Improving engineering processes using Lean Six Sigma

by

Ilir Sadriu
Jenny Larsson

Diploma work No. 194/2017
at Department of Materials and Manufacturing Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden

Diploma work in the Master programme Quality and Operations Management & Supply Chain Management

Performed at: Flexlink AB
Byfogdegatan 11, 415 05 Gothenburg

Supervisor(s): Svante Anderholm
Flexlink AB
Byfogdegatan 11, 415 05 Gothenburg

Examiner: Peter Hammersberg
Department of Materials and Manufacturing Technology
Chalmers University of Technology, SE - 412 96 Gothenburg

Improving engineering processes using Lean Six Sigma

Ilir Sadriu
Jenny Larsson

Diploma work 194/2017
Department of Materials and Manufacturing Technology
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Chalmers Reproservice
Gothenburg, Sweden 2017

Improving engineering processes using Lean Six Sigma

Ilir Sadriu
Jenny Larsson
Department of Materials and Manufacturing Technology
Chalmers University of Technology

This thesis project aims to improve operational engineering processes in the automation industry. The engineering operations at FlexLink are responsible for designing customized conveyor solutions according to customer specifications. FlexLink is expecting significant growth during the next five years and is in need of increased capacity. During the past they have experienced difficulties in growing without investing corresponding resources. In other words, they could only grow at a linear rate. Therefore, FlexLink desires to increase the productivity of their operations in order to achieve larger output with the same amount of input, thus allowing exponential growth.

Several improvement projects were initiated within the global Lean Six Sigma (LSS) program deployed at the company, with the purpose of facilitating the future growth plans. This thesis was one of the initiated LSS projects and had its focus on investigating smaller engineering projects where the outcome is a simple conveyor system design. In addition to the overall capacity and productivity problem, FlexLink had received indications that they are too expensive in the category of smaller conveyor systems and thus less competitive in this area. The company desired to reduce the amount of manual engineering work in the engineering projects as much as possible by automating process steps, as a means to become more competitive in delivering simple conveyor solutions.

The thesis project was performed according to the DMAIC framework known from Six Sigma, in combination with the corporate group guidelines for LSS projects. The process of small engineering projects was investigated in order to both identify waste in the process and explore the possibility of automating process steps. The result was identification of over 6000 engineering hours/year of waste in the process, as well as concrete improvement recommendations with 1.5 MSEK in annual savings by automating process steps into the already existing IT tools. Furthermore, a new productivity KPI was introduced in order to monitor and measure the performance of future improvement projects. The KPI was tested on historical data, which showed that FlexLink had indeed not been able to increase productivity during the past two years.

Keywords: Lean Six Sigma, process improvement, process automation, waste reduction

List of abbreviations

AE – Application Engineering.
BB – Black Belts.
BI – Business Intelligence.
BOM – Bill of Material.
C&E matrix - Cause and Effect Matrix.
CEDOC – software that assists the risk analysis.
CRM – Customer Relationship Management.
DMAIC – an acronym for Define, Measure, Analyze Improve and Control.
DW – Data Warehouse.
EOPL – Polish Operating Unit.
ERP – Enterprise Resource Planning.
ET – Engineering Tools.
FDR – Final Design Review.
FLDT – FlexLink Design Tool.
FLQT – FlexLink Quotation Tool.
FMEA – Failure Mode and Effect Analysis.
GB – Green Belts.
KPI – Key Performance Indicator.
LSS – Lean Six Sigma.
MBB – Master Black Belts.
PA – Project Administration.
PE – Project Engineering.
PLM – Product Lifecycle Management.
PM – Project Management.
P-map – Process map.
PSD – Product and Supply Division.
ROI – Return on Investment.
RPN – Risk Priority Number.
SAP – An ERP system.
SIPOC – Supplier, Input, Process, Output, Customer.
URS – User Requirement Specification.
VOC – Voice of the Customer.
VSM – Value Stream Map/Mapping.
Waste-FMEA – Waste - Failure Mode and Effect Analysis.
WIP – Work in Process.

Table of Contents

1 Introduction ... 1
1.1 Background ... 1
1.1.1 FlexLink and Coesia ... 1
1.1.2 Description of the problem ... 1
1.2 Aim ... 2
1.2.1 Purpose ... 2
1.2.2 Scope ... 2
1.2.3 Delimitations ... 3
2 Theory ... 5
2.1 Six Sigma ... 5
2.2 Lean Production ... 5
2.3 Lean Six Sigma ... 6
2.4 Lean in service operations ... 7
2.5 Six Sigma in Service processes ... 8
3 Methodology ... 11
3.1 Empirical research ... 11
3.1.1 Define ... 11
3.1.2 Measure ... 11
3.1.3 Analyze ... 11
3.1.4 Improve ... 12
3.1.5 Control ... 12
3.2 Literature study ... 12
3.3 Data collection ... 12
3.4 Action research ... 13
3.5 Three point estimation ... 13
4 Define ... 15
4.1 Company structure ... 15
4.1.1 Spaghetti chart of operations ... 16
4.2 Value Stream Map (VSM) ... 17
4.3 SIPOC and customer requirements ... 18
4.4 The European Machinery Directive ... 20
4.5 Engineering tools ... 21
4.5.1 FlexLink Quotation Tool ... 21
4.5.2 FlexLink Design Tool ... 21
4.5.3 FlexCAD ... 21
4.5.4 FlexLink Online Store ... 22
4.6 Expanding problem knowledge ... 22
4.7 LSS Culture at FlexLink and Coesia ... 23
5 Measure ... 25
5.1 Process map/flow chart ... 25
5.2 Baseline and financial model ... 27
5.3 Process cycle time estimation ... 28
6 Analyze ... 29
6.1 P-map ... 29
6.2 Cause and Effect matrix ... 29
6.3 W-FMEA ... 30
6.4 Factors in focus for improvements ... 32

6.4.1 Engineering time in the workshop 32
6.4.2 Rework of drawings 33
6.4.3 FLDT knowledge 33
6.4.4 Knowledge 34
6.4.5 Project documentation and assembly time calculation 34
6.4.6 Production binder 35
7 Improve 37
7.1 Brainstorming 37
7.2 Interviews 37
7.3 Business Intelligence system 37
7.4 Improvement recommendations 38
7.4.1 Automated spare part list 38
7.4.2 Automated assembly time calculation 39
7.4.3 Knowledge base for operating units 41
7.4.4 Engineering time in workshop 41
7.5 Discarded factors 42
7.6 Recommendations for future improvement projects 42
8 Control 43
8.1 Updated W-FMEA 43
8.2 Control plan 44
8.2.1 Monitoring usage 44
8.2.2 Reaction plan 44
8.3 Introducing a new productivity KPI 44
9 Results 47
10 Analysis 49
11 Conclusion 51
12 References 53
13 Appendix 55

1 Introduction

1.1 Background

1.1.1 FlexLink and Coesia

FlexLink is a global company that provides high-end manufacturing solutions to several different industries. The company has around 900 employees, units in 30 different countries and is part of the Coesia Group. The FlexLink headquarters is located in Gothenburg, Sweden and has 125 employees.

FlexLink is a factory automation expert with broad knowledge of improving production processes. The core business is delivering automated production flow solutions that enhance the performance of customer's factories by for example lower operating costs and making safer production systems. The customers can be found in several different industries such as life science, automotive, bearings, food industry, etc. The solutions are based on Lean principles, and give benefits such as reduced waste, increased throughput time and reduced stocks. This thesis had its focus on engineering operations that is responsible for designing the customized conveyor systems. The conveyor systems are the core of the automation services provided by the company. The main purpose of the conveyor system is to transport goods within customers' manufacturing facility. The systems are designed with modularized standard parts that are developed by FlexLink. These parts can be used in millions of different combinations in order to build a customized conveyor system. The conveyors come in several different product platforms. The platforms serve different needs and are different in size, material and functionality.

Coesia is a group of companies providing industrial and packaging solutions within several different areas. The headquarters is located in Bologna, Italy. FlexLink has been a part of the Coesia Group since 2012 and has since then adopted and matured within Lean Six Sigma (LSS) culture. Coesia has deployed LSS as a global improvement program to all subsidiaries, with the purpose of guiding all subsidiaries towards a continuous change and improvement cycle. There are several LSS improvement projects on both Black Belt and Green Belt level completed every year within Coesia. This master thesis was initiated as a part of the ongoing LSS program.

1.1.2 Description of the problem

When a customer orders a conveyor system, an internal engineering project is started within FlexLink. The central part of the engineering project is to design and assemble the conveyor system based on the customer needs. These projects can be of different sizes depending on the complexity of the conveyor system. Some projects are smaller and only require a few hours of engineering time to complete all the necessary steps, while the larger projects require several hundred hours of engineering time. FlexLink is expecting a significant growth during the next five years. In the past they have experienced a problem with growth; they could only grow at a linear rate by hiring more personnel, which requires investment in training. In order to succeed with the expected growth, FlexLink desires to increase the capacity to take on more projects without adding additional costs. This LSS project was therefore one of the initiatives to contribute to that goal.

Furthermore, FlexLink desired that this thesis should focus on the smaller engineering projects, since there were several other LLS projects that already covered larger projects. There are set methods and engineering tools (IT tools) that are used to carry out the projects, sometimes independent of the size of the project. These methods are developed for large projects in order to ensure quality and "fool-proof" the process. This is necessary for large projects but a bit redundant for the small projects. Smaller projects are more frequent and usually have higher profit margin, they are therefore important to FlexLink. However, FlexLink have received indication that they are too expensive in this area because the costs of running them are high. This makes FlexLink less competitive for smaller projects. Furthermore, FlexLink believed that the engineering tools used to design the conveyor systems are also of key importance to this LSS project since they have a direct impact on the performance of the process.

1.2 Aim

1.2.1 Purpose

FlexLink wish to increase capacity by reducing the required engineering time to complete projects that are considered to be simple. They also desire to become more competitive in this area. It was believed that too many engineering hours is required for these smaller projects, which results in a higher price for the customers. There was no previous investigation on why this was the case and there are only time reports for engineering time on a higher level, not for engineering subtasks. There were also no investigations on the capacity. Two thesis projects as well as internal LLS projects were initiated in order to investigate this issue. The projects were carried out by the LSS methodology applied at Coesia Group. Both thesis projects were run in parallel and supervised by a FlexLink Black Belt. There was frequent cooperation between the projects since they were closely related. This thesis had the aim to increase capacity by reducing the amount of engineering time required to complete a project, focusing on the smaller and simpler projects. Furthermore, FlexLink desired to investigate if the engineering process of small projects could be enhanced by integrating/automating process steps into the already existing engineering tools.

1.2.2 Scope

The scope of this project is to improve the engineering process, so that the same amount of work can be done in less time. The engineering process needs to be investigated in order to find out where time is spent. The engineering process also has a strong dependency on the engineering tools that are delivered from the software department. The performance of the engineering process is dependent on the performance and utilization of the engineering tools. Therefore, an important part of this thesis is to consider how the engineering tools are used and if process steps can be automated. The main focus are smaller projects with a revenue below 25 000€ and a high amount of FlexLink material. The following research questions will guide the work in this thesis:

- What factors affect the engineering time of small projects, with the above mentioned definition of small?
- How can the existing IT tools be used to automate process steps?

1.2.3 Delimitations

This report will only consider the engineering phase where the conveyor systems are designed, as well as the handovers before and after that have a direct impact on the engineering phase. During the initial planning of the project it was decided that the delivery of this thesis should only include improvement suggestions and not actual implementations, because of the short time frame of 20 weeks. European engineering projects with a revenue below 25 000€ and above 90% FlexLink material will be investigated. However, if any suggested improvement turn out to be easy to scale up to a global level or any “low hanging fruit” found that are easy to implement it will be done.

