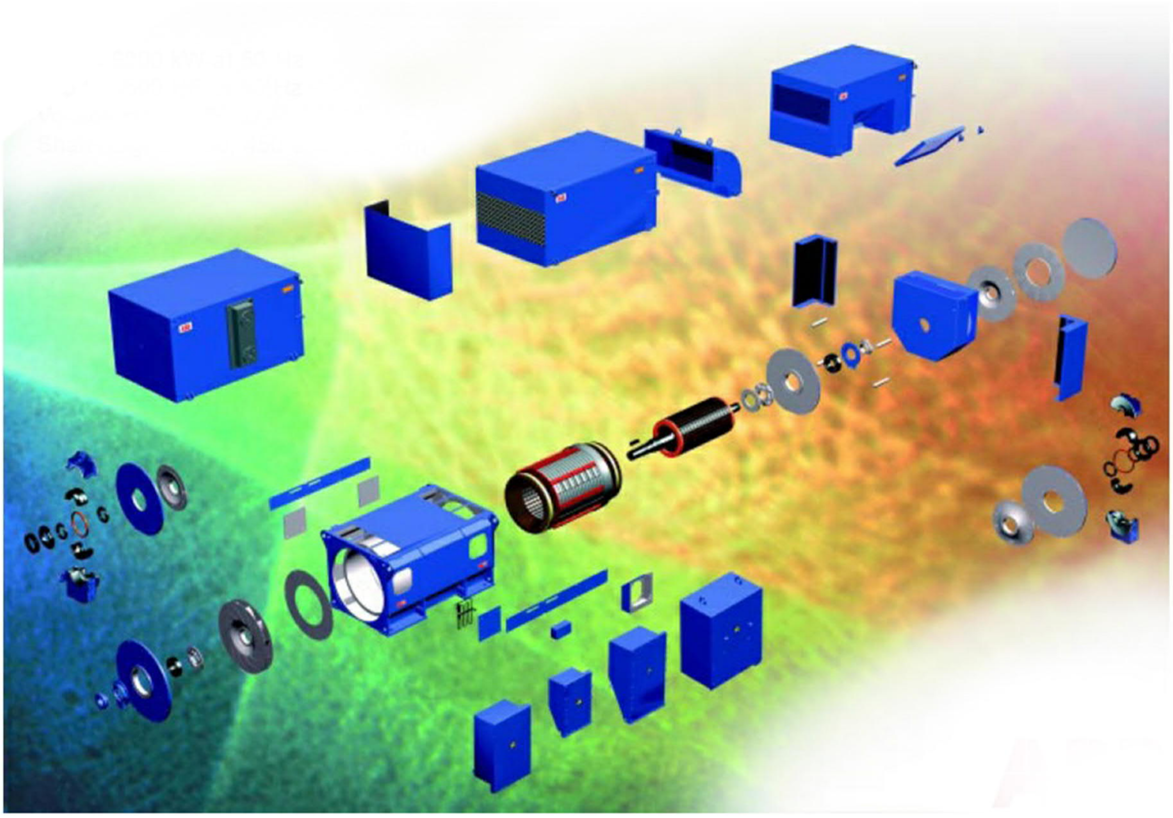


Figure 13. Main sub-assemblies of one the case company's products (Mod. ABB 2012,).

The more customization and more classification requirements the product have, the more demanding the customer project is. All customization and classification societies requirements are not directly involved in the electrical and mechanical design of the product, but they also affect on testing and delivery.

The products of the case company are categorized into three categories according to the difficulty of the product. The lead time of the component, the number of special components and the amount of customization affects how the product is divided. The categories are difficulty class A, difficulty class C, and difficulty class D. Difficulty class does not tell the whole truth about how demanding the product is for the order-based engineering or how demanding it is for the manufacturing or assembly phases, but it gives a good overview of the products that makes it possible to reliably compare products with each other.

Orders which fulfill the descriptions of difficulty class A, are handled in the order-to-delivery process according to the MTO-manufacturing approach, and the level of customization is very low. The product in difficulty class A request the electrical engineering step and both of the mechanical engineering steps. Products in A difficulty class has a shorter delivery time than other products

Orders which fulfill the descriptions difficulty class C has a higher customization level. I many cases, one or more component have a longer delivery time. Due to the designing work and the long delivery time of one or more components, the delivery time of the product is longer. In difficulty class C the products are handled in the order-to-delivery process according to the ETO-manufacturing approach.

Design of difficulty class D has the highest level of customization and several components have a long delivery time. The level of customization and delivery time of components together affect the lead time of the production and increases the delivery time of the product. This project is handled as the ETO-products in order-to-delivery process.

Also, the type of product affects the difficulty class and the lead time of the products. The case company’s product range includes several types of products. The central principle behind the handling of the order-to-delivery process remain the same irrespective of the type of product.

4.5 The order and change orders

The order is the master document of the designing. The order is a physical document. At the electrical and mechanical engineering is based on it. The local sales unit creates the order document by using a special sale tool. The content of the order document is checked in the order checking meeting.

The sales tool contains the options of the standard products of the case company. The salesperson can do basic electrical designing to the product with the sales tool. The salesperson also has an opportunity to add special components to the order document. Some customer requisitions can be registered as free text. The order contains the main information of the product. The order document is saved to the projects design folder. The order document, in its form, cannot contain all the information about the product. Some additional documents are saved as attachments, which are saved to the project design folder. If the project has preliminary drawings or datasheets, they are saved in the project design folder as well.

The sales tool determines the price of the product and the degree of design difficulty class. If the customer decides to change or modify the scope of the product, it is done by the change order. The changes require updating the sales tool. The design responsible of the sale tool transfer from the local sales unit to the project management in the order clearing meeting.

A change order is the information channel which goes through the whole order-to-delivery process of the case company. This information channel is mainly used when the customer wishes to do modifications to the product. The customer can add or remove features from the product or add or remove information from the documentation of the product. Change orders needs to be used when the designing of the product has already begun.

Secondarily, the change orders can be used for internal communication. In this case the change order can be used for example, for booking test slots or notifying the production of the need to use a special tool. Creating customer-oriented change orders is on the responsible of the project management team.

This research is interested in change orders which come from the customer. Change orders from the customer cause have work for the order-based engineering team. Modification of the customer documentation causes less work than the actual changes for the design of the product.

Changes that come after the design of the product is finished affect the subcontracting process and manufacturing process. Late changes may delay the entire delivery of the product and in the worst case, affect the timing of other products.

Updates or clarification to the customer documentation can mean both mechanical or electrical documentation. All change orders from the customer passes through the project managing to the order-based engineering.

4.6 Customers and demanding customer projects

From the point of view of this research, the term “customer” is a difficult definition. The customer of the point of view of the case company is multidimensional and, in many cases, it is a combination of several customers. The products of the case company are a part of complex customer product entities. The designing and manufacturing of the customer's product entities can be divided into several subcontractors, who can form a long chain of information. The end user of the product is somewhere in the end of that chain. In this research, we will keep in mind that the customer is multidimensional, but it will be handled as a single.

Demanding customer projects mean that the customer’s demands, and the technical specifications are very strict. It is highly important to notice that demanding customer projects do not mean that the customers are difficult or challenging. The characteristic of the customer project is a combination of many variables. In business between companies, people are working with people, meaning that the success of projects also depends on human relationships between the seller and the buyer. This research is trying to approach this from a more objective point of view and sum up all the factors which are not dependent on people. Finding and developing these factors can have a higher impact on customer satisfaction.

Demanding customer projects will often cause problems to the case company for various reasons. Previously completed research, which investigated the change order dilemma in the order-to-delivery process of the case company lists the following factors as the sources of the demanding customer projects according to Karppinen (2018, p. 63):

- “Region
- Country
- Industry
- Classification
- End customer
- Special component.”

Demanding customers projects can assumed to be in difficulty classes C and D. The classification and special components can raise the difficulty class of the product. Meaning that those factors are more accessible to notice from the point of view of the order-based engineering. Other factors like region, country, industry, and the end user will not necessarily expose as clearly to the order-based engineering.

One major factor in demanding customer projects is the fact that customers projects are progressing at different speeds compared to the case company's project. Meaning that customers can have a longer process for approv the customer documentation that it is for the case company to manufacture the product. Sometimes this process does not have the same rhythm, and one process can be far ahead of the other. This causes problems for production planning. The schedule of the customers own projects and needed steps of the approval of the documentations, are out of reach of the case company. This steps and time to spend to that process are very challenging to see in advance. If the scope of the customer is unclear at the beginning of the projects or the customer project is not yet reached the stage that the details of the product could be discussed, that can cause many change orders.

5 CURRENT-STATE MAPS OF THE ORDER-BASED ENGINEERING

This chapter introduces the primary process of current-state mapping. Two projects from the case company are mapped in the framework of this research. This chapter goes through the general nature of those maps. It clarifies the symbols and creates a foundation for the future-state map.

This research reviews VSM on the factory level, so-called door-to-door VSM. Meaning that the mapping begins when the order arrives at the production unit. Concerning ETO-manufacturing that would be the CODP and in the case company's process diagram it would be the point where the local sales unit is handing over the order to the production unit, and it becomes a project. The mapping end at that point where the product is ready for the customer. That point does not mean the moment when the customer receives the product but when the product is ready from the production unit. The current-state maps are built on the information which is registered in the logs of the ERP-software, the Product Lifecycle Management (PLM) program and the communication platforms of the case company.

The purpose of the VSM in this research is to create a holistic view of the order-to-delivery process of the case company. The order-to-delivery process is similar to all the projects, but the actions during the process may vary. The basic idea behind VSM is to identify the value stream. The value stream means all the steps in the process, which shapes the raw materials into finished products for the customer (Rother & Shook 2003, p. 3). Because the actions during the process may vary and may vary a lot, in this work, two projects are examined. Both projects are delivered. The structures are similar, the level of customization is very close to each other and degree of difficulty is the same. The customer of the projects is different and part of the different business region. The 1st target of research belongs to the European region, and the 2nd target of research belongs to the Asian region. The project which is examined at first was delivered without significant challenges. This project is called the 1st target of research from now on. The project which is examined secondly was a far more challenging project for the case company. This product is called the 2nd target of research from now on.

The primary illustration of the VSM and current-state map is presented in figure 3 in chapter 2. VSM have own symbols and characters. These symbols and characters are commonly used, but some case-specific characters are needed.

In this research, some special characters are used for VSM, and the color of the symbols gives the reader additional information about the process. The case-specific characters are illustrated in figure 14. Both current-state maps include mainly information flows, which is very typical to the office and administration processes. This information flow is mainly electrical information which is moving from one function to the other. The color coding of the symbols illustrate what platform or program is used for transferring information and where the information is switching between platforms. It should be noted that design phases produce only information flow and the actual material flow starts from the production.

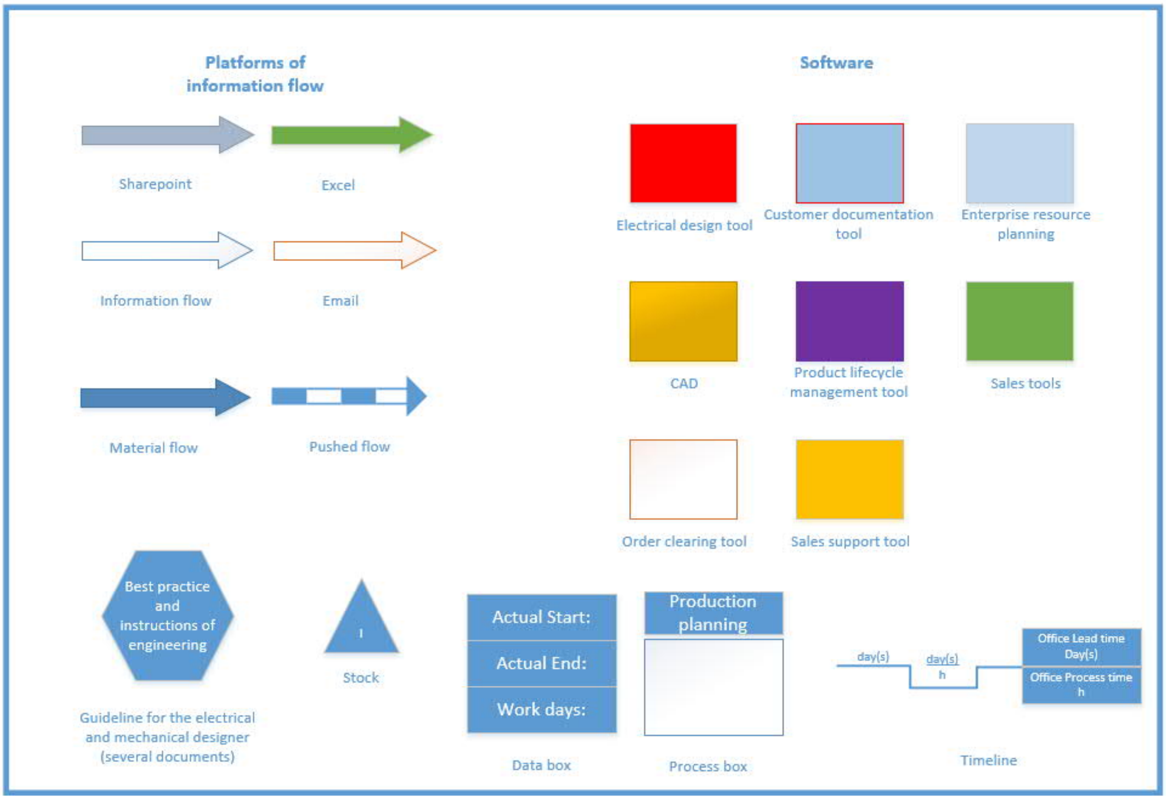


Figure 14. The list of case-specific characters of the current state maps. These characters are differ from those commonly used on VSM characters.

One of the key characters is the process box. A process box is located on the map at every step where the value stream change direction or pivot. The process boxes are the links which tie up the value stream with information stream. The process box or the function of the process can contain lots of action, but in the holistic view of the order-to-delivery process this function ties them together and covers them all. An example of the process box is illustrated in figure 15. In this research the process box contains significant values. The first one is the percentage of total design hours, and the other one is the percentage of total purchase orders. The background of the process box is color-coded. The colors represent the main programs which the process step is mainly using.

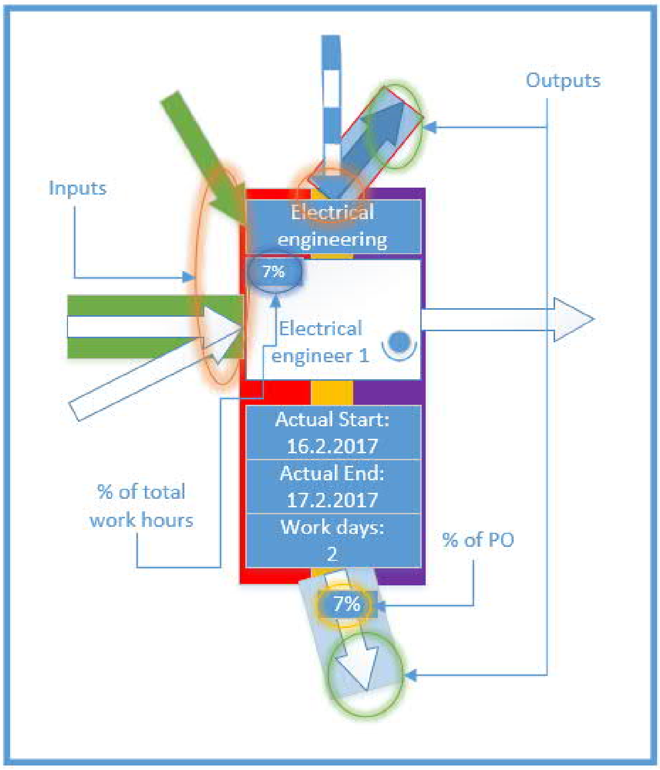


Figure 15. The example of the process box used in the VSM of this research.

The progress of the production has been monitored through the whole order-to-delivery process so that the current-state maps can be formed. The data which is used for the current-state map is collected from the ERP-software of the case company. The ERP-software catches the start and end of the record-keeping throughout the order-to-delivery process. Lots of information is also available on communication platforms and design programs of the order-based engineering.

5.1 The current-state map of the 1st target of research

The current-state map of the 1st target of research is illustrated in figure 16 and is also demonstrated in Appendix I. On the 1st target of research the current-state map is intensified with 5 additional sectors which help the reader to follow the progress of the product in the order-to-delivery process. Those sectors help the reader to understand the value adding and non-value adding actions in the process.

The order-to-delivery process starts from sector A. This sector on the current-state map present the phase where the local sales unit communicates with the customer and, in this case, ask electrical and mechanical assistance from the sales support team. The last step of the sector A is when the local sales unit call the order clearing meeting. The invitation to the meeting must be sent at least 24 hours before the meeting to ensure that all participants have had the opportunity to go through the requirements of the product and the schedule. The output of that meeting is the order document, which includes information about the product and the project. Also, the schedule of customer documentation, engineering, and production is decided at this meeting. At this point, the responsibility for the product transfers to project management.

Sector B includes the part of the project management team. From this point on the project manager is responsible for the progress of the project and works as a link between the customer and order-based engineering. Project management informs all changes and customer request using the change order tool. Mainly those changes and customer requests impact on the structure of the product or the documentation but they can also impact for example testing or the delivery schedule. This current-state map has collected together those change orders which influence the structure of the product.