2 Theory

This chapter presents the theory that was relevant to the thesis project. Theory of Lean and Six Sigma is presented as it was the methodologies were important to the project. Since the investigated process could be defined as a service process, theory on Lean and Six Sigma in service operations is presented.

2.1 Six Sigma

One of the cornerstones of Quality Management is improving continuously. Due to the quality demands from customers, the development of technology and newly created business activities is it crucial for companies to improve the quality of goods and services continuously. The always existing possibility to improve the quality without using more resources is the basis for continuous improvement. Even the smallest steps can echo through an organization with better quality and lower costs. The hard part is to locate those steps. One methodology used to enable continuous improvement is Six Sigma. The methodology was developed by Motorola in 1987 and has since then gained increased popularity. (Bergman and Klefsjö, 2010)

According to Schroeder (2008), there are several different definitions of Six Sigma. One mutual aspect in all versions of the definition is that finding the root cause of problems is the essential part. By doing so, the symptoms of a problem are not mistaken for the real problem. The problem solving steps of Six Sigma is an expansion of the Plan - Do - Study – Act (PDCA) cycle. The expansion is commonly called the DMAIC cycle, where DMAIC is an acronym for Define, Measure, Analyze, Improve and Control. (Bergman and Klefsjö, 2010)
Six Sigma strives to reduce or mitigate the effect of the variation discovered in the product variables perceived as important by the customer. One criteria for Six Sigma projects to be successful is support and commitment from the top management, without that is it not easy for such projects to really make an impact in the organization. (Bañuelas, Antony and Brace, 2005; Bergman and Klefsjö, 2010)

Six Sigma defines quality characteristic y as a function of $x_1, x_2, \dots, x_n$, where the x's are the factors to control in order to gain the desired output of the characteristic. The factors can be classified either as controllable (C), noise (N) or standard operator procedure (SOP). The difference between C and N is that the noise factors cannot be controlled or is selected not to be controlled. The purpose with the Six Sigma methodology is to understand how to use the controllable factors to mitigate the influence of the non-controllable on the selected quality characteristic. They are also referred to as the critical X's of the process that have strong impact on the output Y (Bañuelas, Antony and Brace, 2005).

2.2 Lean Production

Lean production has its origin in Toyota and the Toyota Production System. The founder of the Toyota Production System was Kiichiro Toyoda, who combined inspiration from mass production as well as Japanese quality movements to create the today well known system. The Toyota system is based on the Just-in-Time principle, which strives to deliver the right quantity at the right time. The expression Lean Production was coined by Womack et al. (1990) in their book "*The Machine That Changed the World*" with inspiration from the Toyota way of working. Since then has many books and articles been written on the Toyota way and the Lean principles.

Slack, Chambers and Johnston (2010, p.433) defines Lean as "*to meet demand instantaneously with perfect quality and no waste*". This definition of Lean is based on three aspects: get everyone involved, striving to improve continuously and waste elimination. Waste elimination the most important aspect according to Slack, Chambers and Johnston (2010). Waste is defined as activities that do not add any value to the final product or service. Research show that only 5 percent of the throughput time in companies is spent on value-adding activities (Slack, Chambers and Johnston, 2010). Operations that are not value-adding are thus only adding unnecessary costs to the product or service and can be classified as waste. There are seven types of categories established by Toyota Production System:

- **Over-production** – The outcome from one process is higher than what the next process-step demands as input.
- **Waiting** – Waiting for the next process step.
- **Transport** – The movement of items due to inefficient layout, methods of transportation or organization of the workplace.
- **Over-processing** – Putting more effort than required.
- **Inventory** – Stored up raw material, work in progress or finished goods.
- **Motion** – Unnecessary movement of people.
- **Rework** – Doing the same operations several times, for example due to defects.

One important step to be able to eliminate activities that are considered waste is to distinguish between which activities are value-adding and which are not. This can be done by mapping the value stream of the process. The speed at which the activities flow through the value stream should match the pace of the customer's demand. When all operations are set so that they match the output of the process, which matches the customer demand, the pace is at takt time and there is a pull through the process. Pull is an important aspect of Lean, which means that the customer needs are in control of the production. (Bergman and Klefsjö, 2010)

2.3 Lean Six Sigma

LSS was first used by General Electric. Before that, there is no reported use of a combination of the methodologies. Research suggests that Lean and Six Sigma are in fact complementary to each other (Psychogios, Atanasovski and Tsironis, 2012). It is pointed out by de Koning *et al* (2006) that since Lean and Six Sigma complement each other should a combination turn out well. This is because Lean looks at the process on a more holistic level and Six Sigma provides a core to confirm or redefine, thereafter for solving problems and model for structuring up the organization. The first step of DMAIC is the most important for step changes and innovative development of the organization. Both Lean and Six Sigma support the principle of pull-thinking; start with the customer in mind. (de Koning *et al,* 2006).

Combining the main principles of Lean and Six Sigma gives great advantage to LSS. The main principles for Lean are process improvement based on what is considered value-adding while keeping the customer's requirements in focus when making decisions. The main Six Sigma principles is to understand variation that makes decisions to lower quality deviation based on statistical facts as well as having a training and education structure for the whole organization. (Psychogios, Atanasovski and Tsironis, 2012)

Continuous improvement can be achieved both by a Lean approach and Six Sigma approach. Lean is well-known for waste reduction while Six Sigma is known for reduction of variation. What the two approaches have in common is that both strive for continuous improvement, but using them separately at the same time has proved to be inefficient. In order to reach the best result when combining Lean and Six Sigma they need to be aligned. For example, Six Sigma is a great complement to enhance the changes made by Lean principles. Lean metrics, based on averages, tend to be more directly related to business performance. But the average level can be bad due to too much variation and the Lean toolbox do not address variation, which makes Six Sigma essential. (Pacheco et al., 2015; Assarlind, Gremyr and Bäckman, 2013)

Assarlind, Gremyr and Bäckman (2013) pointed out that Lean is effective at reducing non-value adding activities while Six Sigma has a focus on enhancing the value adding activities. The following quote from the Coesia LSS handbook sums up the view of Lean and Six Sigma within Coesia: "*Lean focus on issues that are a mile wide while Six Sigma focus on issues that are a mile deep*". It can be concluded that a combination of Lean and Six Sigma is supported by both practitioners and researchers.

2.4 Lean in service operations

Åhlström (2004) explored whether translated Lean principles can be implemented in a service context. Emphasis is put on the word translated here, since simply implementing lean production principles as they are for a service operation would not be possible. The lean principles considered in the research were waste elimination, zero defects, pull-orientation, multifunctional teams, decentralized responsibility, vertical information system and improve continuously. Four different organizations were used as cases where the translation was investigated. It was found that all principles could to some extent be implemented in all four cases. What differs from a traditional production context is that customers are in general involved to a higher degree in service operations. This leads to that the elimination of waste becomes subjective, what one considers waste may another think of as value-adding.

Furthermore, services are not possible to store which means that there is already pull rather than push throughout the operations. (Åhlström, 2004)

Using Lean principles in manufacturing is known to have a contribution to increase in productivity, performance and a decrease of waste. Research indicates that using Lean principles in office and administrative can lead to a better business performance and economic benefits. It has been found that continuous improvement in an office environment can be complicated and sometimes does not achieve the intended result. Common office operations such as quoting, accounting and scheduling are often 60 - 80 percent of the lead time of the process. If those operations are inefficient will the overall performance be poor, independent of the quality of the product or service. Finding inefficient processes in an office context have proved to be trickier than in manufacturing, since they are more difficult to define. The process flow in service operations is invisible and the ownership of processes can often be unknown. Furthermore, the process flow is often not measured and there is a high risk of mismatch with the customer needs. (The new improvement frontier, 2005)

2.5 Six Sigma in Service processes

Six Sigma is a well-established business strategy in many organizations in the manufacturing industry. It is also implemented for service operations, although the implementation is not as widely spread in the sector. Companies in the services sector have much to gain when implementing Six Sigma. According to Antony (2006), reported benefits are:

- Lower variability in service performance
- Customer needs are better understood
- Shifting from guessing to relying on data bring more effective decisions by the management
- The internal operations are more efficient and trustworthy
- Tools and methods for solving problems are better understood throughout the company
- Operations that are non-value adding are decreased
- Shift in the culture in the organization from reactive to proactive
- The teamwork across functions are improved in the whole company

In order to make quality improvements in a service operation, it is important to quantify the variation. This is not as easy as in manufacturing processes since service operations are more intangible, that is, people are part of the processes in a larger extent and by that a larger source of variation. Another difficulty with using Six Sigma in a service context is the trouble of knowing how to define a defect as well as to predict the severity of a defect (Antony, 2006). Several research papers argue that one of the most common challenges with Six Sigma in service operations is the difficulty of gathering quality data (Antony et al., 2007; Hensley and Dobie, 2005; Neves and Nakhai, 2011). Another challenge mentioned by Neves and Nakhai (2011) is that data in service operations lack reliability since it is often collected by verbal communication. Antony et al. (2007) mentioned that measuring customer satisfaction is more difficult and that willingness to change is lower than in a manufacturing context as additional challenges.

3 Methodology

This project was executed according the DMAIC cycle. Since the project was a part of the LSS program at FlexLink, it followed the internal guidelines for DMAIC projects developed by Coesia. The practical work was to a large extent guided by the Coesia LSS handbook as well as the Coesia Master Black Belt. The data for the project was mostly collected through interviews. There were 40 interviews conducted in total with project engineers, application engineers, project managers, software developers, administrators, business controllers, operators, middle managers and upper managers.

3.1 Empirical research

This report has been carried out based on the DMAIC methodology. The empirical part is divided into those five phases, thus are this chapter divided into five representative parts. In each phase was appropriate tools used, and during all phases were also qualitative data collected with interviews, structured and visualized.

3.1.1 Define

The first step was to investigate and gain knowledge on what needs to be improved and for whom. A Value Stream Map (VSM) was created to show information flows and material flows in the process steps that are in the scope. Furthermore was a SIPOC, high level mapping over supplier, input, process, outcome and customer, made. This is done when the supplier, input and process is known, and the result is the findings of the selected characteristic of the output and customer requirements.

3.1.2 Measure

A flow chart was done to understand the process on a detailed level. The ultimate goal of the Measure phase was to quantify the cycle times of the engineering process as it is today, that is the baseline. Due to lack of data and large variation in the project time, the cycle times was estimated by using three point estimation.

3.1.3 Analyze

A more thorough process map (P-map) was done, listing all inputs and outputs to each process step, respectively. The P-map is the first tool in the Six Sigma flow of qualitative tools to map potential variation sources. The next tool used was a Cause and Effect Matrix, the process inputs found earlier was analyzed against the seven wastes of Lean (Slack, Chambers and Johnston, 2010). The reason for doing this was to qualitatively filter the gross list of x relative the variation in the output characteristic of interest. Finally was a Failure Mode and Effect Analysis (FMEA) used to identify where waste reduction can be made in the process. The waste analysis conducted in the Analyze phase pointed out wasteful activities in the process. The waste was then quantified by using estimations, such as three point estimation, as well as by the gathered quantitative data, such as project and quotation data.

3.1.4 Improve

Brainstorming sessions were held with selected employees and ideas for improvement were generated. Meetings were then held with cross functional teams in order to improve the ideas, verify that they were possible to execute and start the handover process of the project to the involved stakeholders. Focus was put on defining the costs, saving potentials, benefits and Return on Investment (ROI) for the ideas. The quantification of waste from the Analyze phase was used as a basis for the calculations of saving potentials while the cost of the ideas were estimated during interviews with employees from the software development department.

3.1.5 Control

A control plan was made in order to enable for Flexlink to monitor the usage of the improvement recommendations. The control plan also included information on how to know when performance is dropping and what counteractions to take in case this happens. A new productivity KPI was also introduced, the relationship sales/hour, which aims to track trends and connect trends with future improvements.

3.2 Literature study

A literature study was done in order to gather relevant theory to the project. This was done both before and during the improvement project. Since the Six Sigma organization in Coesia is based on Lean Six Sigma, it was relevant to study theory on both Lean and Six Sigma as well as the combination of the two practices. Furthermore, since the investigated process in this thesis could be defined as a service process, it was relevant to gather information on the benefits and challenges with Lean and Six Sigma in service operations.

3.3 Data collection

The qualitative data in this thesis has been collected in two ways: through observations and interviews. Interviews was the most frequent and important way of data collection. "Gemba" walks were also done in the process. Gemba comes from the Japanese Genchi Genbutsu which means to be at the actual place and observe in order to gain understanding of the process (Liker, 2004).

Qualitative interviews are used to gather qualitative data, such interviews can either be unstructured or semi-structured (Bryman and Bell, 2003). Doing qualitative interview is not as structured as quantitative interviews, when the set of questions to be asked is very clear (Bryman and Bell, 2003). Instead, in qualitative interviews, is it more interesting what the interview object thinks, talking besides the topic is encouraged because it views what that person perceives as important (Bryman and Bell, 2003). When doing a semi-structured interview has the researchers prepared questions on the topic that is desired to be covered in the interview. This list of questions is not the schedule for the interview though, since new questions may be asked based on the interviewee's previous answer. The interviews in this thesis have been of semi-structured character in order to find out what the interviewee sees as important. The stakeholders that have been interviewed have been selected through snowball sampling, which means that next interview is based on the findings of the current interview. Quantitative data of relevance has also been collected, such as financial data and project data (hours spent in project, amount of projects per year, etc.). This data was the basis for calculations done in the analyze phase.

3.4 Action research

Bryman and Bell (2003) states that action research can be defined broadly as when the researchers work together with another stakeholder from the organization both to solve a problem and to find a solution to that problem. Action research aims to give continuous learning to both contributors in the problem solving. The problems in question are real that an organization has and doing action research generates both academic theory and actions for the organization to make (Bryman and Bell, 2003). This master thesis has been carried out as an action research. The current situation at FlexLink has been mapped, by the help of relevant theory and key stakeholders in the organization have problems been defined. Finally has appropriate improvement suggestions been made. The suggestions were up for discussion with selected stakeholders and were then either discarded or subject for development. The state of the company was thus changed during the thesis, meaning that repeating the exact same research would not generate the same result.

3.5 Three point estimation

Three point estimation is a tool that can be used to make the first estimations and predictions, when there is no reliable data available. Hammersberg (n.d.) states that three point estimation can be used when there is variability in the data and it is desired to estimate the mean and variation. This method includes three variables: a,b and m. Variable a is the most optimistic value that can happen. For example the most optimistic case with an occurrence rate of 1/1000. Variable b is the most pessimistic value, with the same occurrence as variable a. Variable m is the most likely value to occur. The expected value is then given by the formula:

$$e = \frac{a + 4m + b}{6}$$

The reason for using this estimation is that the expected value e will be bigger than the most likely value m. That is because the most likely value is not in the mean of the optimistic and pessimistic variables. (Kerzner, 1998)

Three point estimation was used frequently throughout the project as a method to estimate a rough distribution of the data when real data is not possible to collect. The variables a, b and m were filled in for each process step. The values were determined together with the project engineers. The calculations gave the estimated cycle time for each process step as well as an estimation for the average project lead time.

4 Define

The aim of the Define phase was to understand the organization and the high-level process, its suppliers, customers and customer requirements as well as getting a broader view of the problem. This was done by a combination of using LSS tools and gathering of qualitative data through interviews, observations and Gemba walks. The focus during the conducted interviews and observations in the Define phase was to gather the customer requirements and identify problematic activities in the engineering projects.

4.1 Company structure

FlexLink is divided into several different subsidiaries. The subsidiaries that were of interest to this thesis were the operating units and PSD (Product & Supply Division). The operating units are the subsidiaries where all the operational work takes place. This is where engineering projects are sold, designed and assembled. The operating units are strategically located in several different countries in order to have close contact with the local market. PSD is the developer, producer and supplier of all FlexLink material and is where new product platforms are developed. PSD also have units in different countries, however not as many as the operating units.

Figure 1 shows the overall functions of an operating unit. The process starts with sales and User Requirement Specification (URS) which are the customer needs translated into specification. The URS information is then passed to Application Engineering (AE). A concept of the conveyor system is developed by the application engineers based on the URS. If the order is won, an internal engineering project is started and the concept proceeds to Project Engineering (PE) where the entire conveyor system is designed in detail. Assembly drawings are delivered from the engineering phase to the assembly phase, so that the conveyor system can be assembled. The final step is installation at customer site, which is an option for the customer. There is also a Project Management (PM) phase which runs in parallel with the other phases.

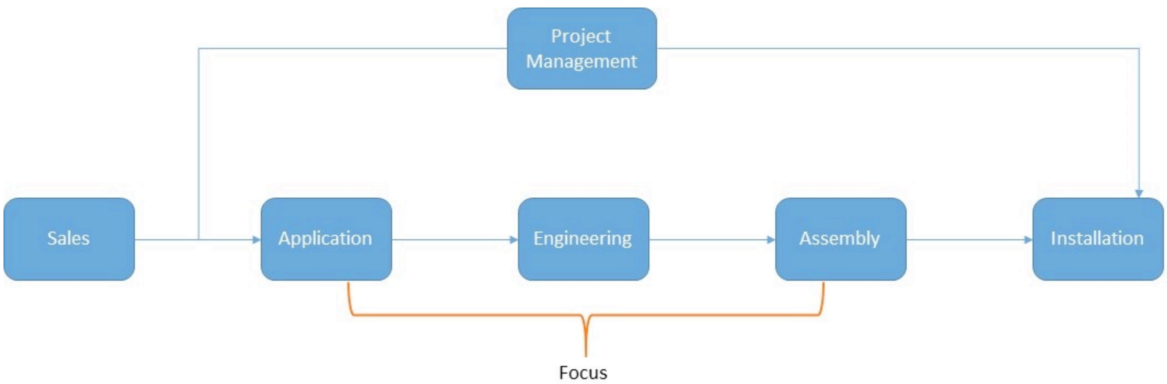

Figure 1

4.1.1 Spaghetti chart of operations

Figure 2 (Gerremo, 2017) shows a spaghetti chart of the central part of FlexLink's European operations. The English, German, Polish and Nordic subsidiaries were the most important to this thesis and are shown in the figure. The Polish subsidiary is divided into PSD and Polish operating unit (EOPL). This subsidiary is very important for strategic reasons. All FlexLink components (in Europe) that are used to build conveyor systems are manufactured at and distributed through the PSD warehouse in Poland. The engineering projects in operating units get supplied with material from the PSD warehouse, except for external material which is supplied from external suppliers. The FlexLink parts are ordered from the responsible project engineer and delivered directly to the local assembly site. The location of the PSD warehouse (Poznan, Poland) is good from a logistic point of view, since it enables smooth distribution all over Europe. EOPL is the largest operating unit in FlexLink with the largest engineering and assembly workforce and thus also the largest capacity to take projects.

The goal for operating units is to have as high utilization in engineering projects as possible. If there is no time to take on another project, the project can be engineered and assembled in EOPL but sold and delivered to the operating unit's origin country. Projects can also be engineered and/or assembled in EOPL solely for strategic or financial reasons, since engineering and assembly hours cost less in Poland compared to most other European countries. To summarize, the engineering projects that are in the scope for this thesis can be completed in three different ways. They can be:

- Designed at an operating unit, for example in Nordic (Gothenburg) and then assembled in EOPL. These projects are referred to as production projects by EOPL. The handover from the operating unit to EOPL includes finished assembly drawings in this case.
- Designed and assembled at the same operating unit.
- Designed and assembled in EOPL, but sold and concept designed in an operating unit from another country. The handover to EOPL includes concept drawings this case.

The German unit has the strongest collaboration with EOPL. The majority of the foreign production projects in EOPL are German projects. The reason is the short transportation distances between the two countries which enable fast and low cost transportation as well as lower communication barriers. Some units, such as the English operating unit had projects in EOPL on very few occasions.

During the Define phase it was found that the units have overall different ways of working, on both a detailed level, such as how drawings are formatted, but also on a higher level, such as work organization. The English unit has for example no project managers due to their smaller size. The project engineers act as project managers in all their projects. This is only the case for the smallest projects in the other described units.

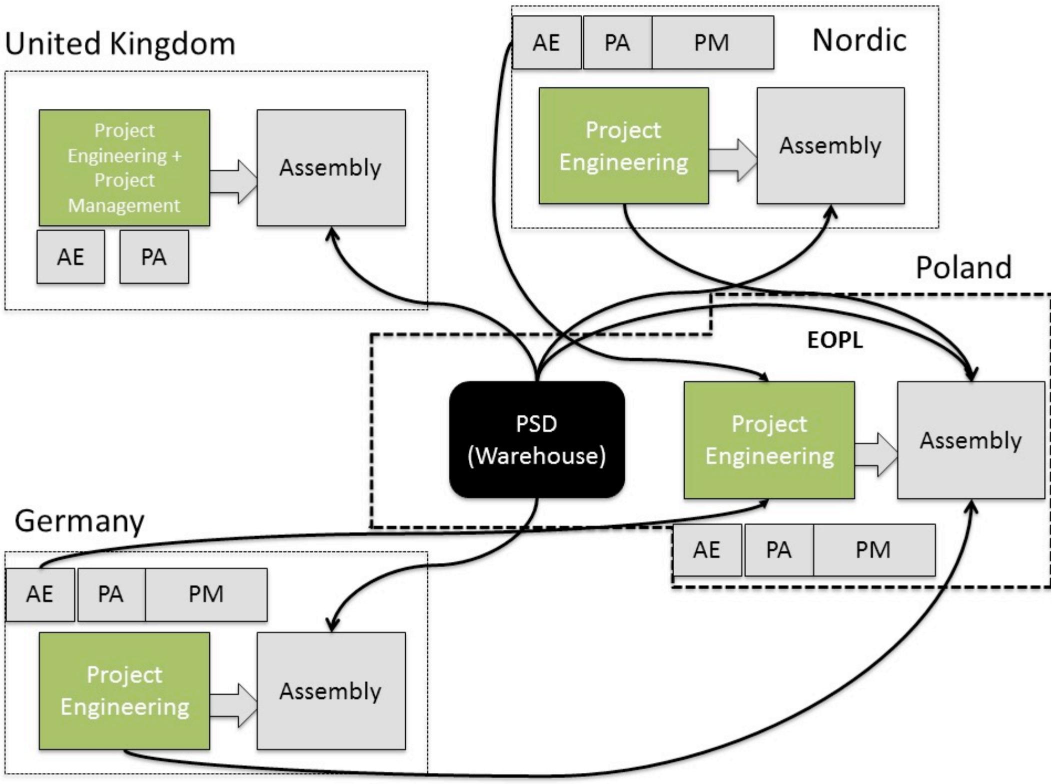

Figure 2

4.2 Value Stream Map (VSM)

A VSM was made to visualize the flow of information and physical material as well as the customer interaction throughout the project steps. The thick arrows represent the flow of physical material while the thinner arrows represent the information flow. The overall process is the same as for figure 3 but also includes the interaction with the customer and the PSD warehouse.