Sector B together with sector C will form the office and administrative processes of the order-to-delivery process of the case company. Sector C will form the core component of the current-state map in this research. The master schedule of engineering controls the timetable of these actions. The order document gives electrical, pre- and mechanical engineering the information from the customer requests. The best practices and instructions of engineering create a foundation for the structure of the product.

Sector D presents the assisting function of order-based engineering. The main guideline of the electrical and mechanical engineering is the best practices and instructions of engineering. This guideline includes a lot of standard solutions, instructions and date sheets of standard components. If at any point the electrical or mechanical designer faces a problem, that needs assisting from outside of the order-based engineering team, the designer can form a support request to reach out the Global Technical Support team (GTS).

Sector E is the final phase of the order-to-delivery process. In this phase, all information flow transforms into the actual material flow. This section is outside the research scope of this research but is a significant part of the order-to-delivery process. Like figure 16 illustrates some of the change orders may also be subject to the production stage. Also, those change orders go through the order-based engineering team and can affect the purchasing and subcontracting phases. This sector ends the order-to-delivery process, and the finished product is ready for the customer.

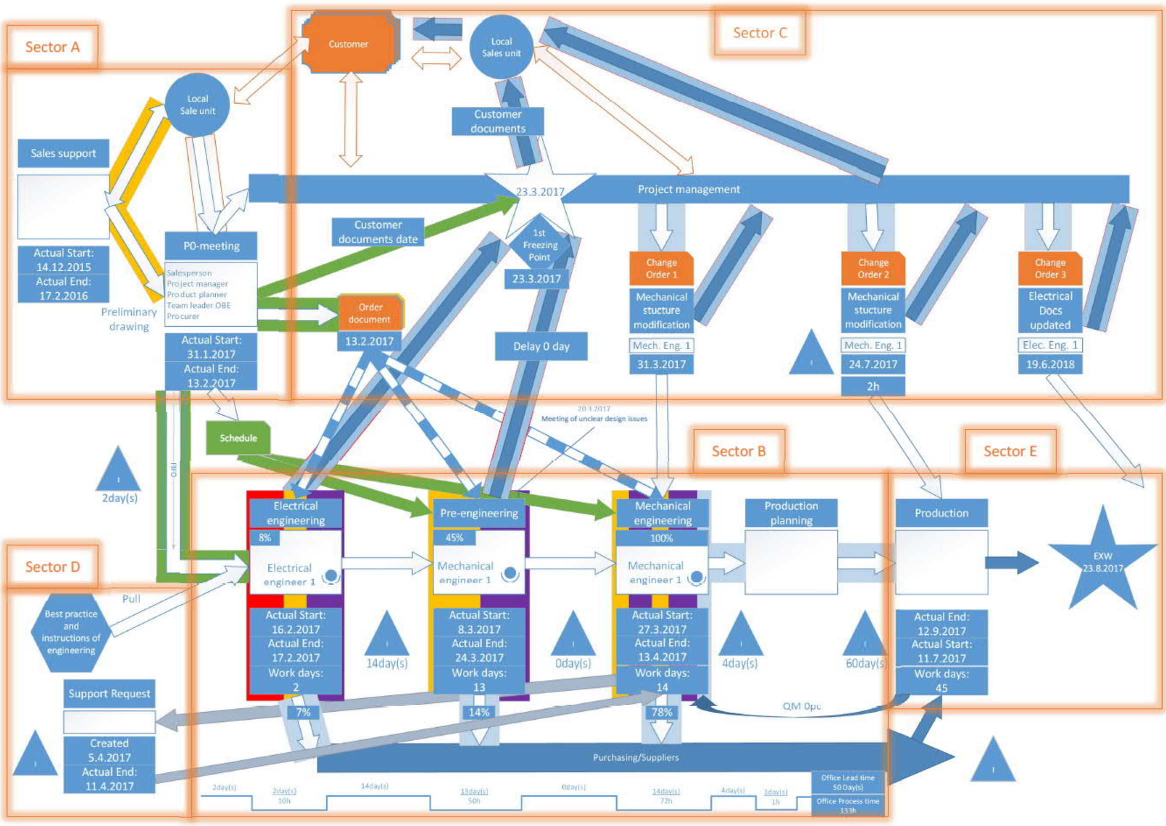


Figure 16. The current-state map of the 1st target of research. The current-state map illustrates the holistic view of the value flow of the order-to-delivery process.

5.2 The current-state map of the 2nd target of research

The structure of the current-state map of the 2nd target of research is similar to the current-state map of the 1st target of research. The 2nd target of research has more actions in every step of the order-to-delivery process. The current-state map of the 2nd target of research is illustrated in figure 17 and also demonstrated in Appendix II.

The current-state map of the 2nd target of research does not include sectors like the current-state map of the 1st target of research. The order-to-delivery process starts from the upper left corner and ends up in the lower right corner. In the left lower corner of the map, one can notice much more support requests then on the 1st target of research. It is also significant to note that a share of the support requests has been made by the project management team. The pre-engineering has released the customer documentation in two batches although a single batch is the general practice, like we can note in the case of the 1st target of research. Noticeable is also the amount of change orders through the whole order-to-delivery process.

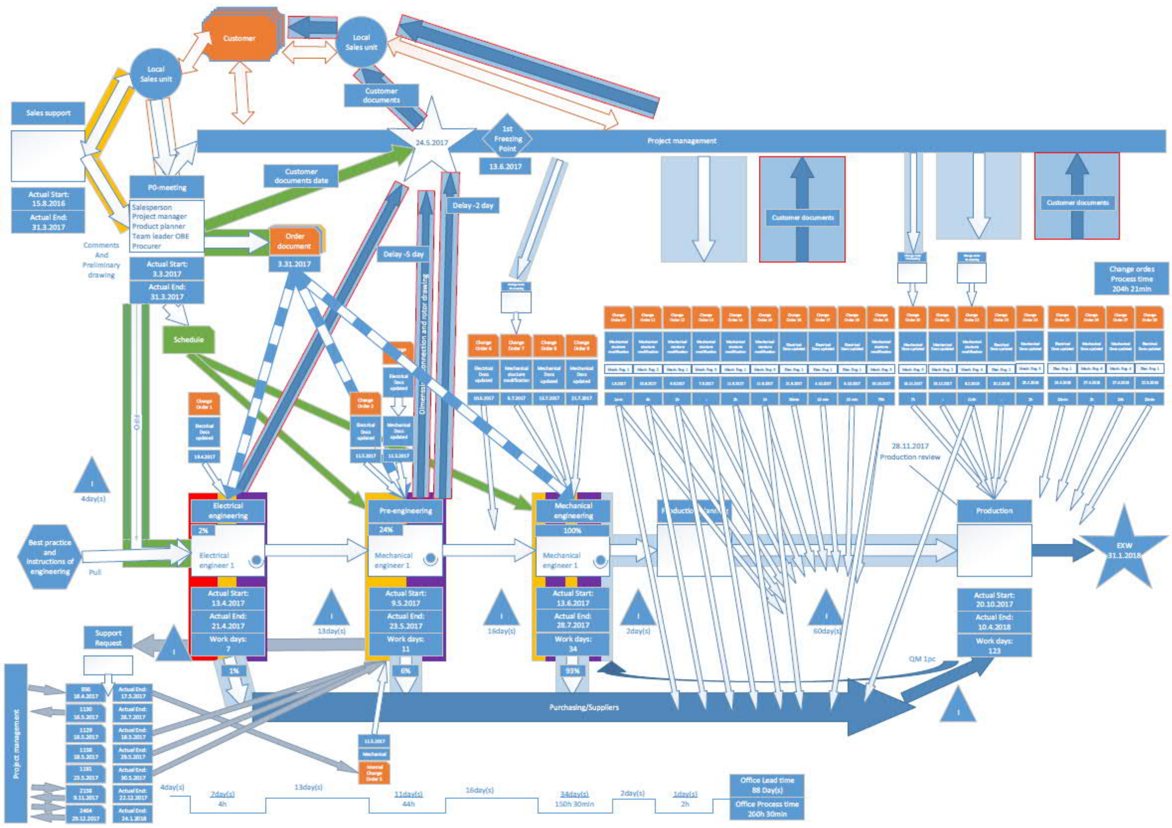


Figure 17. The current-state map of the 2nd target of research. The current-state map illustrates the holistic view of the value flow of the order-to-delivery process

Both current-state maps show that both projects have been delivered later than has been informed to the customer. The current-state maps at this point do not show the root cause for these delays. The current-state maps show a lot of actions for these projects, but the current-state maps do not reveal how successful the projects are in the engineering schedule. The delays can have many reasons. Others are dependent on the administrative process, and others are dependent on the assembly and capacity of the production unit, some delays can be dependent on the subcontracting process. This research is not focused on those delays or the root cause behind them.

The metrics for the current-state maps were office lead time, office process time, change order process time, the percentage of total purchase orders and the percentage of total design hours. Data is collected from the ERP-software of the case company.

The office lead time on the process boxes is reported as work days (5 work days per week). The office lead time is the time between the starting and ending of the steps of the process. The total office lead time is the process boxes is lead times counted together. The office process time is the hours which the electrical or mechanical engineer has recorded for the project. The office process times counted together constitute the total time spent on the order. The assumption is that the designers will use at least 6 hours of the 7.5 hours work day for the project they are working on.

The percentage of the total purchase orders shows how much of the total outcome is ready at that point. The percentage of the total purchase orders does not give a holistic view of the progress of the design or readiness of the design. The percentage of the total design hours shows how much of the total design hours have been used at this stage. The percentage of the total purchase orders and percentage of total design hours give us a rough estimate of how much work the steps contribute to the completion of the work and how the value is added to the product.

5.3 Summary of the current-state maps of the order-based engineering

This chapter summarizes the key findings of the current-state maps. These key findings are used for supporting studies in this research and as a base of the future-state map. The current-state maps demonstrate that the order-to-delivery process is restless. The flow of the value is not efficient and fluent. The current-state map of the 2nd target of research demonstrates how the new information flows into the project and change the structure of the product. The change orders will bring the design of the product back to the drawing board. Redesigning increases the amount of the work of the order-based engineering. In the case of the 1st target of research, the time spended on the changes of structure and documentation was small compared to the used engineering hours. The used hours on changes of the structure and documentation at the 2nd target of research was a significant part of the whole project hours. The change orders are the dominant segment of the current-state map of the 2nd target of research. They are also present in the 1st target of research. Significant here is the fact that change orders come during the subcontracting process and also, in the production phase.

It's important to note that information goes through multiple programs and communication channels. All stakeholders are handling information on different platforms. The information comes in one platform and leaves in another. Even inside of the order-based engineering the information transfers through multiple platforms. In the process boxes, the information develops and becomes a consistent product, but the input and output are not in the same form. It is also important to note that the design phase of the product is even more complicated than what VSM illustrates.

Current-state maps show that the electrical and mechanical engineering can already be done in support and order handling steps before the actual order-based engineering. The sales tool can do light electrical engineering to the product and sales support can do mechanical and electrical engineering to the product, but the information does not flow directly to the order-based engineering. Current-state maps indicate that the sales support is an isolated island in the value stream.

Both current-state maps show that information is stored in many phases of the order-to-delivery process. The maps also point out that the location of storage and storage time may vary. It can be assumed that during the storage, nothing will happen to that information. In the 1st target of research, any of the three change orders have not been targeted to the storage period. In the 2nd target of research, the amount of change orders is so high that most of the change orders have targeted to the storage period.

Order-based engineering requires at least two designers, one electrical designer, and one mechanical designer. In case of the 1st target of research the mechanical designer completes a both pre- and mechanical engineering and all change orders. the case of the 2nd target of research, there were 6 mechanical designers involved in the project. It is a very large group of people who need to adopt the demanding requirements of the project.

The current-state maps and figure 18 point out that the significant part of designing hours is used on the mechanical engineering phase. After the mechanical phase, the design is 100% finished, which means that in the 1st target of research 55% of working hours is used in the mechanical phase and in the 2nd target of research the same number is 76%. Note that the hours used in change orders have not been calculated in this case as worked hours. Also, the most significant amount of output has been produced in the mechanical design phase. In the 1st target of research, the number of purchase orders was 78% and in the 2nd target of research the percentage was 93%. Note that the purchases made by change orders have not been calculated in this case for the purchase orders.

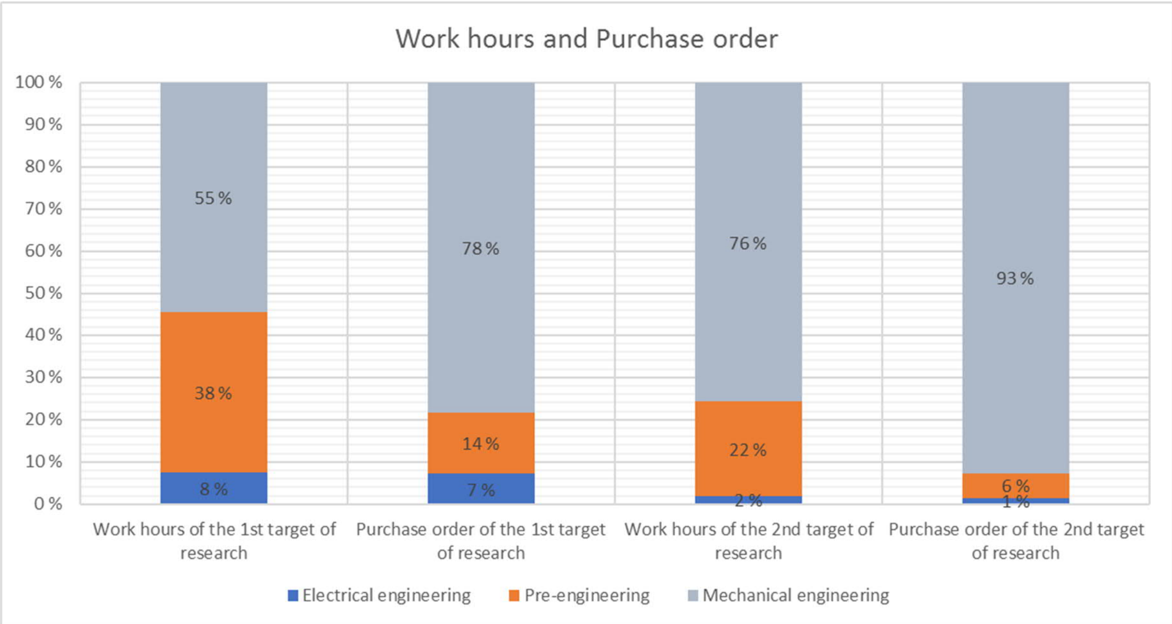


Figure 18. Work hours and purchase order of the 1st and the 2nd target of research

The findings of the current-state maps can be divided into two groups. In the first group, there are findings which can either be explored in the future-state map or find a solution using the future-state map. Some of these findings are value adding action, and some are non-value adding actions. The non-value actions can be shared into necessary actions and pure waste. In the second group, all findings need more clarification. Findings in this group is further studied in chapter 6. The findings of the current-state map are illustrated in table 1.

Table 1. The findings for the future-state map and supporting studies.

	Findings for future state map		
	Description	Determination	Effect
1	The flow of the value is not fluent	Current state maps show that the electrical and mechanical engineering can be done already in support and order handling steps but the information does not flow directly to the design for use.	Value adding actions of previous steps cannot be utilized efficiently
2	The flow of the value is not steady	New information flows into the product and change the structure of the product constantly and unpredictable.	Increases the work and hours of order-based engineering
3	Information is stored in many phases	The location of storage and storage time may vary. Storage uncontrollable.	The effect on the effectiveness of value flow
4	Numbers of mechanical designers	Numbers of mechanical designers involve to the project my vary.	Information is transmitted to a wide but uncontrolled group
	Findings for supporting studies		
1	Behavior of change orders	Amount per order varies. Used time varies. Effect varies. The implementer varies.	
2	Amount of information	The information flow around the office and administrative process are huge, but the amount of input data is unclear. Also, the amount of additional information is unclear.	
3	Schedule of engineering	Lead time and process time varies between 1st and 2nd target of research.	
4	Effect of customer	The nature of the projects varies	

6 WASTE OF THE ORDER-TO-DELIVERY PROCESS

Like at the end of chapter 2, the risk analysis of the VSM found that the VSM does not fully answer to the research problem and all research questions. VSM does not cover all aspects of the research problem, so more information about the office and administrative process of the case company has been collected through gathering information about waste causing actions on the case company’s order-to-delivery process. The data is collected from the ERP-software and PLM-program, but also via e-mails.

The purpose of the VSM is to reveal value adding and non-value adding actions from the mapped process. The non-value adding actions can be considered as a pure waste (Duggan 2002, p. 3). This chapter introduces the most common sources of waste in office and administrative process briefly and then compare them to the findings of the current-state maps.

The amount of created waste in the office and administrative processes can be double compared to the shop floor processes, and waste is often hidden on the form of information flow (Keyte et al. 2004, p. 16). Identifying the waste in the shop floor process or the office and administrative process is based on Lean thinking. Generally Lean point, out 8 types of waste in the shop floor process. Similar groups can also be recognized in the office and administrative process. (Keyte et al. 2004, p. 16.)

6.1 Waste in the office environment

Identifying the value in office and administrative actions and separate it from the waste is challenging. Office and administrative processes like designing, purchasing and making specific products have two main categories of action. These actions define the nature of the value creating in the process. These actions are value-creating actions from the customer's point of view and the non-value creating actions from the customer's point of view. This last non-value created action can be requested to support the various needs of the other stakeholders. The ability to see the difference between these things is the most challenging in the waste eliminating processes. (Keyte et al. 2004, p. 16.)