The value stream starts with a request for quotation by the customer, which is responded with a quotation by the application engineers in the operating unit. If the customer accepts the quotation an order for the quoted conveyor system is placed. An engineering project is then opened in the ERP system by the project administrator and an order confirmation is sent to the customer. The conveyor system is designed by a project engineer. A final approval for the conveyor system is needed from the customer before the conveyor system is assembled. The project engineer sends a request for FDR (Final Design Review) to the customer together with the drawings of the conveyor system. When the engineer receives the FDR approval, the conveyor system is ready for assembly. Material is delivered from the PSD warehouse in Poland to the assembly site of the operating unit. The finished conveyor system is tested and then disassembled into larger modules in order to simplify the transportation. The modules are then packaged and shipped to the customer. The project engineer is also responsible for making the relevant project documentation of the conveyor system, such as spare part lists and operating manuals that are sent to the customer together with the conveyor system.

At this stage it was realized that the cycle times in the VSM would be hard to measure, since every project is unique and there is a large variation in the cycle times between projects for this reason. Furthermore, it was found that there could be several days of waiting time for getting the FDR approval by the customer. This can be annoying for the project engineers since they have to switch over to other projects meanwhile waiting.

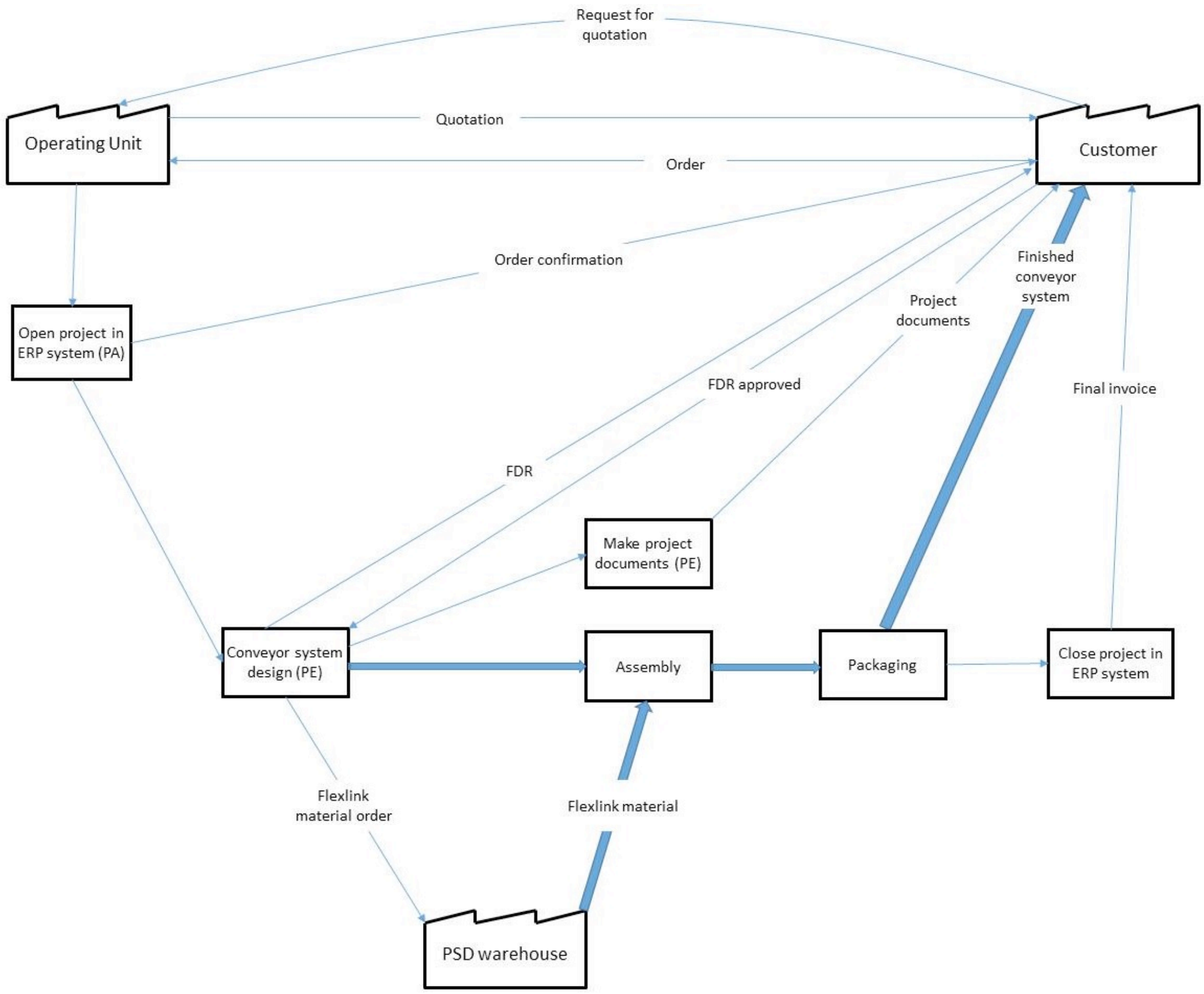

Figure 3

4.3 SIPOC and customer requirements

A SIPOC (Figure 4) was made in order to get an overview of the suppliers and customers to the investigated process. The process used in the SIPOC is the same as previously described, but the focus is from when the URS is delivered to the application engineer and ends when the project engineer have delivered the assembly drawings and Bill of Material (BOM) list to the workshop as well as the project documentation to the end customer. Another output from this process is the actual engineering hours spent in the project.

There were three identified customers for this process; the first customer is the engineers that work with the process. Their requirement on the process output is to complete the engineering projects with as few hours as possible.

The second customer is the operators working in the workshops. The requirements on the process output from the operators are:

- Correct drawings with sufficient detail level.
- Sufficient measurements in the drawings.
- Numbered “balloons” in the drawings for connecting each component in the drawing with the corresponding part in the BOM list (For example a beam with number 15 in the BOM list should have the same number in the drawing, pointed to its position).

The third customer for this process is the end customer that receives project documentation along with the physical product. This documentation consists of a spare part list, operating manuals and a Declaration of Incorporation. The latter is a requirement from the European Machinery Directive (discussed in section 4.4 below), which also puts some requirements on the project documentation. The requirements from the end customer and Machinery Directive on the process output are:

- Correct spare part list with prices for all parts.
- Relevant operating manuals for the delivered conveyor system.
- A Declaration of Incorporation should not be delivered without conducting a risk analysis of the conveyor system (Machinery Directive).
- Operating manuals must be in the language used by the end customer (Machinery Directive).

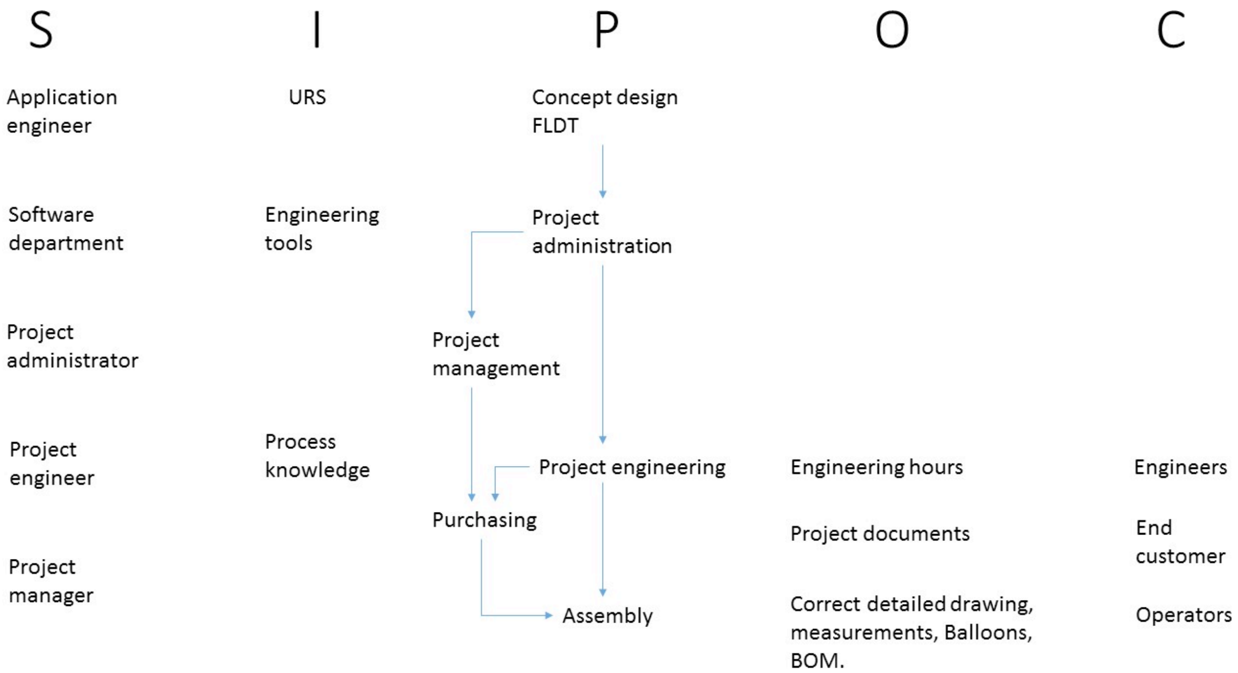

Figure 4

4.4 The European Machinery Directive

The Machinery Directive is legislation within EU that applies to all products that fall into EUs definition of machinery:

"Machinery consists of an assembly of components, at least one of which moves, joined together for a specific application. The drive system of machinery is powered by energy other than human or animal effort." (Machinery - Growth - European Commission, 2017)

The purpose of this legislation is to ensure safety for workers. All machinery sold within EU must be CE marked. A CE marked product guarantees that the producer has followed the basic requirements on health and safety provided by the legislation. It means that the provider of the machinery is responsible if any physical harm occurs because of the machine. In the case of FlexLink, the machines are often supplied as sub-assemblies of a bigger system of machinery. In this case, FlexLink cannot CE mark the whole system but has to use the Declaration of Incorporation that ensures the delivered sub-assembly (called partly completed machinery) of the bigger system is safe. In order to ensure that the delivered machinery is safe, a risk analysis of the machinery has to be conducted. All identified risks should preferably be eliminated, by for example using covers. If the risks cannot be eliminated they should be highlighted as remaining risks. A risk analysis is only kept by the machinery provider and it protects the provider if any accident with physical harm occurs. Skipping the risk analysis can turn out to be very costly for the provider. As described in section 4.3, the Machinery Directive puts some extra requirements on the project documentation delivered to the end customer. (Declaration of Incorporation - Work equipment and machinery, n.d.)

4.5 Engineering tools

There are different engineering tools that are inputs to the investigated process. These can be grouped into: Design tools, Quotation tools, CAD tools, Online tools and Calculation tools. The engineering tools were a central part of this thesis project, since the efficiency of the engineering process is highly dependent on the performance and utilization of the engineering tools. These tools have been developed over a longer time period and were initially simple support tools. They have now evolved to include more advanced functionality to simplify the engineering process. The engineering tools are developed and maintained by the software development department that is located within the FlexLink headquarters in Gothenburg, Sweden. The tools that are important inputs to the process were identified during Gemba walks and interviews and are described below.

4.5.1 FlexLink Quotation Tool

FlexLink Quotation Tool (FLQT) is used to make project calculations and create quotations. FLQT is mostly used by application engineers but also by project managers and project engineers to keep track of project data such as budgeted hours, actual hours spent, project margin, etc.

4.5.2 FlexLink Design Tool

FlexLink Design Tool (FLDT) is used to design conveyor systems containing only FlexLink material by a simple drag and drop functionality. FLDT is mostly used by application engineers when making concept layouts and project engineers for simple projects. It cannot handle design of external parts since it is not a CAD program, but is much faster when designing concepts or conveyor systems with only FlexLink material. It features logic and design rules which prevents from designing inaccurate conveyor systems. Furthermore, it also keeps track of each and every part that is a part of the whole assembly and it can automatically generate accurate BOM lists. It is possible to design entire systems and make assembly drawings by only using FLDT for simple projects that only contain FlexLink material, thus shortening the project engineering time by a significant amount compared to only using CAD. It is therefore a goal for FlexLink to utilize FLDT as much as possible, CAD should only be used when necessary.

4.5.3 FlexCAD

FlexCAD is a CAD library that is used as a plugin for Inventor and AutoCAD. FlexCAD provides standard parts and modules that can be imported into the 3D model, so the modularized standard parts in the FlexLink product catalogue do not have to be designed from scratch every time. It also features logic which can automatically calculate and assist the user with relevant information. FlexCAD keeps track of the parts used and can thus also generate accurate BOM lists. FlexCAD is the most frequently used CAD library in the company.

4.5.4 FlexLink Online Store

FlexLink Online Store is used to order FlexLink material. It is mostly used by project engineers who was responsible for the drawings but can also be used directly by end customers. Customers may have different prices for components based on their importance to FlexLink. There is a connection between the Online Store and FLDT/FlexCAD, meaning that a BOM list can be exported directly to the Online Store from the 3D model. The European orders in the online store are processed from the PSD warehouse in Poland.

4.6 Expanding problem knowledge

At this point in the Define phase, the researchers had gotten enough information about the structure of the company and the process by the different LSS tools that were used. Since the aim was to reduce the engineering hours, the researchers had to expand the knowledge about the actual problem. This was done by interviews, observations and Gemba walks, while the LSS tools helped to identify the customer requirements. The Nordic operating unit was the main focus, but trips were made to the Polish and English units to conduct the same interviews and observations. The German unit was also considered, but interviews were held during conference sessions in Gothenburg and Poznan. At this stage, the interviews focused on areas that negatively affect the engineering time and other areas that are perceived as problematic by the engineers, operators and engineering managers.

One area that got attention was that rework sometimes occurs when engineering projects are put in EOPL for assembly. In some cases, the drawings received by EOPL do not meet their quality standard and are deemed to be lacking important information. In this case, the detailed conveyor design is made from the beginning by engineers at EOPL, meaning that the same work is done twice. The operating unit that sent the drawings are then often invoiced for the extra hours. The engineering manager at the Nordic operating unit stated that there are communication barriers between them and EOPL. There are for example internal procurements between the units when projects are handed over and they sometimes have to argue over the budgeted hours.

Another problem is that EOPL and the German operating unit use another CAD library, which is not compatible with FlexCAD. Since most other operating units use FlexCAD, CAD files sent between EOPL and other units cannot be edited. The engineers at the Nordic unit pointed out that there is a lack of work standard and guidelines. Engineers would for example save project files in different ways and at different locations, which makes it harder for another engineer to go back to that project later. Furthermore, it was found that an overall issue within the organization is that all operating units have developed their own processes and their own tools to aid the processes, and that there is a mindset sometimes to prioritize the benefit of the local unit to the expense of the whole organization.

Most of the engineers perceived the work of making the project documentation as tiresome and repetitive. This was also one of the reasons for saving them for last. The same information has to be put in several different times to the different documents. Furthermore, every unit has developed their own way of making the project documents. Some use different software or self-developed excel tools for different steps.

Interviews with higher managers revealed that the issue that every unit has developed their own processes has caused problems for the company in the past. FlexLink is a flexible organization where people from different units can rotate between units and go for shorter jobs to a unit that is heavily loaded. However, they have experienced long learning periods when personnel have shifted between the units because of that they work so differently.

4.7 LSS Culture at FlexLink and Coesia

Coesia has deployed LSS as a global improvement program to all subsidiaries. The purpose of LSS at Coesia is to guide its subsidiaries towards a continuous change and improvement cycle. The LSS culture is well established within the company and there are a substantial amount of improvement projects on both Green and Black Belt level carried out each year. Coesia employs two Master Black Belts (MBB), 19 Black Belts (BB) and 149 Green Belts (GB) in total within all the subsidiaries. Coesia also runs an internal Six Sigma education program, where employees have the possibility to attend GB and BB training within the company. The education is based within the headquarters in Bologna, Italy, where employees all over the world travel to participate in the education. Coesia has developed processes for conducting Six Sigma projects, as well as their own pocket handbook with helpful tips and tools. Black Belts within Coesia are devoted to improvement projects on full time, while Green Belts spend around 30% of their time in improvement projects. The Six Sigma organization within the company is a parallel meso-structure, as described by Schroeder et al. (2007). The following quote from Schroeder et al. (2007, p.5) concludes the usual Six Sigma structure which is also present in Coesia: "*Six Sigma provides a hierarchical structure where leaders (Champions) initiate, support, and review key improvement projects; Black Belts then serve as project leaders who mentor Green Belts in problem-solving efforts*."

This LSS project was carried out according to the LSS process developed by Coesia. Since the maturity within LSS was high within the company, it became evident during the Define phase that there was no need to focus on implementing LLS techniques or principles throughout the thesis, but rather much focus on improving the initial metric of the LLS project, which was to reduce the amount of hours required to complete an engineering project. There was also frequent feedback and guidance throughout the project from the MBB at Coesia as well as the project sponsor and BB thesis supervisor at FlexLink.

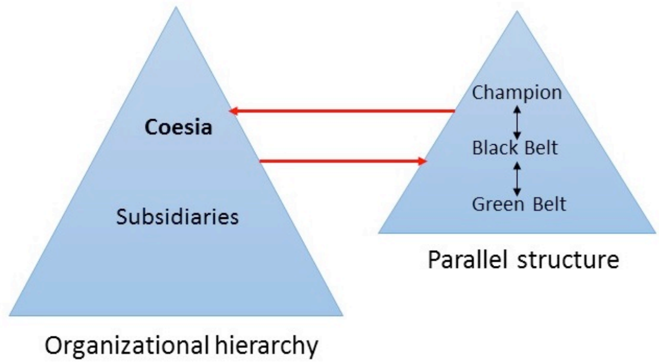

Figure 5 - Parallel meso-structure described by Schroeder et al. (2007).

5 Measure

The Measure phase focused on identifying the current state of the process. Interviews and observations were made in order to define the process. A process flowchart was then made based on the collected data. The flowchart was changed several times until it was verified by the project engineers. Furthermore, the process cycle times were estimated using the three point estimation, according to section 3.5. Since no data was available to calculate the actual cycle times and measuring the cycle times would be too time-consuming for the engineers, the only option was to proceed with estimations, because the primary objective in this stage was to create a process overview and its structure.

5.1 Process map/flow chart

The process map in figure 6 shows a more detailed view of the process. This is not an exact description of the process, since different operating units work in a slightly different way. Even within the same unit the process can be different for different engineering projects since every project is unique and very personal dependent. Some steps are for example skipped or done in a different order depending on the nature of the project and the engineers. The process map is a visualization of the common steps conducted by application and project engineers during a project in the Nordic operating unit.

The process starts with designing the concept of the system. This step is usually done in FLDT. When the concept design is finished, the assembly time of the conveyor system is calculated. The calculation is semi-standardized and done in different ways by different units. It is usually done by using excel sheets or other similar tools. However, the Nordic, German and Polish units have agreed to use the same excel sheet in order to enhance the handover of production projects to EOPL. Otherwise, the assembly time budget for the same conveyor system will be different for different units. The first two steps are normally done by application engineers but can be done by project engineers for smaller projects.

The first step for the project engineer is to familiarize with the quotation and the concept design in order to understand the needs of the customer. There is also a handover meeting when the concept proceeds to the project engineering phase. This step is crucial, since if the customer requirements are not fully understood there is a risk of errors in the conveyor system design. This step will however not be investigated any further since there is an ongoing improvement project regarding the handover phase. For smaller projects the whole process chain is done by only one project engineer, meaning that there is no need for a handover.

The next step for the project engineer is to complete the design of the conveyor system on a detailed level as well as designing external material or custom made parts that might be included in the project. The detailed design is made in Inventor using the FlexCAD library. This step, depending on the complexity of the project, is usually the most time consuming part of the engineering project. The FLDT concept design made by the application engineer cannot be used in Inventor. Thus, the project engineer has to start from the beginning when designing the detailed layout. The output from this process step is assembly and customer drawings, which are used as inputs to the following process steps.

If the project is to be assembled in EOPL, there is procurement between the units using a special document. The units need to agree upon the required assembly hours and additional engineering hours for administration of the project. When the procurement is complete and the document is signed, the assembly drawings are sent to EOPL. The flowchart visualizes the rework of drawings that sometimes occur. This is not part of the regular EOPL process but was important to highlight. When the assembly drawings are of adequate quality, the project administrator in EOPL makes a production binder. The binder is required for the EOPL assembly phase and contains all the information about the project, such as all the assembly drawings but also other administrative information. An equivalent to the binder is however not used in the Nordic and English operating units.

In the cases where projects are assembled in EOPL, the responsibility of ordering material is EOPLs. Otherwise, the project engineer at the origin operating unit orders the material. The FlexLink material is ordered in the Online Store by importing the BOM list from FlexCAD or FLDT. The order is processed by the PSD warehouse and delivered to the assembly site of the operating unit. Purchasing of external material is handled by a purchaser. If external material is used in the project, the engineer prepares information on the external material for the buyer.

The project documents are usually made by modifying existing templates to fit into the current project. Operating manuals are made by using word templates. Parts that are not included in the engineering project are removed and customer information is filled in. When doing the spare part list, the engineers have to go through the product manuals provided by PSD in order to find the recommended spare parts for the material in their BOM list. However, it was found that operating units have often developed their own excel tools in order to speed up the process. The risk analysis is also done differently for different units. The Nordic unit uses the specialized software CEDOC to assist the risk analysis. The German unit use another software, while most other units use an excel template.