There are several ways to classify the waste. The background of the investigator strongly influences the approach. The well-known approaches according to Chiarini (2013, p.17-19) are:

- “Cost of poor quality. American total quality management (TQM) approach.
- Muda, Mura, and Muri. The traditional Japanese approach to the waste.
- Man, Material, Machine, Method. The traditional Japanese TQM approach to the waste.
- Seven wastes. Japanese approaches adopted by the USA.”

In this research, the study focuses on seven wastes (or eight wastes). The approach and contents also vary inside of this classification. The variation is strongly influenced by the approaching background and the fact if the waste definition is done in office and administration process or the shop floor process. Even for the office and administration process, there are several approaches to see the waste in the process. The standard classifications for the waste according to Keyte et al. (2004, p.17) and McManus (2005, p.57-59) are:

- “Waiting
- Inventory
- Extra processing
- Overproducing
- Transportation
- Excess motion
- Correction.”
- “Underutilized people.” (Keyte et al. 2004, p.17)

The wastes mentioned above are introduced at a very general level. The seven wastes (or eight wastes) can be divided into ten more specific existences according to Chiarini (2013, p.144-145):

- “Processes carried out ahead of or behind schedule
- Staff having to wait
- Slow activities/processes
- Pile-up of information or data that requires processing
- Defects and mistakes
- Customer complaints
- Service exceeds the customers’ requirements
- Duplications within the process
- Excessive staff movement
- Unnecessary transport.”

This research will focus on 7 general types of waste. The VSM is made on the factory level. Ten specific types of wastes are more usable if the mapping was made on the process level, but ten specific types of waste gives us a better perspective of the forms of waste. The setting of the research question limits part of the waste types off from the research scope.

The purpose of this chapter is introducing the type of wastes which will be identified in the process at a later chapter of this research. The other purpose of this chapter is light up the blind spots of the order-to-delivery process of the case company which the current-state maps did not cover.

6.2 Demanding customer projects

In this research, we are trying to approach this subject from a more objective point of view and sum up all the factors which make projects demanding from the point of view of the order-based engineering department. The demanding customer projects mean projects, where the customer’s demands and the technical specification are very strict. It is important to notice that demanding customer projects do not mean that the customers are difficult. The problem can be dressed in the disguise of a difficult customer, but the root cause can lie behind misunderstandings and communication errors. The interviews point out that the amount of demanding customer projects has grown.

"The sales of so-called standard motors have decreased and re-directed to the other production units, and more demanding projects are our product unit's specialty" – Project manager

The previously made master's thesis *Two-phased Engineer-to-order Model as Competitive Advantage,* (Karppinen 2018,) which was also made for the case company, sums up the six factors which can affect the project and make project demanding for the case company. From these findings, the classification and special components are those who directly and most prominently effect on the project from the point of view of the order-based engineering. Other factors that are presented are difficult to detect from the point of view of the order-based engineering.

"Demanding customer projects are hard to detect in advance" – Senior designer

Based on the current-state maps and the interviews, it is clear that the customer is the critical factor of all action. The customer determines the degree of difficulty in all sectors of the project. The following vital characteristics have been able to be found in the current-state maps:

- Changes
- Quality of the information
- Project schedule
- Customer specification
- Electrical requirements
- Manufacturing challenges
- Mechanical requirements
- Schedule of engineering

These characteristics can be divided into three groups based on what their most significant influencer is. Project schedule, electrical requirements, mechanical requirements, and customer specification are customer driven factors, meaning that the primary input and the biggest influencer in these factors is the customer. Manufacturing challenges and schedule of engineering are manufacturer driven factors, meaning that their proportion depends on the production unit. Common factors are changes and quality of the information. The customer and the production unit have an equal impact on these factors. These combining factors are shown in figure 19. The key characteristics can individually and combined with each other effect radically the customer project and transform its nature to a demanding customer project. These factors can also multiply the challenges and the problems on the project.

The common feature of these characteristics is that, at a later stage, their impact on the design and the production will rise. If these characteristics comes up late in the production unit, the harder the engineering and production have to adapt to these factors and pivot the direction of the manufacturing. Figure 19 presents the essential characteristics of demanding customer projects from the point of view of the order-based engineering.

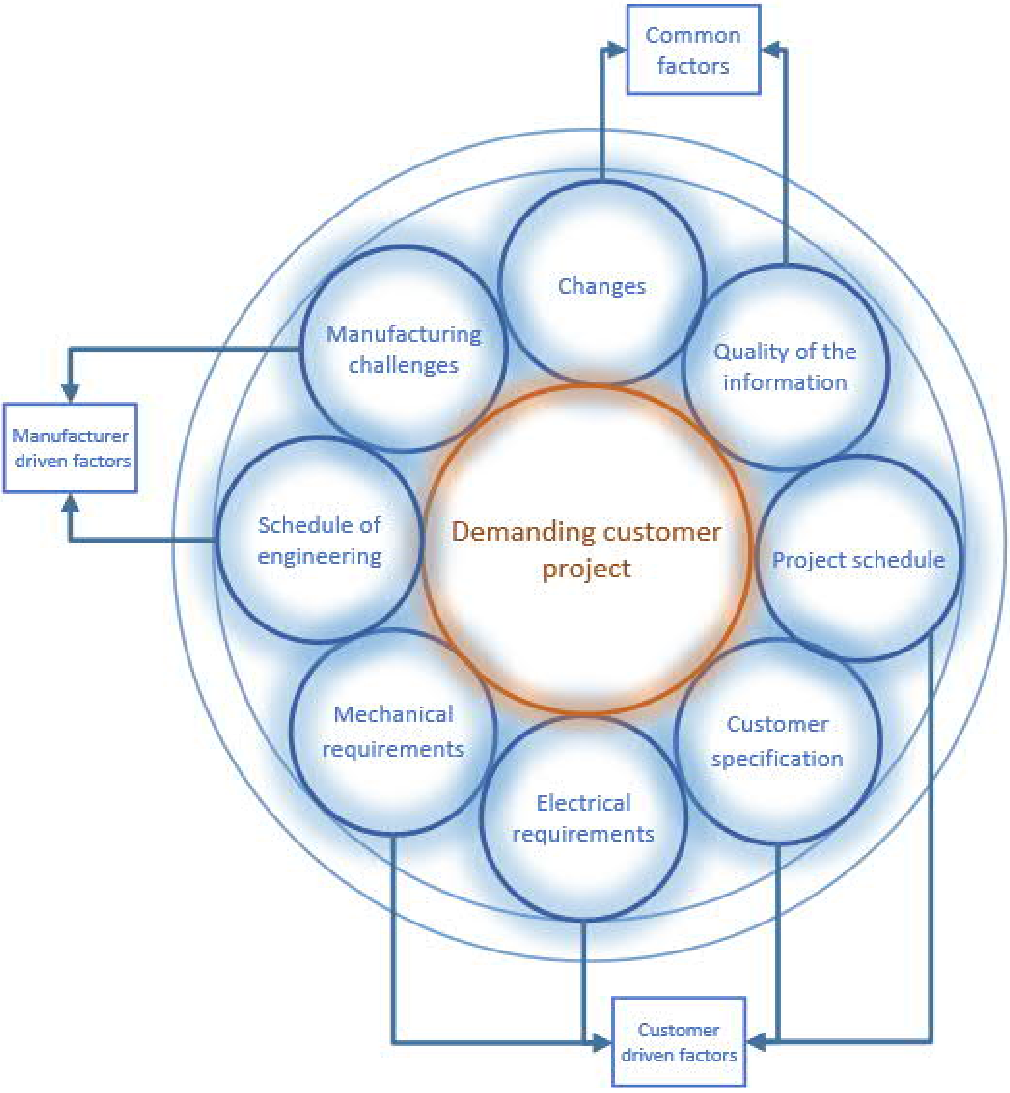


Figure 19. The key characteristics of demanding customer projects.

6.3 Information flow

The primary raw material and main product of the order-based engineering team is information. The information stream transformed into the material stream in the production and subcontracting processes. Like the current-state maps reveal the information flow around the office, and administrative process is massive. The results of the interviews noted that the information flow is bigger than the current-state maps reveal. Some of the information will not be passed through the official tracks, and one single change order can require long email chains before the desired change is clear and even then, the information can still change.

The primary information, alongside with official tracks, is the e-mails. E-mail is the standard communication tool between the customer, local sales unit and project management team, but the communication between other stakeholders like order-based engineering, production, purchase, and subcontractors should go through the order document, change orders, support requests and Bill Of Materials (BOM). The leading idea behind this is to ensure that the latest information is available to every step of the order-to-delivery process. The study of this chapter focuses on the information flow between order-based engineering and the other stakeholders.

Figure 20 illustrates the alternative information flows into the order-based engineering and from order-based engineering to the other stakeholder of the order-to-delivery process. The amount of messages has been counted one by one and messages like ”I am out of office”, “Thank you for your message” or “roger that” has been left out from the scope of this study. That means that one message is one mark in figure 20.

The messages can be targeted to an individual person, but they are treated as a message between stakeholders, meaning that for example, production can mean any part of the order-to-delivery process if it’s in the process after order-based engineering and dealing with in-house manufacturing or production.

In figure 20, the blue arrows represent the technical support. Green arrows are purchasing or suppliers or a combination of both. The orange arrows represent messages between project management. Grey arrows represent the in-house production. In the circle, the arrows are not in chronological order with respect to the time. The time period around order-based engineering has been divided into four quarters. The first quarter is the time period between CODP and end of designing. The second quarter is the period after designing and before manufacturing. Moreover, the third quarter is the time period during the production. The last quarter is the period after the product is finished. The 1st target of research is on the left side and the 2nd target of research on the right side of figure 20.

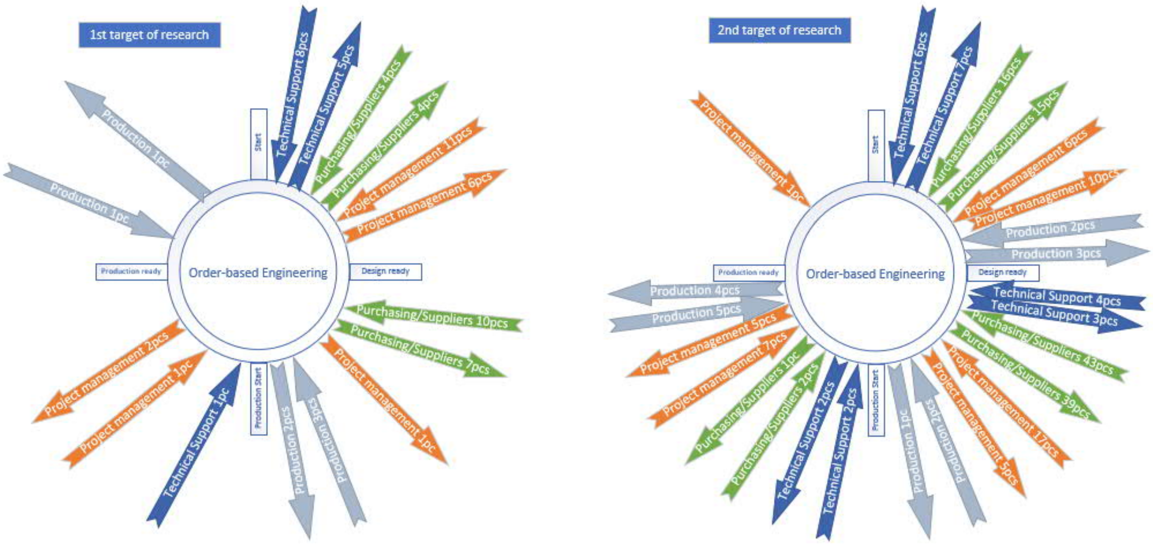


Figure 20. Information flow of order-based engineering.

Figure 20 illustrates that in the 1st target of research the total amount of incoming alternative information is 39 messages and the amount of outgoing alternative information is 28 messages. In case of the 2nd target of research, the total amount of incoming alternative information is 113 messages and the amount of outgoing alternative information is 95 messages. The alternative information flows on the case of the 2nd target of research is much higher. In both cases, most of the communication is happening before production. Some communication happened after the production has started, but in both cases, the amount of that communication is not significantly large.

The communication between order-based engineering and purchasers/suppliers is remarkably high in both cases, especially in the case of the 2nd target of research. A large number of changes can explain some of the communication of the 2nd target of research. However, like it has been said before, the primary communication channel between order-based engineering and purchasers/suppliers should be BOM.

The amount of communication between order-based engineering and technical support is also high, and it seems to be constant through the entire production. This communication includes both project-specific communication and product specific communication. Such communication can be assumed to be a regular in the design phase, but abnormal if it continues throughout production. In the 2nd target of research, the amount of communication is higher than it the 1st target of research. Also, in this case, the communication of the 2nd target of research can be explained by a large number of changes.

Communication between order-based engineering and project management is constant in both orders. Change orders are communication from the project management to the order-based engineering, but the change order is by nature more of a command then a communication tool. In practice, the change order pierces the whole supply chain and leave very little room for interaction. The e-mail is the only communication path between order-based engineering and project management, alongside face-to-face communications.

It is important to note that the amount of all communication has been between actual workers and not between stakeholders or departments. The e-mail is personal, and its distribution area is dependent of the sender. Meaning that the e-mail would not reach the entire staff of the department. A single project includes several purchasers/suppliers, lots of people on production and project management. Order-based engineering requires at least two designers, one electrical designer, and one mechanical designer. In case of the 2nd target of research, there were 6 mechanical designers involved in the project.

6.4 Order document and attachments

As of the result of the P0-meeting, the order document and its attachments are saved to the project design folder. The local sales unit creates the order document by using a special sales tool. The order document contains the primary information about the product and the customer specifications. The order document, by its form, cannot contain all the information about the product. That means that some additional documents are also saved as attachments. Those attachments are also saved in the same folder with the order document.

The design folder also includes other documentation of the project. That documentation can be added to all stakeholders, but it is mainly management by the order-based engineering and project management. Some documents are formed during the design process, and some documents are added in the folder when the change orders are formed. Also, all revisions from the order document are saved to the design folder. The use of the design folder is very diverse, but not standardized.

The design folder of the 1st target of research contains 41 items, which include 5 sub-folders (the content of sub-folders was not included in the total number of items). The design folder of the 2nd target of research contains 97 items, which includes 16 sub-folders (the content of sub-folders was not included in the total number of items). A large number of items on the 2nd target of research design folder can be explained by the large number of changes. The amount of additional information varies a lot between the orders. The variance of studied C and D class orders is illustrated in figure 21.

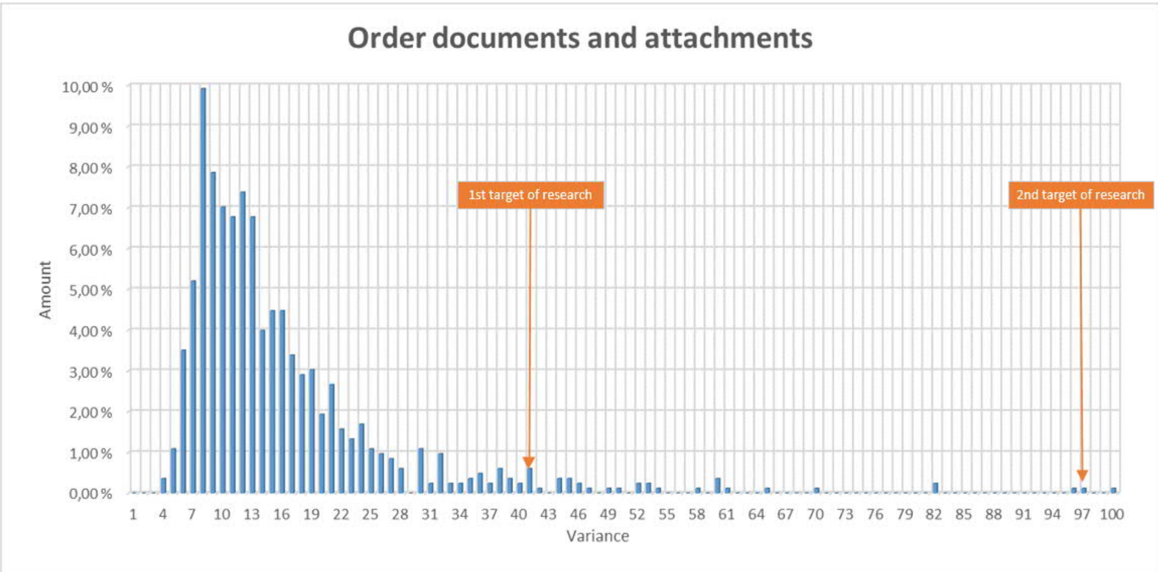


Figure 21. The variance of orders documents and attachments. In the horizontal axle the variance is in pieces.

All projects have at least 7 pieces of attachments. The number of attachments is formed at the beginning of the project and contains the order document itself, electrical documentation and a checklist for the project. From the graph in figure 21, it can be seen that there have been projects that have had less than 7 pieces of attachments. These projects are likely to be identical projects with another project so that the additional information may be saved in the leading order's design folder.

The number of attachments in figure 21 also includes the sub-folders, meaning that in some cases the number of attachments can be more significant. It is also important to note that the number of attachments take a stand on the number of attachments, not to what and how much information they contain, but it is also notable that the study shows that there is no case where 100 attachments are just one-page datasheets.