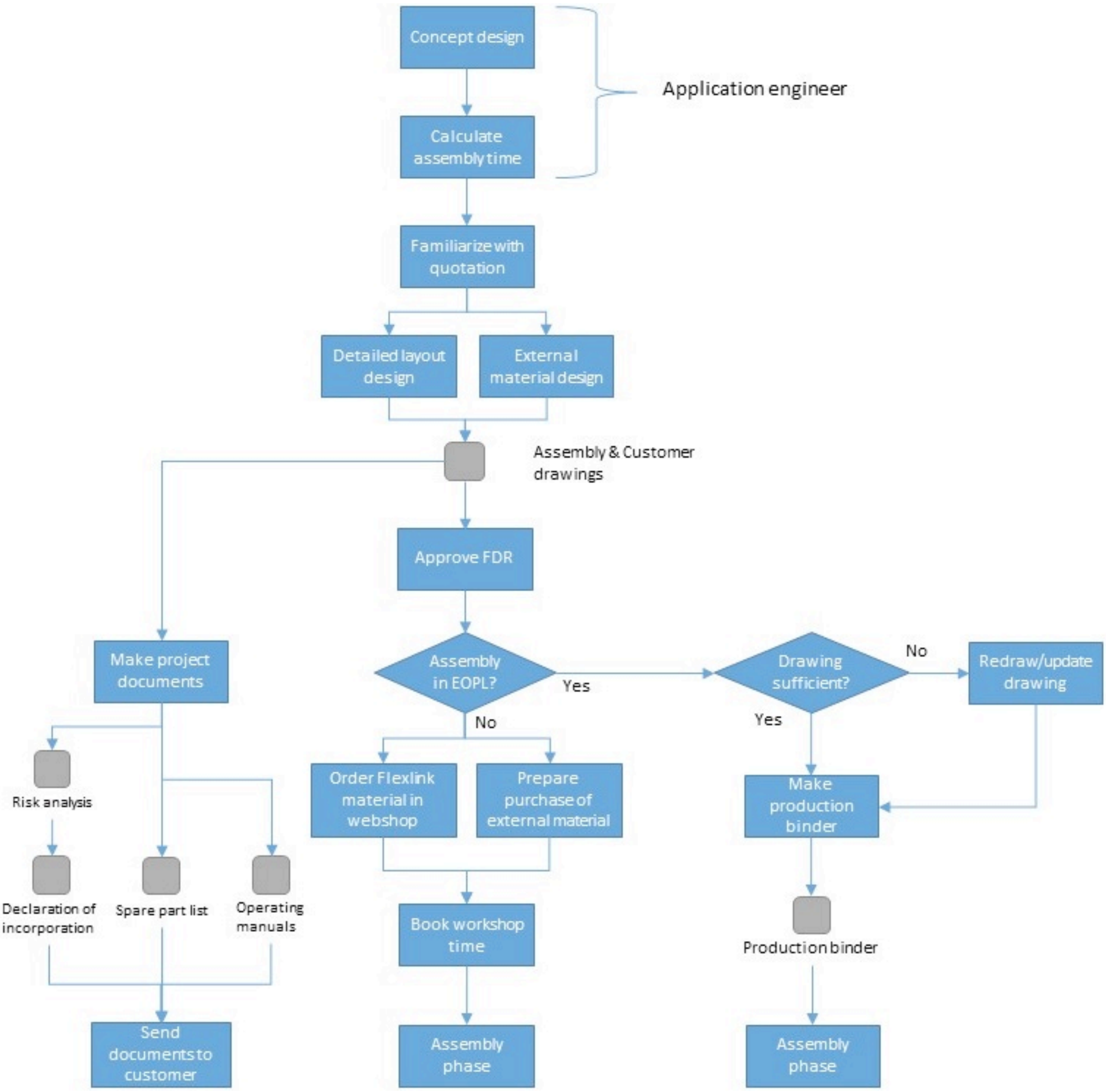

Figure 6

5.2 Baseline and financial model

A financial model for the LSS project was developed by the finance department at FlexLink. It was used as a baseline for the engineering hours spent in projects as well as a tool for calculating potential cost savings by cutting engineering time. There were in total 1855 projects in Europe during 2015. 1336 of those projects qualified as small projects, with a revenue below 25 000€. The 1336 small projects had in total 24 868 engineering hours. According to the data in the financial model, the average small project had around 18.6 hours of engineering time.

There were 112 362 engineering hours when all the 1855 projects were included in the calculation. The big difference in hours from the small projects can be explained by that the largest projects account for a large part of the total engineering hours. The reason for this is that the largest projects are usually very resource demanding because of the many special functions that are included. It could be concluded that the majority of the projects fall into the category of small projects. The large projects are few in numbers but account for most of the engineering hours. There are also projects of medium size, with a revenue higher than 25 000€ but a low amount of external material and special components.

5.3 Process cycle time estimation

In the measure phase, the researchers proceeded with the process map with the goal to measure the cycle time for each process step in order to get an overview of where project engineering time is spent. There is a large variation in the engineering time spent in projects since every project is unique, meaning that there is also a large variation in the cycle time of each process step. The engineering time spent in projects is only recorded on a higher level. This is done in order to calculate the efficiency of the engineering department. Thus, there was not any existing data that could be used to measure the cycle time in each project.

It was decided to estimate the cycle times by using the three point estimation (Appendix). The data (hours) for the most likely, optimistic and pessimistic values for each process step were filled in together with project engineers from the Nordic operating unit and was based on their judgement of the process. Only small and medium sized projects were taken into consideration.

The process step with the highest cycle time was as expected the detailed layout design and making of the assembly drawings .The process steps that got the most attention during the interviews at this stage was the time spent workshop and making the project documents. It was found that the expected time to spend in the workshop for an engineering project was 1.7 hours. That included both the time it took to book workshop time for the assembly of the conveyor as well as the time engineers had to spend in the workshop to answer questions. The questions were mostly related to the drawings. There are often issues that need further explanation. It also happens that engineers leave minor details out on purpose because they are not sure about the best way to assemble them. The expected time for making the project documents was around 2.7 hours. Both these process steps were investigated further in the later stages of the project.

The sum of the estimated process cycle times showed that the expected engineering time of a project is 19 hours (the first two process steps are application engineering time which is not recorded in the project). This estimation also fitted well with the average time calculated from the financial model, which was 18.6 hours.

6 Analyze

The goal of the Analyze phase was to identify the critical X factors in the process, causing the large part of the variation in the engineering lead time. A sequence of qualitative LSS tools was used throughout the Analyze phase in order to identify the factors. The sequence started with a P-map. The outcome of the P-map was used as input to a Cause and Effect matrix and the output from the Cause and Effect matrix was then used as input to a FMEA. Based on the result of the FMEA, factors for further improvement were chosen. The costs of these factors were also quantified in order to facilitate the discussion with the stakeholders.

6.1 P-map

P-map (Appendix) is a process map, similar to the flowchart in section 5.1, but with all the inputs and outputs for all process steps listed. The P-map was used with the purpose of identifying all process inputs that can have an impact on the process. It is also a useful tool for getting a better understanding of the process and the required inputs for a process step to be successfully executed. The information in the P-map was filled in based on the process flowchart and inputs from project engineers. It is important to get the P-map right, since the inputs to the proceeding tools are based on the findings from the P-map.

6.2 Cause and Effect matrix

A Cause and Effect (C&E) matrix was used to make a waste analysis of the process. The goal was to find the critical X factors to focus the research on. The process inputs identified from the P-map were used as an input to the Cause and Effect matrix. The inputs were rated against the seven wastes from Lean theory in order to quantify the contribution of waste from each factor. The factors were then sorted based on their score.

The most significant types of waste found in the process were rework and over-processing. Although waiting scored as high as rework, the contribution to high score in waiting is caused by the noise factor "Approved FDR", since it can take several days for customers to approve the FDR sent by the project engineer. Rework was mostly due to the drawings not being sufficient while over-processing was mostly connected to bad process design. There was no waste present in the category overproduction, since the engineering projects are a pull system by nature. The criteria's for choosing the factors were:

- High score in the C&E Matrix, thus contributing to a high amount of waste in the process.
- Possibility to integrate process input into the existing engineering tools, since an initial goal of the project was to investigate if the engineering tools could be enhanced in order to improve the engineering process.

6.3 W-FMEA

FMEA (Failure Mode and Effect Analysis) is a systematic approach of identifying and prioritizing quality risks within a process with the goal of finding quality improvements. de Souza & Carpinetti (2014) presented the W-FMEA (Waste-Failure Mode and Effect Analysis), a modified FMEA with the focus on waste reduction in processes by identifying the waste modes, effects of waste modes and causes of waste modes for the key process inputs.

A W-FMEA was conducted based on the methodology presented by de Souza & Carpinetti (2014). The process inputs chosen from the Cause and Effect matrix were investigated in the W-FMEA. Risk scores were assigned to each waste mode based on the severity, occurrence and detectability of the waste mode effects. A Risk Priority Number (RPN) was calculated for each waste mode based on the risk scores. The input with the three highest RPN scores was the assembly drawings. The corresponding process step has the longest cycle time and is the main delivery to assembly. The causes of the waste modes for the assembly drawings were either related to lack of information in the drawings or lack of FLDT knowledge. The causes of waste modes for the project documentation inputs were not related to the actual process steps but rather the information and tool ownership behind.

Table 1 – W-FMEA

Input	Waste Mode	Effect of waste mode	Cause of waste mode	RPN
Assembly drawings	Engineering time spent in workshop	Increases engineering hours in the project	Assembly drawings lacked important information	100
Assembly drawings	Rework of drawings in EOPL	Increases engineering hours in EOPL	Assembly drawings sent did not match EOPL standard	50
Assembly drawings	Simple conveyor system designed in CAD instead of FLDT	Increases engineering hours in projects	Lack of FLDT knowledge	50
Production binder	Waste created in motion and transport when the physical binder is moved around	Increases engineering hours in EOPL	Current EOPL process design requires signatures from different employees to ensure work tasks were done	45
Spare part list	Tools and methods maintained locally by each unit	Increases costs	No standardized tool	45
Assembly time calculation	Tools and methods maintained locally by each unit	Increases costs	No standardized tool	40
Knowledge	Long learning periods when shifting engineers between units	The engineer is not productive until the new way of working is learned	All units have developed their own processes, methods and tools	36
Operating manuals	Tools and methods maintained locally by each unit	Increases costs	No standardized tool	30
Production binder	Waste created in waiting time when waiting for the binder to arrive to the workshop	Increases lead time of the project	Current EOPL process design requires the binder to be ready before the assembly phase can start	30
Knowledge	Training of new personnel is time consuming	Engineering hours spent on training	No central guide on how to train new personnel	27
Assembly time calculation	Information updated several times at once when new product platforms are launched	Increases costs	No central information owner	20
Operating manuals	Information updated several times at once when new product platforms are launched	Increases costs	No central information owner	15
Risk analysis	Information updated locally when there are new updates to the Machine Directive	Increases costs	No central information owner	8
Risk analysis	Tools and methods maintained locally by each unit	Increases costs	No standardized tool	8

6.4 Factors in focus for improvements

The factors from the W-FMEA were in focus for improvements and were further investigated. In order to calculate the cost of each factor the annual hours spent had to be quantified. However, it was not possible to quantify all factors, since some of the factors contribute to hidden costs in which there was neither time to measure nor old data to base estimation on. The factors in which it was possible to quantify the annual hours, the estimation was based on the three point estimation of the process cycle times, project data from the financial model and annual quotation data. It is important to point out that this is only an approximation and should not be seen as the actual values, since there are potential errors in both the estimated cycle times, project data and quotation data. It is however a good enough guideline to understand the magnitude of each factor. The time and cost for the quantified factors were also scaled up to show an estimation of the impact on a global level.

Table 2 – Quantified costs

Input	Waste mode	Impact Europe (hours)	Cost Europe (€)	Impact Global (hours)	Cost Global (€)
Assembly drawings	Engineering time spent in workshop	3 150 h	189 000 €	5 936 h	356 000 €
Assembly drawings	Rework of drawings EOPL	Unknown	Unknown	Unknown	Unknown
Assembly drawings	Simple conveyor systems designed in CAD	Unknown	Unknown	Unknown	Unknown
Production binder	Preparing and processing the binder	640 h	23 600 €	-	-
All project documents + assembly time calculation	Tools and methods maintained locally by each unit	Unknown	Unknown	Unknown	Unknown
Spare part list	-	464 h	27 800 €	873 h	52 400 €
Assembly time calculation	-	1 085 h	65 100 €	1 646 h	98 700 €
Operating manuals	-	927 h	55 600 €	1 746 h	104 700 €
Knowledge	Time consuming to train new personnel and shift personnel between units	Unknown	Unknown	Unknown	Unknown
Risk analysis	-	Unknown	Unknown	Unknown	Unknown

6.4.1 Engineering time in the workshop

As mentioned in chapter 5.3, there was around 1.7 hours of engineering time spent in the workshop per project in the Nordic operating unit. It was found that engineers in England also spend time in the workshop to answer questions on a regular basis. The other LSS thesis project (Gerremo, 2017) conducted a survey, showing that there was a significant amount of time spent in the workshop by the engineers at EOPL as well. This time can be classified as waste, since the goal is to deliver just enough information so that no questions arise. The cause of this waste mode is that the assembly drawings lacked important information.

The time spent in the workshop is not reported separately, so the exact duration of the workshop visits remains unknown. The estimated time from the Nordic process was used to calculate an approximate value for the waste created on all projects. The estimation showed that this is the most costly factor from all the factors that was possible to quantify.

6.4.2 Rework of drawings

The rework of drawings is the most obvious waste mode in the process, since the same process steps are done twice. The underlying reason for this issue is believed to be that there is no standard way of making drawings with sufficient information in the company. There is also a variation in the preferred way of working and the experience of the operators amongst the units. This has led to that every unit has developed their own way of delivering information to assembly. Another issue that was brought up during the interviews in the Nordic unit was that they did not feel like they belong in the same organization, due to communication barriers and all the internal procurements between them and EOPL.