The correct number is not so interesting for this research. There is no perfect number for the attachments due to the nature of the products. In this research, the actual number cannot be determined. The variance of attachments is still interesting for this research. The 1st target of research has almost three times the number of average attachments on order. The 2nd target of research has over double of that. The 2nd target of research falls in the category which has the most attachments. Only one other project has had more attachments.

6.5 Change orders

The business segment and product of the case company are by nature such as customer's projects and requirements are in constant change. That means that the change orders must be counted in the core business of the case company. For this reason, is cannot be ignore in this research, but the main focus of this research is to study the change order on a general level.

Like it can be seen in the current-state map of the 2nd target of research (figure 17), the change orders are the dominant segment of the entire map. On the current-state map of the 1st target of research, the amount of change orders is more reasonable.

The 1st target of research has 3 change orders from the customer, and the 2nd target of research has 26 change orders from the customer. If the 1st and the 2nd target of research are compared to each other, the 2nd target of research has significantly more changes. Without a proper reference point, it is impossible to say whether this amount is exceptionally large compared to other projects.

Also, the time used for the change order is significantly higher for the 2nd target of research. This chapter will focus on the amount of the change order in general and the time spent on change orders on a general level. Data about the change orders can be collected from the ERP-software of the case company.

Our research deals with all delivered projects in the case company in the time frame of 1.1.2017-22.8.2018. In that period, the case company has delivered 1482 projects. Figure 22 illustrates the distribution of projects between the various degrees of difficulty. 42% of all projects were designed at difficulty class A. Difficulty class D was the smallest group of projects in that time period.

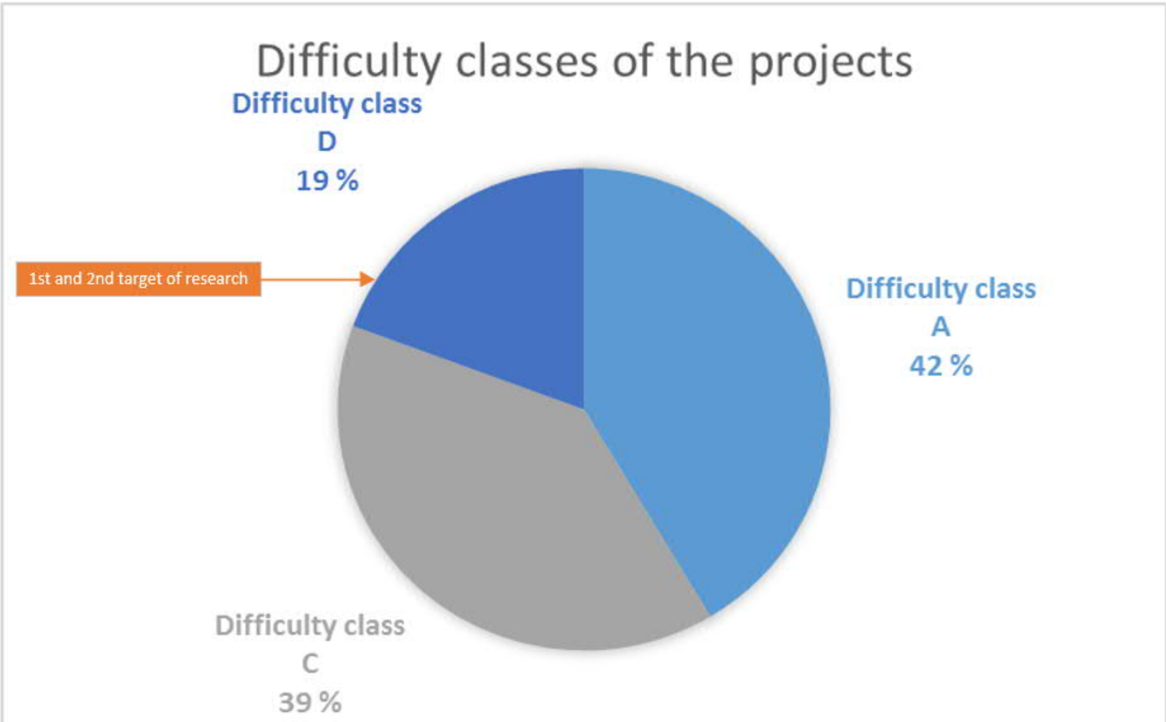


Figure 22. The relationship of difficulty classes to each other as a percentage. The 1st target of research and the 2nd target of research both belonged to the difficulty class D.

Like figure 23 illustrates, 65.5% of all projects have at least one customer change. This number does not include internal change orders. If change orders are divided by the difficulty degree of the products, can figure 23 show that the number of projects that have had at least one customer change will increase considerably when moving to more difficult orders. In difficulty class A has had at least one change order in less than half of the orders. The exact percentage is 47.

From the point of view of this research, the more interesting projects are in difficulty classes C and D. The difficulty class A represents the standard product which has a very low level of customization. The producta in C and D difficulty classes represent ETO-products.

In difficulty class C 77% of projects have at least one customer change. The 1st target of research and 2nd target of research both belonged to the D difficulty class. The D difficulty class has at least one customer change in 82% of the all studied projects.

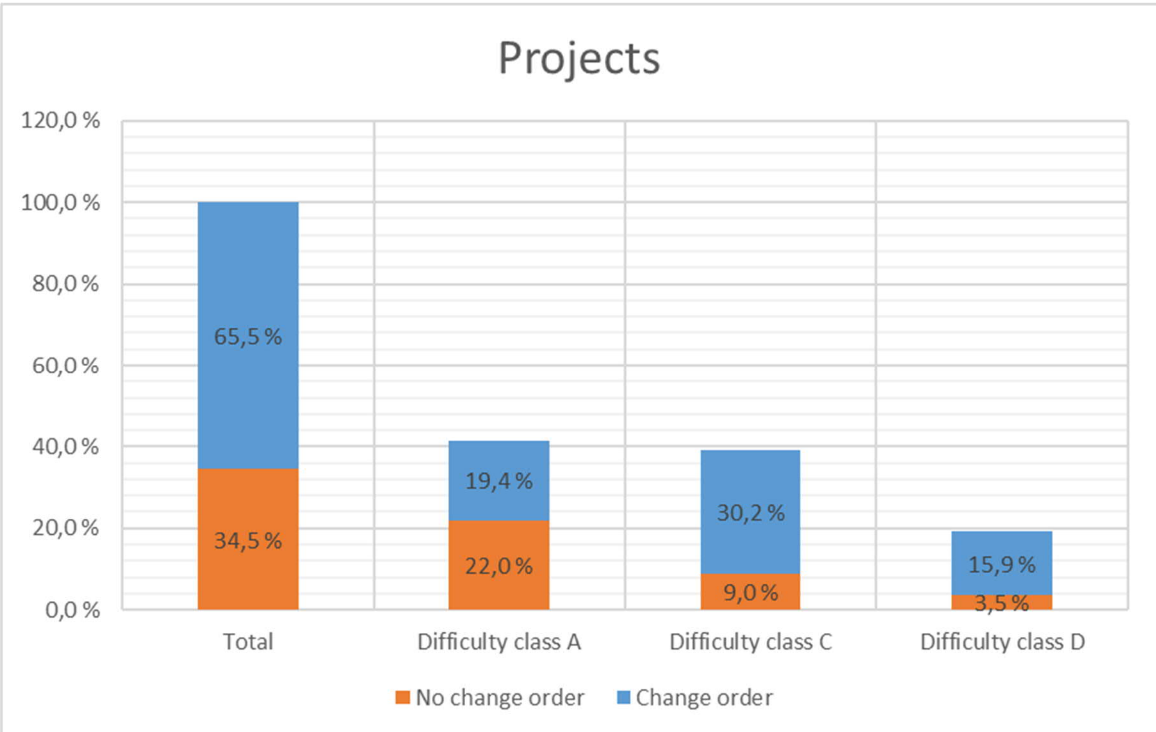


Figure 23. Percentage of change orders per project and amount of change orders divided by the difficulty classes presented as a percentage of total amount of change orders.

The number of projects which has had at least one change orders is high. It is evident that the changes are a part of the everyday work process of the case company. Difficult projects have more changes. Figure 23 indicates that many projects have at least one change, and that indicates that the scope of the project has not been clear at the beginning, when the order has been transferred from the local sales unit to the production unit.

The large number of change orders does not directly imply that the order clearing process is inefficient. The scope of the customer project may also change as the customer project progresses. All change orders are not necessarily structural changes, meaning that all change orders do not mean that the electrical or the mechanical design of the product is changed.

If we look closer on only the group which has at least one change order from the customer and we refine our search to the products in difficulty classes C and D, then figure 24 illustrates how the amount of the change orders has divided to the projects in C and D difficulty classes. The amount of the projects which have only one change order is still a dominant number in the results. In difficulty class C the significant part of the changes is in the group 1 to 7 change orders per project, and in difficulty class D a significant part of the changes is in the group 1 to 9 change orders per project.

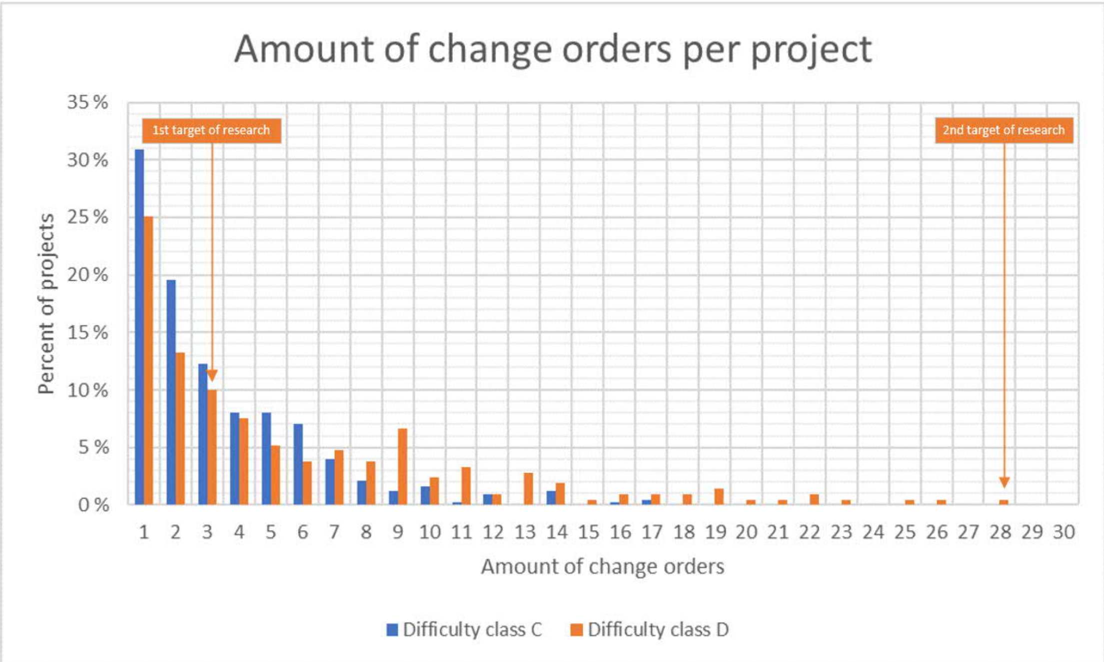


Figure 24. Amount of change orders per project. In the horizontal axle the variance is in pieces.

Figure 24 illustrates that the amount of change orders on the 2nd target of research is significantly larger than the average amount of changes per order. In difficulty class C, the maximum number of change order per project was 17 pieces. In difficulty class D, the maximum number of change order per project was 28 pieces. The number of projects which have more than 15 change orders is small.

The last aspect of the study of the change orders is the time which is used in the change orders in the order-based engineering department and the frequency of the change orders. In the 1st target of research, the time spent on the changes of structure and documentation was small compared to the used engineering hours. The used hours on changes in the structure and documentation of the 2nd target of research was a significant part of the whole project hours. Figure 25 also illustrates the used hours on the change orders in the studied period of time. Figure 25 illustrates the relationship between the amount of the change orders and the used hours on a weekly level. The current-state map of the 2nd target of research (figure 17) illustrates that the on that change order has demanded more process time for the order-based engineering department then the entire office process has.

At this point, it is clear that the change orders demand a lot from the stakeholders of the order-to-delivery process and especially from the order-based engineering department. If in the figure 25 illustrated amounts of the change orders are divided equally with the weeks, the result is that every week 32.8 new change orders are registered in the system. That means that 100 hours per week are spent only on processing changes.

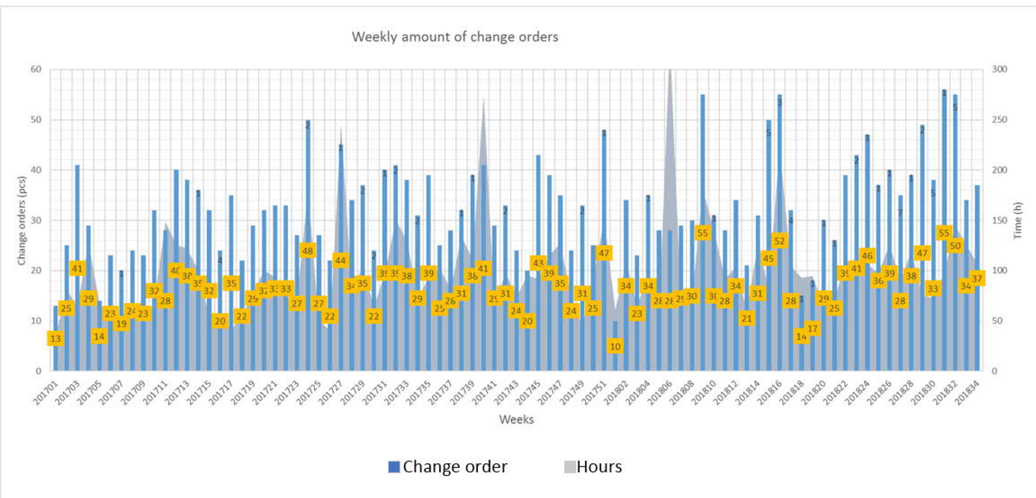


Figure 25. The weekly amount of change orders.

6.6 Waste in designing process

The design process of the order-based engineering is based on that the fundamental idea that after the designing is completed, the design of the product is finished, and the structure of the product is unchangeable. This is the fundamental assumption in ETO-processes and supports the idea that the engineering is only one block between customer and production.

Like the findings in change order chapter demonstrates more than often this is not the case. The structures of the case company's demanding customer projects may change several times. After every change the assumption is the same, the design of the product is ready, and there will not be more changes. Changes that come after the design is finished, regardless of whether it is electrical or mechanical design, do not only add information to the structure of the product, they also replace or change some information.

Thinking that the structure is ready and unchangeable will cause waste in the designing process, because parts or components which has already been designed and put in the purchase process, must be revised. Figure 26 illustrates simplified demonstrations behind this problem. Each block represents one set of components of the product, which includes the information needed for subcontracting and assembly.

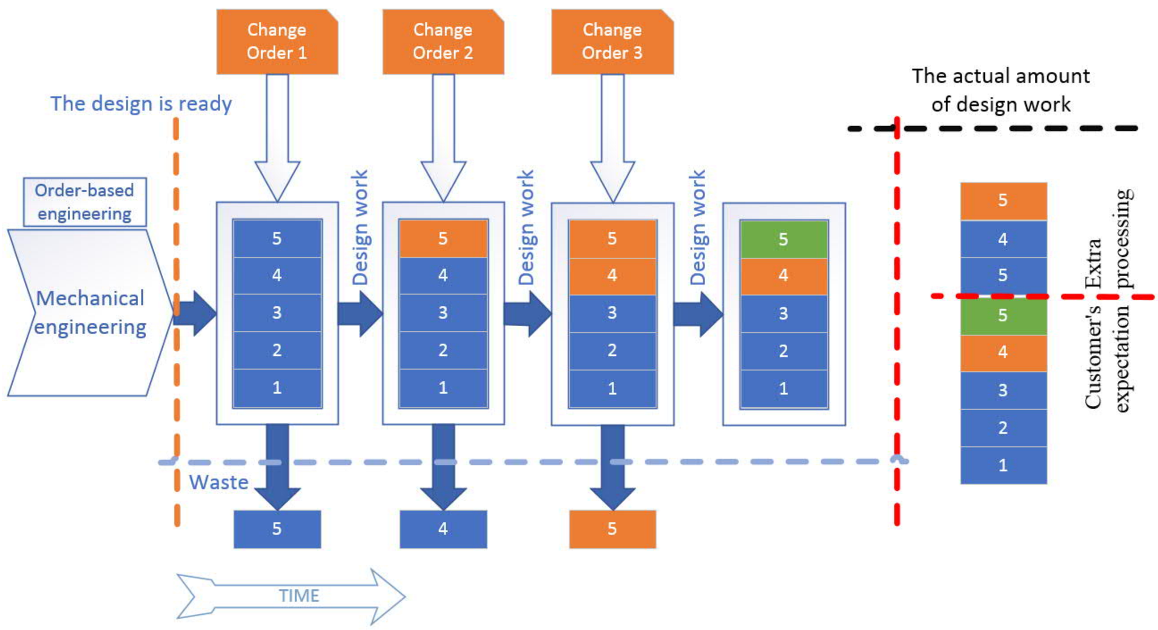


Figure 26. Changes create waste in the designing process.

Every time a change order comes, the designer must modify at least one block in the structure. In this simplified demonstration the whole block needs to be changed, meaning that the time and effort which the designer has put into that design will be lost. In same way the effort of other stakeholders will be lost. The information which is released in the process becomes waste and may cause problems and misunderstandings in the process. The released information is very hard to chase down and remove from the system.

This kind of waste is complicated to define or measure because all structures are individuals and changes are not systematic. In other structures a large number of change orders which comes after the design is ready, can still cause only little of waste where one significant change can cause a lot of the waste.

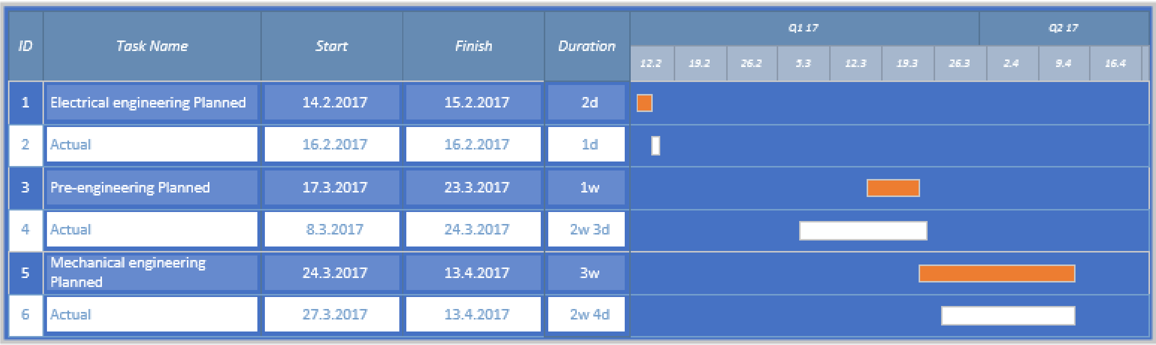
The time used for the changes can give a good understanding or estimation of the amount of waste. If the matter is generalized and the previous studies are summed up, the average working hours of one change order is 3 hours. That means that in the figure 26 illustrated example, the design time has increased at least 9 hours. In the case of the 1st target of research it can be assumed that the waste caused by changes is relatively small although the mechanical change did come very late compared to the progress of the manufacturing of the project. In the case of the 2nd target of research, it is safe to assume that the changes caused lots of waste. The used hours for the change orders were more significant than the process time of the electrical and mechanical engineering together.

The changes can cause two types of waste. Waste that can be measured by lost time and effort. The time losses generally apply to the information flow, and it is hard to measure accurately. The second type of waste can measure losses of material. This one is easier to measure and more accurate. After all, they both cause losses that can be measured in money.

6.7 Planned schedule of engineering Vs. the actual schedule of engineering

The case company has two order-to-delivery models (like it has been illustrated in figure 11 on chapter 4.2). Both studied projects were scheduled on the model which is dependent on a requested delivery date from the customer, meaning that the scheduling of office process and production process are determined by delivery date of the project.

In figures 27 and 28, the planned design schedule of both cases is illustrated. The orange bar represents the planned schedule, and the white bar represents the actual schedule. The planned design time for both projects was almost identical. The planned mechanical engineering step was one day longer in the 2nd target of research compared to the planned design time of the 1st target of research. The one day longer design time applies to pre- and mechanical engineering.



ID	Task Name	Start	Finish	Duration
1	Electrical engineering Planned	14.2.2017	15.2.2017	2d
2	Actual	16.2.2017	16.2.2017	1d
3	Pre-engineering Planned	17.3.2017	23.3.2017	1w
4	Actual	8.3.2017	24.3.2017	2w 3d
5	Mechanical engineering Planned	24.3.2017	13.4.2017	3w
6	Actual	27.3.2017	13.4.2017	2w 4d

Figure 27. The planned schedule of engineering Vs. the actual schedule of engineering for the 1st target of research.

ID	Task Name	Start	Finish	Duration
1	Electrical engineering Planned	5.4.2017	6.4.2017	2d
2	Actual	13.4.2017	21.4.2017	1w 2d
3	Pre-engineering Planned	17.5.2017	24.5.2017	1w 1d
4	Actual	9.5.2017	23.5.2017	2w 1d
5	Mechanical engineering Planned	14.6.2017	5.7.2017	3w 1d
6	Actual	13.6.2017	28.7.2017	6w 4d

Figure 28. The planned schedule of engineering Vs. the actual schedule of engineering for the 2nd target of research.

In both cases, the electrical engineering started late, but has not seemed to be affect the start of the pre-engineering phase. In the 1st target of research, the planned time of electrical engineering was longer than used time. In the 2nd target of research, the actual time was three times longer than the planned time. The gap between the electrical engineering and the pre-engineering was almost identical. In both cases, the pre-engineering was started earlier than planned but finished on schedule.

The mechanical engineering of the 1st target of research starts right after the pre-engineering. In the 2nd target of research there is a significant gap between pre-engineering and mechanical engineering phase. The time gap between engineering steps is standard if the schedule of the delivery allows it. The mechanical engineering step in the 1st target of research was shorter than the planned. In the 2nd target of research, the mechanical step was over twice longer than planned.

The scheduling of the engineering phases is an essential phase in the order-to-delivery process, and it has a significant impact of that specific project. The successes or challenges also hase a significant impact on other ongoing design processes. The change orders of both projects have not scheduled beforehand.

6.8 Summary of waste in the order-to-delivery process

In chapter 6.1 the classifications of waste have been introduced. In this chapter, the research will focus on only waste types that takes place in the order-to-delivery process of the case company. This last chapter will also crate an overview of the findings of the blind spots of the order-to-delivery process.

The order-based engineering has a critical role in the order-to-delivery process. The order-based engineering process provides a great deal of information to other stakeholders. All that information is not adding to the value of the product in the eye of the customer but does add value and give valuable information to other stakeholders. These stakeholders, who are dependent on that information, are production planning, production, project management, purchase and subcontractors.

Although information flow is essential and a prerequisite for success, the amount of information is massive. All studied information is additional information for the product structure and bill of material. Order-based engineering receives and sends many messages. The amount of information is in this study a more important finding than the content of the messages.

The study shows that the amount of information flow decreases as the project progresses. Although lots of communication is settled in the middle two quarters in figure 20. The communication between order-based engineering and technical support can considered as value adding action. The communication between order-based engineering and purchasers/suppliers that takes place after engineering can considered as non-value adding actions. The local sales unit does not occur in the information chain at all.

An interesting find about the information flow is also the number of attachments. The order document and attachments together form the foundation for the engineering. Amount of order documents and attachments vary between projects and the difference between the extremities is massive. The reason for the high amount of attachments can be related to a large number of variables but does not change the fact that a large amount of information is more difficult to manage and utilize effectively.

The change orders are the dominant element in the order-to-delivery process, and their significance is undeniable. For this reason, their essence has been studied a lot in this research and in general in the case company. The most important finding is that the number of projects which has at least one change order is greater than the number of projects in which there is no change order. The number of projects that have had at least one customer change will increase considerably when moving to more difficult orders.

Figure 29 shows the relationship between the change orders and the amount of attachments. In this illustration, the vertical axel is not interesting. The interesting part is to notes that change orders are increasing the amount of information. The projects which has not had any change, the amount of attachments is between 4 and 25 and the number of projects beyond 14 attachments is relatively small. While in the projects which have at least one change, the amount of attachments varies more. Projects which have many attachments, more than 26, have also been involved in at least one change order.

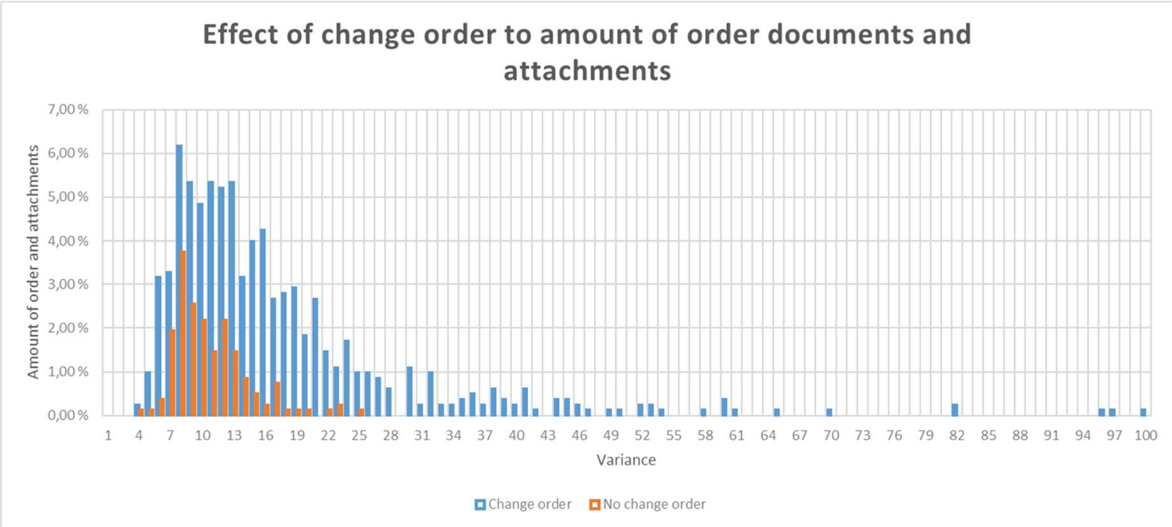


Figure 29. The effect of the change order to the amount of order documents and attachments. In the horizontal axle the variance is in pieces.

The change orders are a large share of the workload of one individual project and a significant share of the weekly workload of the whole order-based engineering department. The amount of change orders vary between projects and the differences in the extremities are large. Despite the large number of work, change orders are an important part of the case company's business. The waste in the design process is very difficult to define or measure. Especially the measure part is challenging because all structures are individual, and changes are not systematic. The reason for this loss, however, is the idea that the structure is unchanged, or/and the changes cannot be predicted in advance.

The factors mentioned above also have a significant on effect the project's timetable. The analysis of information flow presents that a large part of the alternative information flow happen after the design phase is finished. This means that the design of next project has begun and has been interrupted because they required the designer's attention and took up the designer's time. They become factors of the project's timetable and not just to that specific project, but also the timetable for other projects.

Change orders have their own factor on the timetable of the project. These factors make the planning of the work schedule of order-based engineering very difficult. This can be noticeable in too short timetables. Despite short timetables, in both cases all actions has finished on time.

In the framework of this research, the waste types have also studied. Using Keyte et al. and McManus (Keyte et al. 2004 p.17; McManus 2005, p.57-59) classification method on the waste, following waste types has been identified from the order-to-delivery process. For the description, characteristic and nature of waste, the Andrea Chiarini's (Chiarini 2013, p.144-145) 10 more specific definitions gives more perspective to the inspection.

Waiting or slow activities/processes reflect long communication chains. The customer and local sales unit seems to be out of reach of the order-based engineering. This will create a wave movement in the progress and development of the project. Delays in information flow will add uncertainty and lead to changes in the product structure.

Inventory means in this case pile-up of information or data that requires processing. One of the indicators of this inventory waste is a high amount of order attachments. The inventory is connected to transportation. In this case, the transportation means information flow and information is the main product of all stakeholders before the production phase. Studies show that the amount of inventory of information and the flow of information is high. The information comes from many sources and is spread to many places. The communication passes through informal routes and is not available to everyone. The result of this is a fuzzy holistic view of the project. A blurred view leads to inefficient work.

Correcting is one effect to the enormous amount of information. In this case, it does not mean manufacturing errors. It means misunderstandings about the needs and request of the customer. The misunderstandings are reflected in a large number of change orders because requirements are not understood and can met at once. Unnecessary work is being done and time has been wasted. The nature of the projects can explain part of the amount of infromation.

Extra processing lead to duplications within the process and the duplications within the process are the result of the changes. The customer request is tried to be determined through trial and error. When information has been changed, there is a risk that incorrect information cannot be removed from the system. Also, the duplicates can be seen as material duplicates, where the new design replaces the old design, but the old design has advanced so far that it cannot be canceled.

Overproducing, in this case, can be seen as processes carried out ahead of or behind schedule. For this kind of behaviour there can be many reasons. Designers needs to jump between projects and the timetable has an impact on other projects. The workload of order-based engineering can be a factor and change orders also have an impact on this matter.

The seventh waste is excess motion. Excess motion is one of the wastes which can be best understood from the current-state maps. The motion does not mean moving from one place to another. In this case, it means searching the information which is pile-up somewhere in the system or moving that information between programs and communication platforms. The findings of the waste in the order-to-delivery process has collected in table 2.

Table 2. Waste of the order-to-delivery process.

WASTE OF THE ORDER-TO-DELIVERY PROCESS			
	Waste type	Determination	Effect
1	Waiting	Long communication chains between order-based engineering and customer	Long communication chains create a wave movement the progress and development of the project. Delays in information flow will add uncertainty and leads to changes.
2	Inventory	Pile-up of information or data that requires processing.	The high amount of order attachments is blurring the holistic view of the project. The vision of the customer are blurred, and the vision of the designer is also blurred. This leads to inefficient work.
3	Transportation	Transportation of information	Amount of flow of information is high. Information comes from many sources and is spread many places. The communication passes through informal routes and is not available to everyone.
4	Correcting	Misunderstandings about the needs and request of the customer	This is reflected in a large number of change orders because requirements are not understood and can be met at once. Work is being done unnecessarily and time has been wasted.
5	Extra processing	Duplicates within the process	The customer request is trying to determine through trial and error. When information has been changed, there is a risk that incorrect information cannot be removed from the system.
6	Overproducing	Processes carried out ahead of or behind schedule	Projects move on overlap and cross. Designers need to jump between projects. The timetable has an impact on other projects.
7	Excess motion	Searching and moving information	Searching information which is pile-up somewhere into the system or moving that information from between programs and communication platforms.

7 FUTURE-STATE MAP OF THE ORDER-BASED ENGINEERING

In this chapter, the study is focused on the current-state map of order-based engineering. The research is focused on find in the strengths and weaknesses in the workflow of the order-based engineering department, and the result will be the future-state map. This research includes two current-state maps. It would have been natural to create two future-state maps, but all projects have unique features, so two future-state maps would not serve a purpose. The one map which compounds the findings of both projects, produces the best transformation plan for the order-to-delivery process of the case company.

The VSM does not cover all aspects of the research questions, so more information about the office and administrative process has been collected by gathering information about waste causing actions in the case company's order-to-delivery process. To support these findings of the current-state maps and the waste in office process, interviews have been conducted. The interview groups were senior designers, project managers, and engineering manager of another production unit. The interviews were made in separate groups.

The goal of the VSM is to create flow in the process and combine that flow with the customer's needs with supporting actions. In this case, the customer means internal and external customers. The order-based engineering department is working closely with both. The needs of the internal and external customers vary and in fact, the needs of the internal customers vary a lot. The future-state map is introduced in figure 30, and the improvements are listed in the end of this chapter (table 2).

This chapter goes through the backgrounds of the improvements and combines them with the studies done in this research. Chapter 8 will then study and estimate how difficult it would be to make these changes a part of the order-to-delivery process of the case company and which stakeholders these changes would involve.

It would be very tempting to draw a future-state map, that does not contain any change orders. However, the changes are a part of the business. The question is not how the changes can be avoided, but how the changes can be controlled in the best and most efficient way. The solution must satisfy the external customer's needs, but it must also satisfy the need of the inner customer as well. Like the studies have shown the amount of the projects that have at least one change order is the majority of all projects.

The information must flow through the whole process from the beginning to the end, but because the projects are continually evolving, and the request of the customer is specified during the process, the information must also flow in the opposite direction. Meaning that the information and the development of the product needs to be brought to the attention of the local sales unit. That way the scope of the product can be followed on many levels and the latest information is close to the customer.

The future-state map is designed in a way that supports both order-to-delivery models. Many factors can influence the choice of the order-to-delivery model, and in both cases, project processing must be supporting the order-to-delivery model. The future-state map is illustrated in figure 30 and also demonstrated in Appendix III

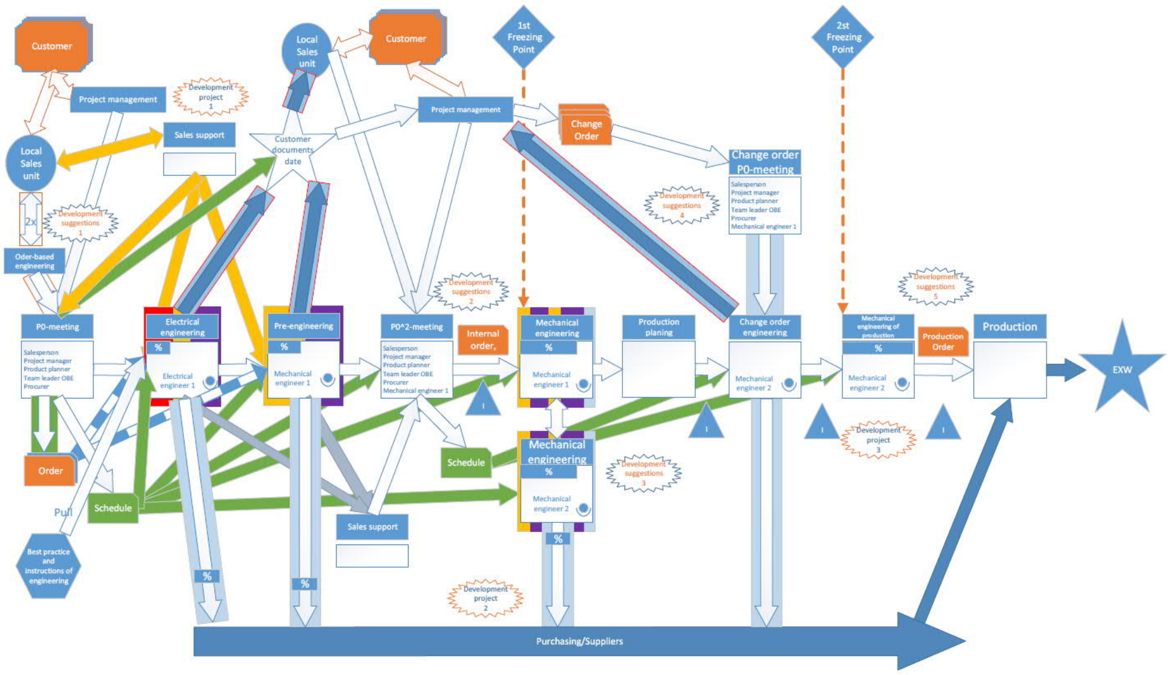


Figure 30. The future-state map. The holistic view of a modified order-to-delivery process.