It was not possible to estimate the waste for this factor since there was no data on how often and how much time was spent on rework of this kind. However, there were several projects found during the thesis project where rework had occurred with over 100 hours spent on redoing drawings. One example was a production project coming from another European unit to EOPL, where 45 hours of engineering was spent in the origin country and another 40-50 hours of engineering was spent to redo the drawings in EOPL. The drawings for the projects with rework were collected and compared. Several interviews were held with engineers and operators from multiple units. It was found that lack of measurements and views were the most important reasons for redrawing. However, there was found to be mixed opinions on how to make drawings amongst the engineers in the different units. Some engineers' opinion is that EOPL puts too many details in the drawings while some would agree more with the detail level provided by EOPL, while most of the operators would in general prefer the detail level provided by EOPL.

6.4.3 FLDT knowledge

It is a goal for FlexLink to utilize FLDT as much as possible, since it is faster than using CAD. There was found to be a large variation in FLDT knowledge amongst the units. This causes engineers to sometimes process drawings in CAD when the conveyor system could have been designed in FLDT instead in the fraction of the time. FLDT was initially designed to be a tool for application engineers to quickly make a concept drawing. It has however evolved to include more advanced functionality and it is now possible to complete small projects without using CAD at all. It was found that some units have not kept up to date with all the updates in FLDT. Other units also prefer to use AutoCAD in the application phase instead. This was evident when interviewing several key stakeholders from different units, not least the head of software development that is also responsible for training in the engineering tools. According to him, the Nordic unit gives by far the most improvement proposals through FLDTs own feedback system. The Nordic unit is also where FLDT is utilized the most. The reason for this is believed to be that the software development department is located in the same building, thus improving the communication between them and the engineers. Communication barriers are believed to be a reason for the slower adoption of FLDT in other units.

It was not possible to quantify the time and cost for this waste mode, but there is a risk that this waste mode could be a large hidden cost. The time spent on the conveyor design is the most time consuming process step and the cycle time estimation revealed that it is more than 50% of the total project time, which means that there is a large time saving potential by using FLDT instead of CAD in cases where possible.

6.4.4 Knowledge

This cause of this waste mode is that there is no efficient way of spreading knowledge as well as lacking work standards. There are no formal work standards and guidelines for the engineers, except for some defined processes in the Quality Management System, which was found to be seldom viewed and poorly communicated to the engineers. The following quote from a project engineer describes the situation: "*Nobody tells us what to do, we often have to find a way by ourselves*". This is evident when passing knowledge to new employees. Since there is no standardized way of training new employees and consultants, it requires the engineers to spend a significant amount of time in training new personnel. The engineer has to come up with his own way of teaching. Another issue is that the engineers have to "reinvent the wheel" in certain situations because there are no specified guidelines, which also increases the risk of making errors. Another issue is that all the units have developed their own ways of working because of a lacking central standardization of processes. It hinders a smooth cooperation between the units with the long learning periods when shifting employees between units. This factor contributes to hidden costs that are difficult to quantify.

6.4.5 Project documentation and assembly time calculation

The project documentation consists of operating manuals, spare part list and a declaration of incorporation. The latter requires that a risk analysis was done. The waste modes related to these factors are hidden costs when every unit has to update and maintain their own self-developed tools. For example if a new platform is released, the documentation and tools needs to be updated for that platform. Another problem is that there is no central information owner. These factors had medium-low RPN score in the W-FMEA, since the occurrence of the waste modes is low. They were chosen for further investigation because it was believed that they could be automated by integrating functionality into the existing engineering tools, thus reducing the cycle time of the process step to almost zero and at the same time eliminating the necessity of keeping local tools. Furthermore, the Voice of the Customer (VOC) showed that these are tiresome activities that are usually saved for last.

The minimal cycle time for project documentation was found to be one hour but the average time from the three point estimation in chapter 5.3 was 2.7 hours. Project documents are always prepared, no matter how small the project is. It means that the proportion of time spent on documentation for very small projects becomes unreasonably high. The time and cost was estimated for each of the project documentation component as well as the assembly time calculation by using the annual project data (financial model) and the estimated cycle time for the process steps.

6.4.6 Production binder

Production binder is an extra administrative set of documents used in EOPL that are not used in other units. The binder contains both documents that are value adding, such as assembly drawings (required to assemble the system) as well as documents that are non-value adding, such as documents of entirely administrative nature due to their current process design. The production binder is put together by the project administrator in EOPL. All the assembly drawings are printed out and then sorted in the right order. Compiling the production binder with all the necessary documents and sorting them in the right order takes about one hour, based on three point estimation. The administrative documents in the binder are then filled out by different employees, meaning that waste is created transporting the document between personnel. The operators in EOPL are in favor of using the binder since it simplifies their work. However, the administrative document in the binder is not adding any value.

7 Improve

In the Improve phase, potential improvement ideas were generated and discussed for the different factors in the W-FMEA. Brainstorming and interviews with key stakeholders was the most important part of the Improve phase. Some ideas turned out to be improvement suggestions while other factors were discarded for different reasons. The solutions were chosen based on ROI (Return on Investment) as well as contribution to standardization amongst the units, since every act that would make the operating units more standardized was seen as a benefit from the company. Furthermore, many of the improvements were focused around the engineering tools and the project documentation. Therefore, the focus of the interviews in the Improve phase shifted from the operating units to the software development department. The cost of each solution were estimated and the potential benefits were based on the estimations from table 6.2.

7.1 Brainstorming

Brainstorming sessions were held continuously during the Improve phase. The sessions included project engineers as well as the FlexLink Black Belts. The sessions generated ideas that were later approved or discarded during the interview sessions. Some of the ideas were mentioned by employees during the thesis project and were further discussed in the brainstorming sessions.

7.2 Interviews

The interview sessions during the Improve phase gathered key stakeholders from operating units, PSD, software and IT departments. The purpose of the sessions was to start a discussion between the departments about the different improvement ideas, since some ideas required cross functional teams to develop. It was found that some of the ideas that had been brought up by other employees in the past did not get much attention. Therefore, these sessions turned out to be very successful since the discussion happened directly between the key stakeholders and common agreement between the stakeholders was reached. The researchers had the intention to make them own the solutions themselves rather than to act as middlemen between the stakeholders. It was also important to discard the ideas that were too complex to develop as well as to ensure that the proposed improvements were possible and realistic to develop. All the stakeholders were positive towards the ideas that were turned to improvement recommendations.

7.3 Business Intelligence system

Figure 7 describes the present Business Intelligence (BI) system at FlexLink. Data is stored in the Data Warehouse (DW) within the system from four different sources:

- Product Lifecycle Management (PLM) system
- Enterprise Resource Planning (ERP) system
- Customer Relationship Management (CRM) system
- Engineering Tools (ET)

Data stored in the DW is then easily accessible from multiple different sources. The PLM system is used by PSD to store all the product data on component level. This PLM system was important to the thesis, since some of the solutions were based on data collection from the PLM system. There was also an ongoing project to release the same PLM system for all the operating units and another project to switch the current ERP system to SAP. Both projects were taken into consideration in the improvement recommendations.

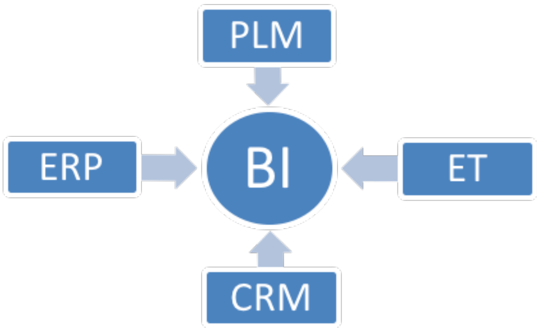

Figure 7

7.4 Improvement recommendations

It was important that the ideas would be easy to maintain and that the data ownership did not fall to the software department. All the improvement recommendations were validated to ensure that they are possible to do. The recommendations are described in general but the technical details discussed within the company are left out. The researchers focused on putting a price and a benefit on the solutions in order to facilitate the decision-making for FlexLink on which projects to proceed with. All the identified benefits and drawbacks were listed.

7.4.1 Automated spare part list

Generating the spare part list is a process step that takes on average 15 minutes to complete. There is however a large variation in this cycle time depending on the size and complexity of the project. The cycle time was estimated based on the three point estimation and input from project engineers during interviews. There is also variation between the operating units in how this list is generated. As mentioned, it is common for different operating units to use self-developed tools such as excel sheets in order to facilitate producing the spare part list.

This recommendation suggests that the spare part list should be automated by integrating functionality into FLQT. Since FLQT keeps track of the parts that have been used to design the conveyor system, it is also possible to keep track of the recommended spare parts. The solution will use the BOM list available in FLQT and check the PLM system for all the used parts' corresponding spare part. It will then automatically present a recommendation of spare parts for the project engineer. The prices for all parts will be included based on the specific customers discount level and are automatically retrieved from the Online Store.

Furthermore, PSD have agreed to be responsible for adding spare parts in the system for future product platforms.

It was believed that automating the spare part list would reduce the cycle time for this process step to almost zero. The estimated annual saving potential is then 464 hours in Europe and 873 hours on a global level. This corresponds to 52 400 € annual savings on a global level. Based on information from interviews, this solution requires 236 hours to develop:

- 40 hours of software development in FLQT.
- 36 hours of database updates in order for the FLQT functionality to be able to retrieve the data.
- 160 hours of feeding information to the PLM system.

The benefits that were identified for this solution are listed below:

- It can easily be scaled up to all projects and to a global level since all units already use FLQT.
- Will contribute to a more standardized way of working between units, thus eliminating waste by for example removing the necessity of developing and maintaining self-developed excel tools. The information and the tool will be updated centrally for the whole company.
- Easier to ensure spare part lists are always sent to customers.
- Reduces risk of making human errors in the spare part list.
- Customer price included automatically. With the current solution the engineers have to find the specific customer price in the Online Store.
- ROI less than a year.
- Stakeholders are in favor of the solution.
- Spare part list can be produced in the application phase instead without adding much extra time. FlexLink wants to investigate if this might increase their spare part sales.
- Simplifies the engineering process.

The drawbacks are that it will only provide the engineer with a recommendation of spare parts. The engineer will still in some cases have to modify the list according to the conveyor system design, for example changing the quantity of parts. Furthermore, it will only include the FlexLink material at this point.

7.4.2 Automated assembly time calculation

The assembly time calculation takes on average 20 minutes to complete. Like most other process steps, there is a variation in the cycle time depending on the size and complexity of the engineering project. The three point estimation was used to calculate the cycle time. The current excel tool used by the Nordic, Polish and German operating units had an extensive amount of development hours in order to determine accurate formulas for the calculation. The formulas are for example based on the length of the beams used in the conveyor system. It was initially investigated if the current tool could be easily implemented into the engineering tools. However, it was found that the formulas are too many and too complicated to integrate to a sustainable solution that is easy to maintain.

The recommended solution is instead similar to the previous solution. Functionality will be integrated into FLDT, so that the assembly time of a designed system can be automatically calculated by the material in the BOM list. FLDT will retrieve the information from the PLM system, which requires that assembly time is determined on subgroups of parts of the conveyor system. Determining how to divide into subgroups as well as the assembly time for the determined subgroups requires extensive product knowledge. This work was initiated during the interview sessions with the stakeholders. PSD have agreed to own the process of putting assembly time on subgroups for new product platforms in the system. Today, every operating unit has to figure out the assembly times on their own when new platforms are released. Furthermore, it is recommended to have EOPL as the owner of updating the assembly times for the subgroups, since they have by far the highest assembly volumes. If it is found by any unit that a certain subgroup should take more or less time than the time defined in the PLM system, a process should be started at EOPL to determine if the assembly time should be updated.