The main characters are the same as in the current-state maps, and the purpose of the process boxes are identical. The construction of the map has not changed. The future-state map is now containing two boxes for the customer, the local sales unit and the project management. The reason for two boxes is just to simplify the future-state map and underline that those stakeholders are present in those two phases.

The order-to-delivery process has not changed. The local sales unit call for the P0-meeting and send the invitation. The development idea for this point is that the meeting invitation would be send out two days before the actual meeting. That gives all stakeholders one more day to react to the content of the new order. The idea is that the order-based engineering replis and comments on the invitation in the first 24 hours and that gives the local sales unit an extra 24 hours to reply to comments of the order-based engineering. The aim is to get the order content, i.e., the information about the product to the best possible level before the P0-meeting. The Order document and its attachments are formed and inspected in the P0-meeting. In the same way, the schedule of the engineering and the customer documentation is confirmed in the meeting.

The current-state maps show that the electrical and mechanical engineering can be done already in the support and order handling steps, before the actual order-based engineering. The sales tool can do light electrical engineering to the product, and sales support can do mechanical and electrical engineering to the product. The sales support can be seen as an isolated island and not fully supporting the other stakeholders at the downstream. Designs cannot be directly used in the product. It can solve the individual problems of the product, but it cannot be directly used to design phases of the order-based engineering. To utilize design solutions, form the sales support could be one of the development projects which needs to be taken care of outside of the scope of this research.

Between electrical and pre-engineering, there is no storage on the future-state map. Also, this is a change order free zone. If the structure of the product needs to be changed at this point of the order-to-delivery process, the order needs to be returned to the P0-state, and the schedule needs to be re-evaluated.

Studies show that the amount of information in some of the projects is massive. The amount of information increase as the project progresses. This research has concluded that it is recommended to check the accuracy of the information from time to time. The checking is done to ensure that all stakeholders have the same knowledge about the progress of the project and that they all have access to the latest information. Therefore, after the electrical and the pre-engineering, a so-called second P0-meeting (P0^2-meeting) could be considered.

If there is so called storage between the pre-engineering and the mechanical engineering, one can assume that the information flow stops and fades away. The reason for the storage is not important. The reason for it may be the order-to-delivery models or the workload of order- based engineering department or even national holidays. The reason for that the information flow stops is that there is no plan for the project to be taken forward as the information is in so-called storage. The information fades away during the passing time because there was no summary made about the project before putting it into storage. At the starting point of the mechanical engineering, the information needs to be gathered together, and the unimportant information must be separated from the critical information once again. The main idea is that the flow cannot stop, and the information can not fade away. For that reason, the P0^2 meeting would come in handy. The purpose of the P0^2 meeting is creating an internal order document, which brings together all the solutions made at the earlier stages and the problems that have been resolved at the earlier stages. The internal order document is produced in such a form that everyone throughout the whole order-to-delivery process can use it. The idea is to merge the P0^2 meeting as a part of the pre-engineering but because it is a new function, it has been drawn as an independent process box.

Because the new inner order document has formed in co-operation with all stakeholders, it does not matter which order-to-delivery model is used. The mechanical engineering may begin immediately after the P0^2meeting, or it can wait for customers documentation approval.

The electrical engineering and the pre-engineering steps keep their shape, but the mechanical steps are experiencing changes in the future-state map. The mechanical steps are divided into two steps, or the mechanical engineering is changed to work as an assembly cell because it is a new function and it has been drawn as an independent process box.

In demanding customer projects, the scope and the customer specifications are large, and the level of customization is high. For that reason, the mechanical design work is divided between two mechanical designers. The idea is that there will be one leading designer, who has more experience of demanding customer projects, and an assistant designer, who works under the leading designer. The leading designer can be, for example, a senior designer. The design of the product is the leading designer's responsibility. The second aspect is that in this way the knowledge of the product structure and the knowledge of the project scope is sheared between two designers. Limits and instructions for shared design can be one of the development projects that needs to be taken care of outside of the scope of this research.

Like the current-state maps and supporting studies display, the changes are a significant part of the demanding customer projects. This study only focused on revealing the number of changes. The reason for a large amount of the change orders and predictability of them need to be studied separately. The future-state map proposes for the change orders to have an individual design phase. This phase can be prescheduled in the mechanical designer’s work queue and be informed to the customer. The already-used change orders P0-meeting is a viable extension to this process. The mechanical part of the changes may be the responsibility of the assisting designer.

The studies have also pointed out that lots of information is produced in advance and later changed. Especially the information which is created for the production, is produced at the same time as the information for the purchasers/suppliers, even though production needs the information much later. The future-state map proposes that the instructions for the production are formed after the second freezing point. This could also be the response for the assistant designer.

In this mechanical engineering phase for the production, the documentation for the production is formed and some items which have a short delivery time can be ordered it this point. What the components are that can be purchased this late in the process, needs to be defined separately. This study is not in the scope of this research.

Studies also show that the information flow between order-based engineering and purchasers/suppliers is massive. The amount of information indicates that the information which is produced for the purchasers/suppliers does not match their expectations. This could be one of the development projects that needs to be taken care of outside of the scope of this research.

Finally, the overview of the findings of the future-state map. These findings are divided into development suggestions and development projects. The development suggestions are ideas about how the process steps can be reorganized so that the flow would be better. The development projects are projects that are aimed at developing activities or competences. The findings are presented in table 3.

Table 3. Development suggestions and development projects of the future-state map.

	Development suggestions		
	Description	Aim	Actions
1	One day more to P0-invitation	The aim is to get the order content to the best possible level before the P0-meeting	Meeting invitation will send two days before the meeting and Order-based engineering will comment during the first 24 hours and the sales unit will comment to that in second 24 hours
2	P0^2-meeting and internal order	The purpose of P0^2 meeting is creating an internal order and future actions for stakeholders	The internal order brings together all the solutions made at the earlier stage and the problem that has been resolved at the earlier stage and produces it in such a form which everyone throughout the whole order-to-delivery process can use.
3	Two mechanical designer	There will be one leading designer and an assistant designer.	Leading designer have more experience of demanding customer projects and an assistant designer who works under the leading designer. The mechanical design works is divided between them.
4	Planned change order engineering phase	The change orders have design phase.	One additional design phase to be added and scheduled. The design phase is located after mechanical engineering step and before production.
5	Mechanical engineering of production	Instructions for the production.	Instructions for the production is from after the second freezing point. This can be responsible for the assistant designer.
	Development projects		
1	Exploit the competence of the sales support	Information needs to flow and be usable	Training and closer co-operation
2	Contents of information for purchasers/suppliers	The information which is produced for the purchasers/suppliers support their work better	Study what information is needed and in what form
3	Mechanical engineering of production	What component can be purchased later	Study of storage items and short delivery time items. Training

8 ANALYSIS OF THE IMPACT AND EFFORT OF FUTURE-STATE MAP

The last step of the studies in this research is evaluating the findings from the future-state map. The future-state map presented a list of improvements to the value flow of the order-based engineering. This chapter will evaluate the difficulty of implementing those improvements. For this evaluation the impact effort matrix is used. The matrix illustrates what the benefits or impacts of the changes are and how much work is needed to make these changes happen.

The list of the development targets can be seen in chapter 7, table 3. These findings are divided into development suggestions and development projects. The development suggestions are ideas about how the process steps can be reorganized in a way that the flow would get better. The development projects are projects which aim at developing activities or competences. The development targets are illustrated in figure 31.

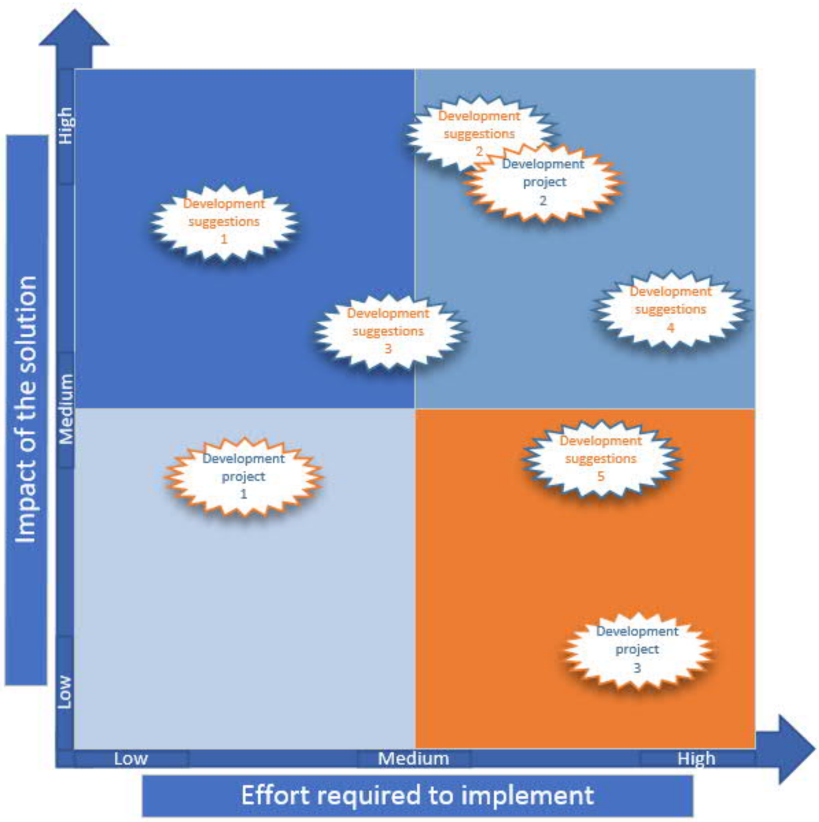


Figure 31. The impact-effort matrix. The development targets are set in the Impact-effort matrix.

The axes of the impact-effort matrix are as follow. The horizontal axel is the effort requirements of the implementation. The effort requirements represent the amount of the work that is required to achieve change in the case company. The vertical axel is the impact of the proposed development targets. The impact means how much it will affect the value and information flow. The axes are divided into three sections; low, medium and high.

All development suggestions and development projects are placed in the impact-effort matrix, and like figure 31 illustrates, most of the suggestions have been estimated to have a high or at least medium impact to the value flow of the studied order-to-delivery process. However, the needed amount of the effort is medium or high in all development suggestions.

The first development suggestion is evaluated to have a relatively high impact on the value flow and could be done with relatively low effort. Adding one day to the P0-invitation requires internal arrangements within the case company.

The second development suggestion is evaluated to have high impact, but it also requires more work. The second P0-meeting (P0^2) or sum-up meeting of the engineering, increases the stakeholder’s knowledge of the project. The internal order document can be the guideline of future actions. This change requires a great deal of work from all stakeholders.

The third development suggestion is two mechanical designers in the mechanical engineering phase are evaluated to have a medium impact and request a medium effort. The challenge is to have co-operation between designers and scheduling this. The co-operation needs to be effective and effortless. Also, the hierarchy must be clear from the beginning. The impact of these actions can be seen in the spreading of information and knowledge about the project.

The fourth development suggestion is evaluated to have a high impact and high effort. Change order related developments have an excellent impact for value flow on the order-to-delivery process but scheduling the change order engineering phase involves a lot of organization, co-operation, and forecasting. It requires a lot of daily work for the team leaders of the order-based engineering.

The fifth development suggestion is evaluated to have a relatively low impact and requires a relatively high effort. This is the third suggestion which requires scheduling, but in the scheduling of this the mechanical engineering of production could get help from the production planning team. The impact on the production and the amount of information waste can be higher than it has been evaluated in figure 31, but the impact on the order-to-delivery process is not that high.

The development projects are divided into a broader area on the impact-effort matrix. The development projects are supporting projects that would backing and enable development in the value stream. The scope of these development projects needs to be studied further outside of the research scope of this research.

The current-state maps and the interviews indicate that the sales support is an isolated island in the value stream. The first development project would be the utilization of the competences of sales support in the full use of the order-based engineering. This development project is evaluated to have a relatively low effort and a relatively higher impact than the effort it requires.

The second development project is evaluated to have high impact and a relatively medium effort. The communication between purchasers/suppliers has a significant amount of alternative information flow. To end the spiral the quality of the information needs to improve.

The third and last development project is evaluated to have a low impact and high effort. This development project is related to the mechanical engineering of the production development suggestion. So that the mechanical engineering of the production can be deployed more studies around this issue must be done.

9 DISCUSSION

The purpose of this discussion chapter is to gather together all findings from the current-state maps, waste in of order-to-delivery process, future-state map and impact and effort review. In this chapter, the findings of this research are compared to literature findings and previous made research. This chapter will bring out the findings of the researcher and justifies the conclusions. Also, this chapter takes a stand to the validity and reliability of this research as well to the objectivity. The key findings are presented, and the novelty value and generalization opportunity for key findings are underlined.

9.1 Comparison and interfaces with previous research

In this research, similar problems and factors were found then previous studies have revealed from the order-to-delivery process of the case company. Change orders and their management have been the driving factor for many types of research that have been carried out for the case company. The impact of change orders to the order-based engineering and the entire supply chain is undeniable. Other researchers have also come to this conclusion when examining the case company's order-to-delivery process. It is known that change orders raise the amount of information that is related to projects. This observation can be made from both targets of research. Demanding customer projects can contain a tremendous amount of information. In some cases, the number of attachments may increase to as many as 100 items.

Positive observations were obtained from the VSM when it was used to map the value flows in the office environment. VSM not only describes the material and information streams in the process, but it also clarifies the interaction between the stakeholders. VSM gives a better holistic view of the process than traditional process diagrams. Between current-state and future-state maps can be seen similar development then maps the literature findings. Books *Complete Lean Enterprise* and *Creating Mixed Model Value Streams* have similar solutions than in this research. However, in this research, similar dynamics were not able to obtain to the flow, like was obtained as previously mentioned books. It is also noteworthy that the process of previous books did not include any change orders, or they were not taken into account as a similar factor like in this research.

Like the findings of this research has presented the value stream of the projects is very messy. That has raised in both targets of research. This is a common starting point for many VSM research although the information is the only input and output of the order-based engineering and other stakeholders of the administrative process. The amount of information related to the projects is relatively high, and the amount of change orders can increase to 28 pieces per project, and the amount of attachments can increase to 100 items per project. Information does not move linearly in the process. Although many times it is believed that information should be moving down-stream and up-stream in the process (Rother et al. 2003, p. 5; Keyte et al. 2004, p. 5). In both targets of research, the information is bouncing around the process and pile-up uncontrollably. Here, information refers to the produced and received information. Supporting studies of this research will also reinforce this attention. In the literature studies of this research, the similar case where the amount of information would have been raised as a factor of the value stream could not be found.

ETO-manufacturing and other manufacturing approaches are described as straightforward processes. Studies are available in the literature where the change orders are taking into account, and the effects of changes have been studied, but in the framework of this research, the researcher could not find literature works which take a stance on managing of the change orders. Based on literature findings the leading idea seems to be to get rid of the changes and in this way make manufacturing more efficient. This type of thinking is not suitable for the case company’s business approach. The more realistic idea is to change the focus point of the change orders then delete them. Shifting the focus point of the change orders upstream can be more attractive and more realistic option. Shifting the focus point at the downstream or the end of the order-to-delivery process should not be ruled out. The main focus of this research was not to discover the reason for the change orders but raises the importance of managing them. Interesting feature between the amount of change orders and the amount of order documents and attachments is that in both cases the variability is very high. High variation is not easy to manage. It is also important to note that the changes may expose the projects to errors.

Like Caron et al. (1995, p. 313–319) and many ETO-manufacturing examples after that are presented so that the information transfers linearly from one process to another and from start to end. On the basis of this research, this is not the situation in the case company. The information is bouncing between stakeholders and is refined in every turn, but it also disappears and is blurred. It is widely recognized that the engineering phase determines a large part of the total cost of the product and effects also the cost of manufacturing (Earl et al. 2000, p. 179-190; Ehrlenspiel et al. 2007, p. 12). This assumption could not be confirmed in the framework of this research. However, this research shows that the time spent on designing and change orders is significant.

In this research, previously presented master's theses *Two-phased Engineer-to-order Model as Competitive Advantage*, (Karppinen 2018,) introduce the customers country as one factor that makes projects challenging. In this research, the same kind result can be seen from the current state maps. The targets of research belong to a different region and apparent differences in the behavior of these projects can be observed.

Literature that deals with VSM are presenting that back and forth movement in the process and overlapping processes cause waste. The literature emphasizes the importance of improving flow. Based on this research similar conclusions can be made. It is noteworthy that that back and forth movement in the process and overlapping steps are difficult to detect from the process. This conclusion is supported by a finding of literature that states that the utilization of the VSM in the office and administrative processes require creativity (Keyte et al. 2004, p.1).

9.2 Objectivity

This research approaches the research problem and research questions from the point of view of the order-based engineering. That point of view may be different from the point of view of the other stakeholders, and it is evident that customer's point of view is far simpler than the point of view of the order-based engineering. Although, the order-based engineering or engineering, in general, is presented as just one part of the order-to-delivery process. Like the VSM of this research have presented the order-based engineering is present in every step of the order-to-delivery process and works in close co-operation with all the stakeholders.

In this research, the triangulation method is used to ensure that the results of the study are as objective as possible. Triangulation means that the results are obtained in several ways or several sources have been used (Bryman &. Bell 2015, p. 729). Sources of triangulation in this research are VSM, supporting studies, interviews of senior designers and project managers and the researcher's silent knowledge. In this way, the research tries to find the most objective approach to the research problem and questions.

9.3 Validity and reliability

This chapter will take a stand to the validity of this research and reliability of this research. The validity of VSM is evaluated. It is studied whether the VSM will also provide answers to the research questions and that way to the research problem. For this evaluation the same method which is often used to estimate risks in the work environment. The technique is based on BS 8800, and it has been customized to fit better to the research questions. In this evaluation, the result is that the VSM will partially respond to the research questions and the research problem. Based on this finding, research was expanded to include more supporting studies. These supporting studies can be used to support the VSM and to explain the findings at a deeper level.

As pointed out at the beginning of this research, VSM will not fully answer to the research problem and all research questions. For this reason, the study of this research is expanded with interviews and supporting studies. The results of the interviews have not been addressed in this work more widely, but the interviews are used as help when the supporting studies are selected, and the future-state map is formed. Supporting studies gave this research valuable information and helped to compare targets of research with the general practice in order-based engineering.

Based on literature findings the validity of VSM methods can be assumed to be in such detail that it can be used as main research tools in this research. Literature finds present that VSM can be used to improve flow in the order-to-delivery process. In books *Complete Lean Enterprise and Creating Mixed Model Value Streams* VSM has uses in the process which corresponding to the process of the case company. The literature findings show that the VSM can also be used for office and administrative processes. The use of the VSM is not a new practice for the case company. Previously VSM has been using for the manufacturing process steps this is the first time it is so wildly used for office and administrative processes in case company.

Reliability of this research is evaluated as follows. The major part of the results of this research is dependent on the performance of the case company. In more detail, they depend on the volume of sales. It can be assumed that the amount of change orders will increase if the number of orders increases. However, on the other hand, it can be assumed that the amount of change orders per project will not increase even if sales volume increases.

Measurements can be found to be very stable. The measurements are not exposed to a random error. Repeatability of measurements is good, and repetition is even desirable for the constant development. This way, after development, it can be ensured that the flow improved.

VSM can be assumed to be in such detail that on that base it can reliably come to conclusions about the current state of the order-to-delivery process of the demanding customer projects. Supporting studies can also be expected to tell a true view of the process. The distribution of measurement results is concentrated in a relatively clear area so that it will expose a large distribution. The measurement error does not alter the conclusions.

As has been said, the repeatability of measurements is excellent. Similar results can be obtained from the system even if the measurement period is changed. The most significant factor influencing measurement conversion is a natural need of the process to develop. Similar results available for a different period can be seen as a cause of concern for the process development.

9.4 Error and sensitivity analysis

We look first in the error analysis of the research. In measurements of this research, the source of the measurements is 1482 projects from the case company’s ERP-software. In this respect, the number of measurements can be considered reliable. The source of measurements is studied through five different measurements. Measurements and refinement of the results are mainly done manually, and calculation software is used only in the filtered data. Manual measurements may include a measurement error due to manual work, but the most doubtful outcome is double checked. The manual measurements and the resulting errors are not expected to affect the decision-making process.

The calculation of the error from the VSM is challenging. The current-state maps are based on observations and measurements. The future-state map is based on current-state maps, supporting studies and literature findings. Future-state map is based on facts but is not the only possible conclusion. Future-state map is the researcher's conclusion and therefore may have the most significant error.

Secondly, we will look at the sensitivity analyses of the research. This research involves two types of investigation, the first and main research method is VSM and the second are supporting studies. All projects in the case company are individual by nature, meaning that the process may have many different events. In such a situation, using only one current-state map can lead to wrong conclusions and can lead to an entirely different description of the future-state map. VSM is working better for a standardized process which includes actions which have standard lead and process time. As shown by the results of this research this is not the situation in the case company. These two factors are taken into account in this research, and it has come to the conclusion that two current-state maps could prevent this error from occurring.

The differences presented by the current-state maps are significant, so in that the light of that the error made by manual measuring is not so significant. In supporting studies, the difference of the results appears in such a large scale that a possible mistake will inevitably be part of the marginal. The problems are visible on the results, so it can be concluded that the effect of the error on the outcome is insignificant.

This research does not include creating actual models. The only results which can consider as models are current and future state maps which are used as the source for the conclusions. Conclusions are made based on the findings and insights of the researcher. Based on this, it can be concluded that the VSM and measurements created in support of the conclusions are reliable. It can be said that the research tries to look at the problem from many angles.

9.5 Key findings

About the key findings of the research, the following can be concluded. The information is the main product of the order-based engineering. It is on responsible for order-based engineering to find and refine the information into a form where it serves both internal and external customers. Although targets of research represent different ends of the spectrum, the conclusion is identical. Design of demanding customer project stars before the project is given to the production unit, but the information does not flow to the production unit in such a form that it can be directly used in order-based engineering. That means designing starts from the beginning in the order-based engineering and design made in the earlier phases is used as an example or reference. The flow of information is not linear from one process step to another. Information flows through several stakeholders and even bouncing between them before it gets its last form. Order-based engineering also distributes the information for many parties. Some of these parties are internal customers, and some are external customers. Communication and co-operation happen between several stakeholders, and this can be seen as a good thing.

According to the researcher's findings, the communication and co-operation eliminate functional silos from the process. On the other hand, a large number of communications can be a sign of the poor quality of communication, especially if communication takes place immediately after the completion of process steps. It is also possible that the official channels of communication are too rigid for interactive communication. In this case, however, communication should take place during the process steps, not after it. A large amount of communication takes place through informal communication routes. This type of communication is not available for everyone and may lead to errors and delays. This makes it an especially big challenge if designers and other stakeholders are changed during the project. Change orders and the emails sent simultaneously with them are overlapping information which, in the worst-case scenario, may be contradictory.

Current-state maps show that the projects are constantly evolving. One reason for this is the nature of the product, and the other factor is the evolving in the customers own projects. The result of that evolving is waste. The waste can be divided into two main categories, waste that flows into the order-based engineering and waste that flows out of the order-based engineering to the other stakeholders. Incoming waste is in the form of misinformation. The reason for that can be misunderstandings, assumptions or evolving of customers own projects. There is a connection between the wastes and large numbers of incoming information. That leads to a large number of outgoing information. This can be seen in both current-state maps and supporting studies of information flow. When that information flow is spread across the whole timeline of the project that creates waste which in the initial stage of the project only occurs in lost working hours and later stage of the project the material losses also come into the picture. The key finding is that the focus of information flow should be on the quality not in quantity. Communication and co-operation between order-based engineering and other stakeholders increase the amount of work and time spent on the project.

It turned out that the order document is not agile enough answering the challenges of demanding customer projects. It forces the customer's information into a standard format which does not serve demanding customer projects in the best possible way. Internal order document clarifies the holistic view of the project and would decrease the amount of stored information. In office and administrative process, the size of storages can grow relatively large because there is not the same kind of physical limitation which occurs in stock material and information stocks do not tie as much money as the material stocks do. The study shows that the amount of order document and attachments can vary between 4 and 100 items when the 7 items are the minimum what all project request. Massive storage is harder to manage, and a continuously growing number of documents make it messy.

Research shows that there is no clear endpoint for the design of the product. In both targets of research, changes have been made for the structure after the mechanical design step has finished. The main reason for this seems to be the customer's requirements, but the product structure has its share for the change orders. Current-state maps reveal that new information from the customer has been received throughout the manufacturing process. That is one factor which grows the number of messages sent from order-based engineering to other stakeholders, but this does not fully explain the large amount of information flow between purchasers/suppliers and order-based engineering. A large number of information flows between purchasers/suppliers and order-based engineering suggest that the content of the information that does not serve the purchasers/suppliers in the best possible way. That extra communication ties up lots of designer’s time. The time frame of information suggests that the designer must return to the previous project after the next project has already started. That leads to overlapping of projects. Overlapping is slowing down the progress of both projects and creates challenges to keep up in design schedule.

According to results of this research, change orders have a significant effect on workload, schedules, and need for human capacity of the order-based engineering. Change orders significantly increase the amount of project-related information. Studies show that changes are not uncommon. In difficulty class C 77% of projects have at least one customer change, and difficulty class D has at least one customer change on 82% of all studied projects. The used work hours for the changes are 100 hours per week, roughly speaking this means that 3 designers are mainly working with change orders every week. Based on the researcher's findings increased the amount of data can lead to chaos or loss of important information. One common characteristic of all change orders are that they increase the amount of informal communication between stakeholders. In light of current findings, this increase can be seen as a bad factor. The increased amount of information requires more processing time and information that has changed several times increases processing time even more, and this leads to a growing amount of waste. Based on the results of this research, it can be concluded that this applies to all stakeholders. Change orders also cause the material losses, and amount and probability of material losses will be increasing the later stage changes appear. The key finding of change orders is how to manage them, not how they can be prevented. The number of changes must be balanced. It cannot be said that the reason for waste is change orders. Change orders are the result of the massive amount of information, complex projects, unpredictable changes, and unmanaged stocks. Based on this research, the researcher believes that if the case company can invest to decrease the amount and is able to improve management of change orders and information it will be able to make improvements in managing demanding customer projects.

Based on the findings of this research, it is impossible to directly take a stand on whether the change orders increase the amount of errors. It can be only said that the increasing number of change orders and increasing amount of information increases the possibility of errors.

Mechanical engineering is according to this study the most time demanding process on the order-to-delivery process of case company. The design of the product is completed on mechanical engineering phase. A large percentage of the total design hours is used in the mechanical engineering phase, and a large percentage of the total purchase orders are produced in the mechanical engineering phase. The mechanical designer must manage all the information about the project. That would be easier if one mechanical designer does both the pre-engineering and the mechanical engineering, but if those steps are divided between two mechanical designers the information flow between designers needs to be efficient. For that problem, the internal order document comes with a solution. It is possible that both mechanical designers take part in creating the internal order document.

It is hard or even impossible to define the optimal amount of attachments based on this research. The amount of attachments depends on the nature of the project. Based on the research it can be stated that uncontrolled growth is challenging from the perspective of project management. It also brings challenges to the order-based engineering. Those challenges can be seen in the form of scheduling and workload. The scheduling and the workload can be challenging for the order-based engineering, but like this researcher present, order-based engineering is able to stretch and stay on schedule. However, the ultimate stretch process is not a viable condition for any process.

One of the key findings of this research is that the process contains uncontrolled stocks. The information gets stuck in these stocks between processes and stakeholders. The information is not processed in these stocks. The future-state map suggests that the amount of the stock is reduced. The implementation of the future-state map will demand according to the results of this research relatively high or high level of effort. However, on the other hand, according to this research, the achieved benefits are also high. The changes presented in this research are believed to have a big impact on the flow.

This research changing the steps of the order-to-delivery process in such way that the designing steps are divided over a more extended period in such a way that the actual designing work is done closer to the stage which needs the end come of order-based engineering. Meaning that the order-based engineering is trying to respond to the need of the customer (inner and external) closer to the moment when the customer needs it. For example, documentation for the production is produced just before the starting date of the production, so the changes in project scope do not require a re-design of the production BOM. It is believed that those actions will make the flow more peaceful. At the same time stocks in the process will be taken under tighter controls so that the movement of information does not stop uncontrolled. The number of designers participating in the demanding customer project is limited to two designers.

9.6 The novelty value of results

Previously the case company has identified the existence of demanding customer projects and sees it as a competitive advantage. Also, the effects of change orders to the process have been identified. The results of this research reinforce these ideas. This research has been able to prove that change orders have a significant impact on the workload and effectiveness to the order based engineering and demanding customer project request a large amount of the designer's attention at different stages of the order-to-delivery process. This research under the line that change orders are the primary element on the order-to-delivery process of the case company and their significance is undeniable.

The results also show that the number of change orders varies according to the degree of difficulty of the product. Difficulty class A has fewer change orders than the difficult classes C and D. Variation has been identified earlier, but this research gives new information about the variance and effect of the change orders.

One of the most significant findings of this research is determining and finding out the amount of information that goes through unofficial routes. This process is complicated, almost impossible for an external observer to detect. This research was made possible because the researcher was part of the process.

Noteworthy is that the success of challenging customer projects requires co-operation between the stakeholders, and the results of the research must not be interpreted as that co-operation should be reduced. It should be intensified, and preventive co-operation should be increased. The results show that with the careful preparation of the project scope good outcomes can achieve. In all cases, this is not possible or dependent of the case company.

9.7 Generalization and utilization of the results

Although the research focused on the progress of two products which have a very similar structure, the results can be generalized also to other products of the case company. The best benefits are obtained when the future-state map is used for demanding customer projects. The benefit of that the future-state map will bring the standard product is believed to be minor.

Research's results about the amount of communication and change orders can be used when evaluating the state of the running projects. The research does not set direct boundaries for these factors, but by comparing current projects with the results of this study, it can be seen if the amount of information or the amount of change orders gets out of control. Further studies can reveal suitable variation areas for these factors. It cannot be said that the reason for waste is change orders. Change orders are the result of the massive amount of information, complex projects, unpredictable changes, and unmanaged stocks. It is clear that the changes are a large part of the projects. Change orders are adding the amount of information on the project and use a significant part of work hours of order-based engineering. Future-state map comes around with the idea that focuses on the quality of information at the beginning of the project. Adding 24 hours in the time frame of the P0-meeting invitation the researcher believes that the dialogue about the project can be opened before P0-meeting and both parties have the opportunity for background research before the project is transferred to the local sales unit to the production unit.

It is safe to say in general terms that all processes involve informal communication. The results of the research cannot be directly generalized, but the result of the research shows that the amount of informal communication can be measured and determined. As well as the results of this research confirm that the changes are part of the ETO-manufacturing approach. The amount of changes is dependence from the product and delivery model.

9.8 Topics for future research

A subject for further research could be VSM for the design process. This research was reviewing values stream map on the factory level, so-called door-to-door VSM. In future research, the targeted could be a process level. This research could provide valuable insights into internal processes within the process of order-based engineering. Process level VSM research could also be extended to other stakeholders. If studies are desired to target challenging projects, these projects should be collected systematically from the more extended period.

Future state map points out three subjects for future studies. Those subject are exploring the competence of the sales support so it will come part of the value flow. The content of information which is produced for the purchasers and suppliers needs to study more so the information will be better served the need of those stakeholders. The last future study subject proposed that the parts of mechanical engineering can be left to a later stage of production. These future studies are necessary so that the future-state map can deliver the best possible result.

The problem of a massive amount of information has been made to respond in the future-state map. The future-state map proposes that after pre-engineering and before mechanical engineering a meeting is held. The purpose of that meeting is creating an internal order document. The relevant information is collected to internal order document, and irrelevant information is either deleted or archived. This internal order document works as a guideline for all further activities including customer changes. This internal order document should be created in co-operation with all stakeholders. The form of this internal order document is out of the scope of this research. The internal order document creates an excellent opportunity for future research. Internal order document is made by all the stakeholders of the order-to-delivery process. The order document is made by local sales unit. It is assumed that there is a difference between these documents. By studying differences in these documents, useful development knowledge can be gained.

The sources of change orders were not covered in this research. The reasons for the changes are significant for the future research topic. Understanding the nature of the change orders is essential for the case company.

9.9 Closing words

The results of this study may give such a picture about the operation of the order-based engineering department and the other stakeholders of the order-to-delivery process that the activities would not be controlled and professional, but this is not the intention or the truth. The purpose of this research is to highlight the factors that will make the activity even more effective. For order-based engineering and other stakeholders it is important that they create for themselves and for each other environment which gives everyone the opportunity to make an excellent performance. This research should not be seen as an opportunity to fix things, but as an opportunity to make massive innovation instead.

It is noteworthy that order-based engineering is like any other manufacturing method, and it is heavily dependent on the quality of the raw material. Quality of turner products are limited with the lathe accuracy and quality of raw material. Turning cannot improve the quality of the material. In the worst case, it can have a negative effect on the quality of the material. The same basic rules apply to the order-based engineering. As the quality of turned products are dependent on the quality of the raw material same way the quality of products of order-based engineering is dependent on the quality of information.

The mighty oxymoron is the reactive designing department or reactive supply chain, nevertheless. The action of the designing department and supply chain must be proactive. Actions of the whole supply chain need to be in a form where things have been done one at a time, all things have been done on time and everything only done once.

10 SUMMARY

This research is focused on the information flow through the order-based engineering. The main purpose of order-based engineering is to produce product related information to the other stakeholders in the order-to-delivery process of the case company. The order-based engineering modifies the product's structure based on the customer's information in a shape that matches the customer's wishes. The order-based engineering is a part of the case company’s organisation and the case company is a production unit of a multinational corporation. The case company’s products are individually customized electrical equipment. The products fulfill complex customer product entities, and the product needs to fulfill specific customer demands and the technical specification of the classification societies.

The case company is operating in a highly competitive market sector, where product requirements and performance levels are continually rising. The highly customized product competes with the level of customization and delivery time along with the price and the effectiveness of the product. The case company has been able to overcome challenging projects and wishes to utilize the best possible benefit out of those deals. Under high customization and a tight schedule, the simple products can become challenging, and the problems and the challenges can multiply. Unclear and constantly changing projects are creating challenges for staying on schedule. Changes in the structure of the product causes extra work and material losses. The projects can be dressed in the disguise of a difficult customer, but the root cause lies behind misunderstandings and communication errors. Order-based engineering has the crucial role in these projects and in designing of customer-specific product structures. The structure of the product includes information that is serving inner and external customers as well as subcontractors.

In this research, the order-to-delivery process of the case company was studied using VSM in a way that the order-based engineering is at the center of the research. A current-state map is a part of the VSM methods. Two different projects have been mapped in the framework of this research. The current-state maps are based on observations and measurements. Supporting studies are built around the value stream mapping to help research factors in the order-to-delivery process. To support these findings, stakeholders of the order-to-delivery process were interviewed. The interview groups were senior designers, project managers, and an engineering manager of another production unit. The interviews were made in separate groups. The created future-state map is based on the current-state maps, supporting studies and literature findings. The research scope is limited on a specific period in the order-to-delivery process, which starts after the customer order decoupling point and ends before the manufacturing starting point. However, in the case company’s order-to-delivery process, the order-based engineering plays a key role, and this expands the research area to cover almost the whole supply chain.

The main part of this research was to find answers to the research problem but also to the research questions. Based on the results of this research it can be said, that the most important factor in challenging projects is the customer. The customer specifies the features of the product and the timetable for the delivery. The manufacturer has an impact on the product's characteristics and on the timetable of designing and manufacturing. Change management and good quality of information is the responsibility of both the customer and the manufacturer.

Studies of this research indicate that the demanding customer projects are multidimensional projects, which include a tremendous amount of information. The research also points out that the order-based engineering handles a lot of that information and refine it not just to the use of customer, but also for other stakeholders as well. The demanding customer projects may include challenging and extensive customer specifications. The customer can set a tight schedule for the project, which forces the case company to tighten internal designing and manufacturing schedules. However, based on this research, only the change orders move the projects to the so-called demanding customer project group.

Based on this research, it is difficult to raise one factor over another that would be the main reason for the loss of efficiency and would waste the most time in demanding customer projects. Based on the current-state maps, the change orders are one significant individual factor that will waste time in the order-to-delivery process. The impact of the change orders on the order-based engineering department's weekly workload is significant and undeniable. As it has been said, the change orders are not the reason for the waste. The researcher believes that the change orders are in fact the result, not the reason.

Another important point is that the time for change orders is scheduled randomly and is not scheduled directly to a specific project. It is challenging to prepare for change orders, because the nature of them is not recognized well enough. Changes may be applied to any part of the structure. All parts of the structure can be modified according to the customer's requirements, and the whole design of the structure is completed in the mechanical engineering phase. That raises the impact of the changes. The future-state map suggests that a new engineering phase for change orders is added to the engineering schedule. That would be the counteraction to the fact that change orders comes to more than half of the projects. The future-state map also suggests that the electrical and pre-engineering are switched to change order free zones. The idea is to shift the flow of change orders to a more manageable form.

The answer to the main research question can be summarized as follow. The characteristics of the business segment and the nature of the product forces the project to a form that the projects include a lot of information and continuous development. This is reflected in the order-based engineering as a large number of change orders and attachments information. A large amount of information increases the workload of order-based engineering. Change orders during and after the engineering phase makes the transmission of information challenging. The stiffness of official information routes transfers parts of communication to the informal channels. Change order management and the information that has to be sent to the stakeholders about the order-to-delivery process increases the workload and adds extra work to the order-based-engineering. Another reason for the loss of efficiency and time is overlapping communication that passes through many stakeholders but will still eventually become fuzzy. Some of this communication takes place after the design phase and that leads to overlapping projects.

To answer the first secondary research question, following conclusions can be drawn. The presumption would be that the amount of communication and co-operation between order-based engineering and other stakeholders would have a reducing effect on the amount of the work and time which order-based engineering is using for each project. Based on the research it can be stated that the influence is the opposite. The communication and co-operation between order-based engineering and other stakeholders increase the amount of work and time spent on the project. According to this research, the factors that have a negative impact on the demanding customer projects are uncertainty, lack of straightforward behavior on the flow of the value, a massive amount of information, complex projects, unpredictable changes and unmanaged stocks. Based on the researcher's findings, these factors appear in the process as a large amount of information and communication. Especially information seems to be moving uncontrollably in the process. As another negative factor, the designers must solve the problems of several demanding customer projects at the same time. The number of communication platforms and programs can also be seen as a challenging factor. This can be seen to have a negative effect or so-called drag in the value flow process.

The second additional research question deals with waste that is generated by the challenges in the process. The waste and its generation have been thoroughly dealt with in this research. The findings of the research highlights the three largest producers of waste. The transportation of the information between stakeholders produces waste in the production and this also contains the searching of the information. Correction of the product structure is the result of the change orders and the changes in customer's project scope. Inventory of information is the result of the scale of customer projects, and that information has not been processed correctly. Based on the result of research, it has been concluded that the most significant amount of waste is a result of these factors.

The subject of the third secondary research question was discovering if the process steps of the order-based engineering can be modified in a way that the flow can be increased. The future-state map contains new design phases, which seek to respond better to project and production challenges. In the future state map, the mechanical engineering step is divided into two parts. The future-state map also takes into account the requirements of the change orders and the need of the production. It can be stated, that changing the steps of the mechanical engineering and focusing on the change order management, it is possible to influence the course of the projects. However, this research did not test the real effects of the future-state map. In this research usefulness of the future state map was evaluated using the impact-effort-matrix. The results show that it is possible to get great benefits with the changes that are suggested in the future-state map. However, the impact-effort-matrix also shows that the changes require a great deal of effort.

Controlled and guided flow is believed to have a reduced impact on the number of challenges in demanding customer projects. The idea is based on the fact that good flow reduces factors that creates challenges. Continuous flow is also expected to release designers more time because the number of overlapping projects is expected to decrease.

LIST OF REFERENCES

ABB Group Internal Documents (2012). Internal documentation

Berry, W.L., Jacobs, F.R., Vollmann, T.E. & Whybark, D.C. 2011. Manufacturing Planning and Control Systems for Supply Chain Management. 6th edition. New York: McGraw-Hill international edition. pp. 35, 37–38.

Bryman, A. &. Bell, E. 2015. Business research methods. Oxford University Press cop. 4th edition. p. 729

Caron, F. & Fiore, A. 1995. Engineer to order companies: how to integrate manufacturing and innovative processes. International journal of project management. Vol. 13. pp. 313-319.

Chiarini, A. 2013. Lean Organization: from the Tools of the Toyota Production System to Lean Office. Milan: Springer. pp. 33, 17-19, 144-145

Duggan, K.J. 2002. Creating Mixed Model Value Streams: Practical Lean Techniques for Building to Demand. New York: Productivity press. pp. 9, 3

Earl, C.F, Hicks, C. & McGovern, T., 2000. Supply chain management: A strategic issue in engineer to order manufacturing. International Journal of Production Economics, 65(2). pp. 179-190.

Ehrlenspiel, K., Hundal, M. S., Kiewert, A & Lindemann, U. 2007 Cost-Efficient Design. Berlin Heidelberg: Springer-Verlag. p. 12

Hummingbird, E.A. & Tersine, R.J. 1995. Lead-time reduction: the search for competitive advantage. International Journal of Operations & Production Management, 15(2). pp. 8-18.

Karppinen T. 2018. Two-phased Engineer-to-order Model as Competitive Advantage. Espoo: Aalto University, Industrial Engineering and Management. p. 63

Keyte, B. & Locher, D. 2004. The Complete Lean Enterprise. Value Stream Mapping for Administrative and Office processes. pp. 1, 3, 5, 15-17, 68-70

Kundu, S., McKay, A. & de Pennington, A. 2008. Selecting of decoupling points in supply chains using a knowledge-based approach. Journal of Engineering Manufacture. Vol. 222 nro 11. pp. 1529-1549

Lampel, J. & Mintzberg, H. 1996. Customizing customization. Sloan management review Vol. 38, nro. 1. pp. 21–30.

Little, D., Rollins, R., Peck, M. and Porter, J.K., 2000. Integrated planning and scheduling in the engineer-to-order sector. International Journal of Computer Integrated Manufacturing, 13(6). pp. 545-554.

McManus, H.L. 2005. Product Development Value Stream Mapping (PDVSM) Manual 1.0. Massachusetts. The Lean Aerospace Initiative. pp. 10, 24, 33, 49, 57-59, 71

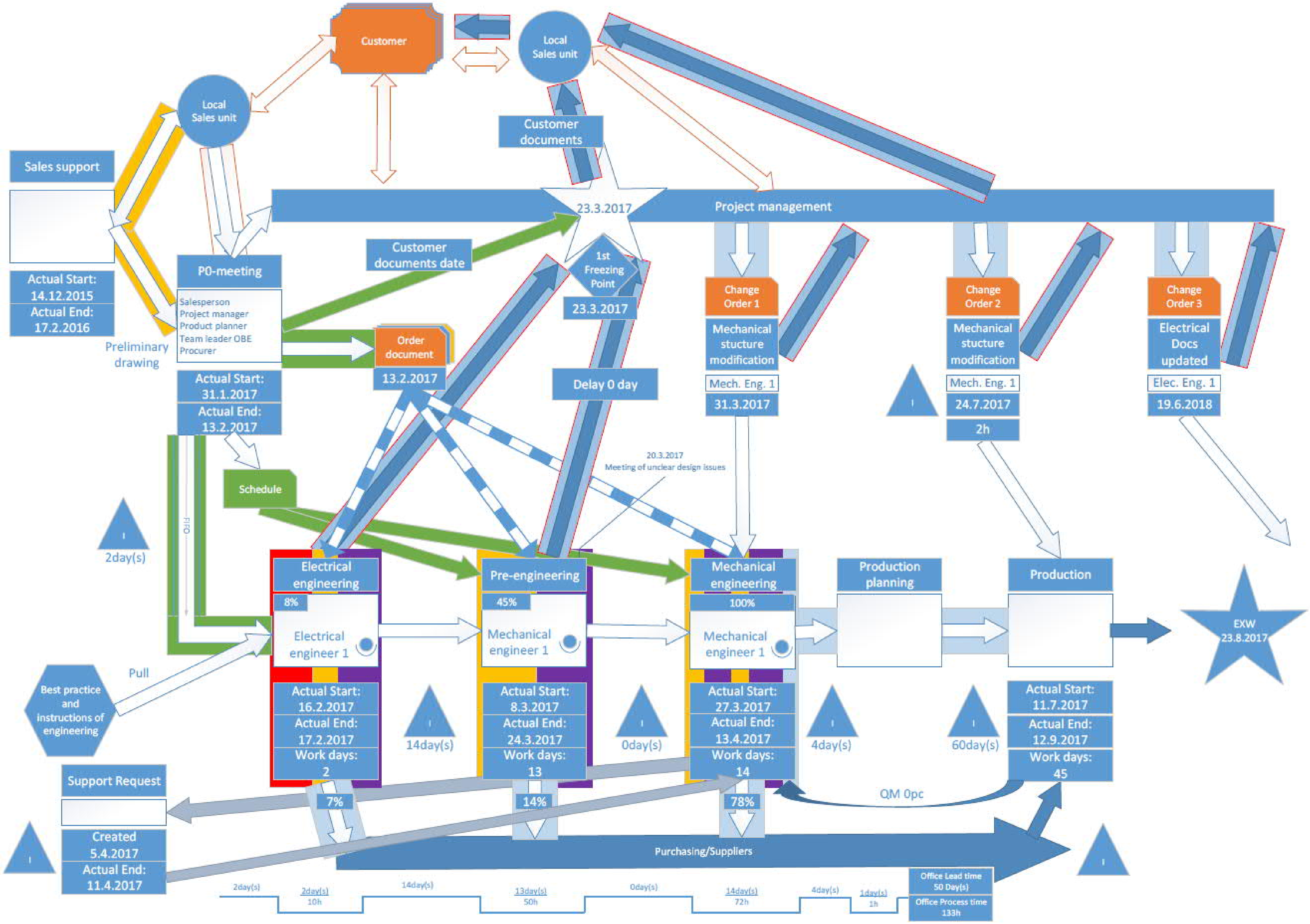
Olhager, J. 2010. The role of the customer order decoupling point in production and supply chain management. Computers in Industry. Vol. 61, nro. 9. pp. 863–868.

Rother, M. & Shook, J. 2003. Learning to see: value stream mapping to create value and eliminate muda. pp. 3, 5-6, 9, 72

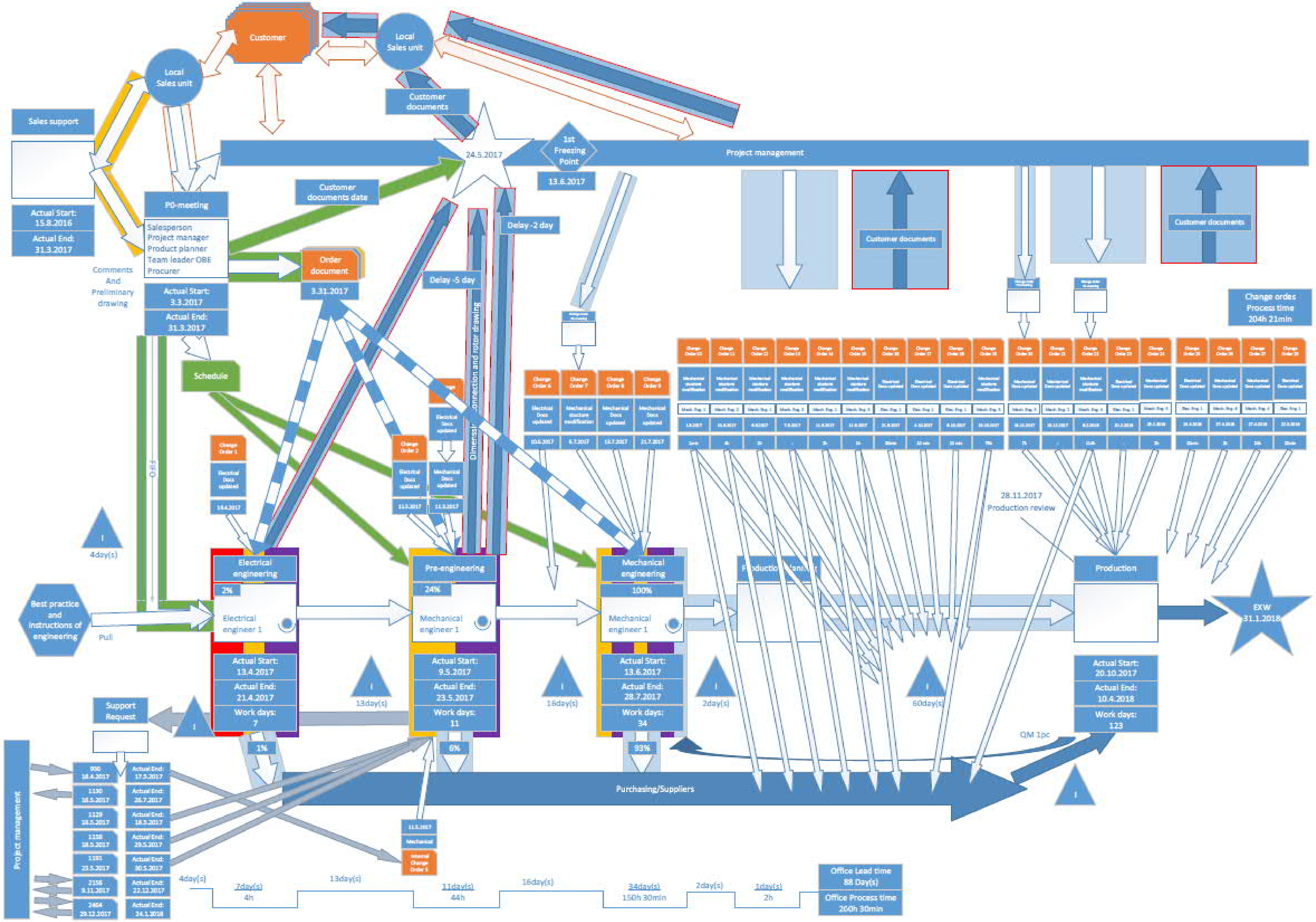
Steger-Jensen, K & Svensson, C. 2004. Issue of mass customisation and supporting IT-solutions. Computers in industry. Vol 54, nro 1. pp. 83-103

Yang, B. & Burns, N. 2003. Implications of postponement for the supply chain. International journal of production research. Vol. 41, no. 9. pp. 2075–2090

The current-state map of the 1st target of research.



The current-state map of the 2nd target of research.



Future-state map of demanding customer projects