It was believed that 15 minutes could be cut from quotations by automating this process step. Some quotations are revisions of old quotations and do not always include assembly time calculation. The revisions were sorted out from the quotation data and an estimated buffer was then added to cover up for the revisions where the assembly time was calculated. The annual benefits was then estimated to be 1085 hours saved in European application departments and 1646 hours saved on a global level, corresponding to 98 700 €. The cost to develop the solution was estimated to 480 hours, based on information from the interviews. The 480 hours were divided into 320 hours of software development and 160 hours of developing the necessary framework for the assembly times on subgroups. The benefits that were identified for this solution are listed below:

- It can easily be scaled up to all projects and to a global level since all units already use FLDT for concept designs.
- Will contribute to a more standardized way of working between units, thus eliminating waste by for example removing the necessity of developing and maintaining self-developed excel tools. The information and the tool will be updated centrally for the whole company.
- Reduces the risk of making human errors.
- Reduces time spent by application engineers means reducing time not paid by customers.
- Stakeholders are in favor of the solution.
- ROI less than a year.
- Simplifies the engineering process.

The drawbacks are that the solution only includes FlexLink material and will require some manual work for the most complex designs.

7.4.3 Knowledge base for operating units

This improvement suggestion is connected to the second highest scoring factor in the Cause and Effect matrix “Knowledge”. The waste modes from this factor identified in the W-FMEA were that it is time consuming to train new personnel and shift personnel between units. The causes for the waste modes was that there is no process owner for spreading standards, guidelines and information that are applicable for all operating units and that all units have developed their own ways of working.

This solution recommends creating a knowledge base for all operating units. A knowledge base is a system for storing and spreading knowledge within a company. Such a system already exist at FlexLink, one with public information and one only for PSD. Thus, extending it to operating units was seen as an easy task by the software department. The public system includes knowledge and tutorials about all the engineering tools. However it was found that not all engineers are familiar with it and it is seldom used. By using a separate knowledge base for operating units, it can be used as a communication channel for training, tutorials, standards, guidelines, etc. It can thus also be used as a tool to increase FLDT knowledge, which was a cause of a high scoring waste mode in the W-FMEA. The idea is to have a general page that applies to all operating units but also include subpages with information that only applies to local units. The goal is to use it as a tool to unite the units towards a more standardized way of working. For that to work, it requires a structure behind it with employees that have ownership and responsibility to communicate standards, guidelines and information.

Another area in which this solution could be beneficial was the upcoming release of the PLM system for operating units and the switch to SAP. During interviews with employees from PSD, it was found that the PSD knowledge base was used mostly when using the PLM system. The PSD employees believed that if the information did not exist in the PLM system, they would have to ask the IT department every time. It is reasonable to believe that the same need for fast accessible information will arise from the project engineers when the PLM system is rolled out for operating units as well as from employees working with SAP.

7.4.4 Engineering time in workshop

The approximation in table 6.2 showed that over 6000 engineering hours per annum are wasted by engineers spending time in workshops. One cause of this waste mode was that the assembly drawings lacked important information, so the engineers had to go to the workshop and answer questions or solve problems. However, further investigation is needed since it was believed that there are more causes, or that the above mentioned might not be the actual root cause. A recommended action is to initiate a new LSS project with the goal to reduce this waste mode.

7.5 Discarded factors

Several factors were discarded during the Improve phase for different reasons. The factors "Production binder" and "Rework of drawings" scored high on the waste analysis and were investigated further. It was estimated that possibly over a thousand hours were wasted annually from these factors. However, they were handed over to the other LSS thesis (Gerremo, 2017) since they were better aligned with the other projects' goal.

An automated solution for the risk analysis and operating manuals was also investigated. Meetings were held with representatives of CEDOC, were a possible solution of integrating CEDOC with the engineering tools was discussed. This was however discarded since the license costs and costs of development would be too high. Automating the operating manuals was problematic since it was concluded that all units need to agree on the same format standard for the manuals first. This had been tried several times before by the head of quality at FlexLink but had never succeeded.

7.6 Recommendations for future improvement projects

Because of the global LSS program deployed by Coesia, it was beneficial for FlexLink to receive expanded problem knowledge. Since several LSS projects are conducted every year, it was beneficial to have ideas for future projects. Those were problems that were picked up during the thesis but not part of the scope. They were brought up at the request of FlexLink to have as potential future LSS projects.

One problem that was reoccurring several times was the lack of ownership within the company. For example the software development department that is already heavily loaded is sometimes afraid to take improvement projects regarding the engineering tools, since it has happened in the past that the ownership of data falls to their lap. Another area with potential is to increase the data quality within the company. By for example reporting engineering time in subcategories, it would be possible to calculate average cycle times. This would facilitate future improvement projects.

8 Control

During the Control phase the focus was on developing control metric for the project. The project was also handed over to the FlexLink Black Belt since no actual control could be implemented at the time. The reason for this was that the development of the improvement recommendations would take several months for the software department to complete. Instead, an initial control plan was formulated. A new productivity KPI was also introduced in order to measure future performance

8.1 Updated W-FMEA

The W-FMEA was updated to include the recommended improvement actions and the new corresponding RPN scores. The updated W-FMEA showed that automating process steps had the largest impact on the RPN score for the waste mode of locally maintained tools. This is not surprising, since the introducing functionality into the existing engineering tools will remove the necessity of keeping other tools on a local level.

Table 3 – Updated W-FMEA

Input	Waste Mode	Effect of waste mode	Cause of waste mode	Recommended action	RPN	New RPN
Assembly time calculation	Information updated several times at once when new product platforms are launched	Increases costs	No central information owner	Automate assembly time calculation	20	3
Assembly time calculation	Tools and methods maintained locally by each unit	Increases costs	No standardized tool	Automate assembly time calculation	40	2
Spare part list	Tools and methods maintained locally by each unit	Increases costs	No standardized tool	Automate spare part list	45	2
Assembly drawings	Simple conveyor system designed in CAD instead of FLDT	Increases engineering hours in projects	Lack of FLDT knowledge	Use knowledge base in operating units for FLDT training	50	12
Knowledge	Training of new personnel is time consuming	Engineering hours spent on training	No central guide on how to train new personnel	Use knowledge base for training new personnel	27	6
Knowledge	Long learning periods when shifting engineers between units	The engineer is not productive until the new way of working is learned	All units have developed their own processes, methods and tools	Use knowledge base as a tool to increase standardization and communicate work standards	36	8

8.2 Control plan

A control plan was formulated together with the stakeholders, with the purpose of knowing what to measure, how to measure it and what to do if the recommended improvements are not used to the desired extent.

8.2.1 Monitoring usage

It is possible to retrieve different types of data from the engineering tools, such as how many drawings/quotations are made in FLDT/FLQT. Retrieving such data can be used to monitor the usage of the improvement recommendations automated spare part list and automated assembly time calculation, thus monitoring that the solutions are used to the desired degree. It is recommended to use the data to make control charts of the frequency of automatically generated spare part lists and assembly time per operating unit. A predefined threshold value is to be decided by FlexLink, (for example 95% usage), as a signal to take action.

8.2.2 Reaction plan

It is recommended that the data is delivered quarterly from the software department to the FlexLink Black Belts. Control charts should then be updated and sent to the FlexLink area directors that are responsible for sales in their predefined area. If any unit drops below the predefined threshold values, the area director should designate an employee from that unit to investigate reason.

8.3 Introducing a new productivity KPI

The new productivity KPI sales/hour was introduced during the Control phase. The goal with the KPI was to use it as a future measure to identify trends and connect them with past improvement actions as well as a control parameter to monitor that the development is not moving in the wrong direction. It was not important to be able to separate the gains of each single improvement action, but rather to see the gains of all the combined improvement actions from several projects. This would then not be very beneficial for this particular LSS project, but beneficial for the company as a future measure of performance for both engineering departments and LSS projects.

The sales and project engineering hours data from the financial model was used to test the KPI (figure 8). A high productivity is desired, since it means that more revenue is generated with less input. There is some variation in this metric, such as the nature of the projects. Some projects have lower hours but high revenue because of a high amount of material. However, by using a moving average over all projects and a longer period of time can this measure be used to identify if the company is headed towards the right direction. As mentioned, FlexLink is expecting significant growth and the goal is to be able to grow without the need of hiring so many people. The moving average of sales/hour was made from 2014-2016 financial data. The graph (EWMA chart) showed that there was variation in the KPI from 498 to 459 €/hour. This variation is hard to explain without deeper investigation. However, it could be seen that over the investigated time period the KPI had not increased. Figure 9 shows the growth in hours during the same time period. This is proving that FlexLink did not have any increase in productivity during the last two years and they had thus not been able to grow without spending more resources.

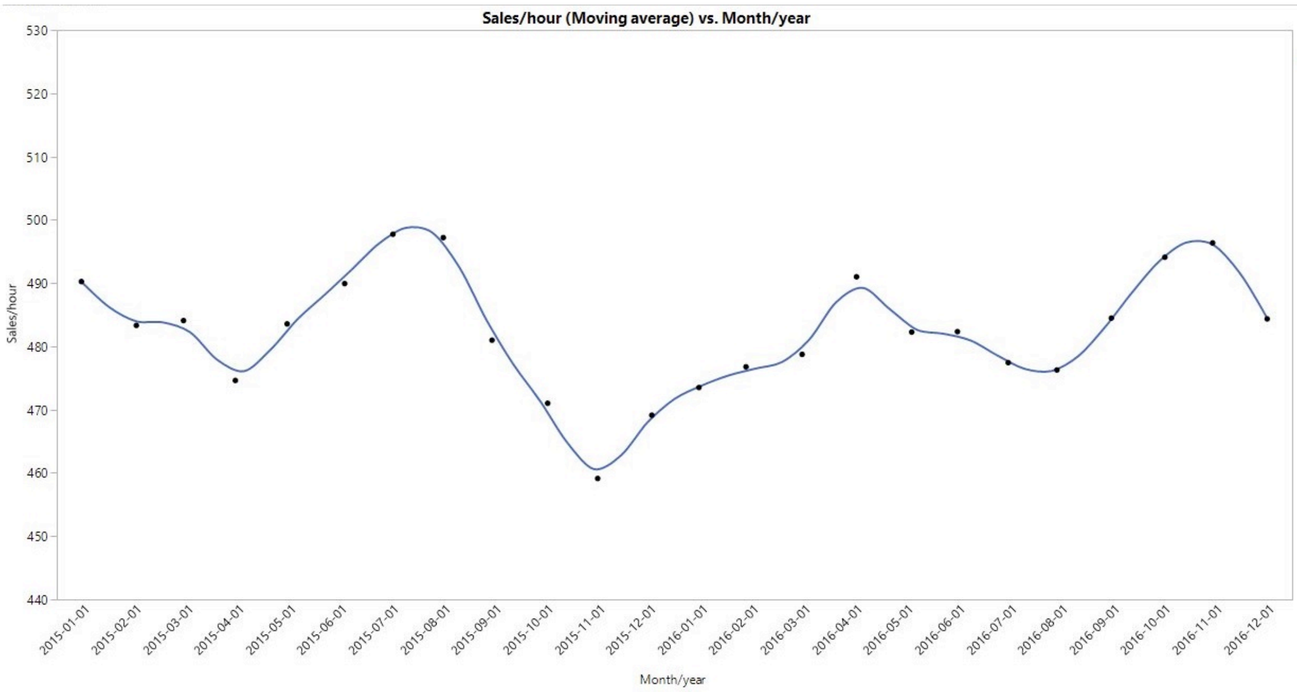

Figure 8

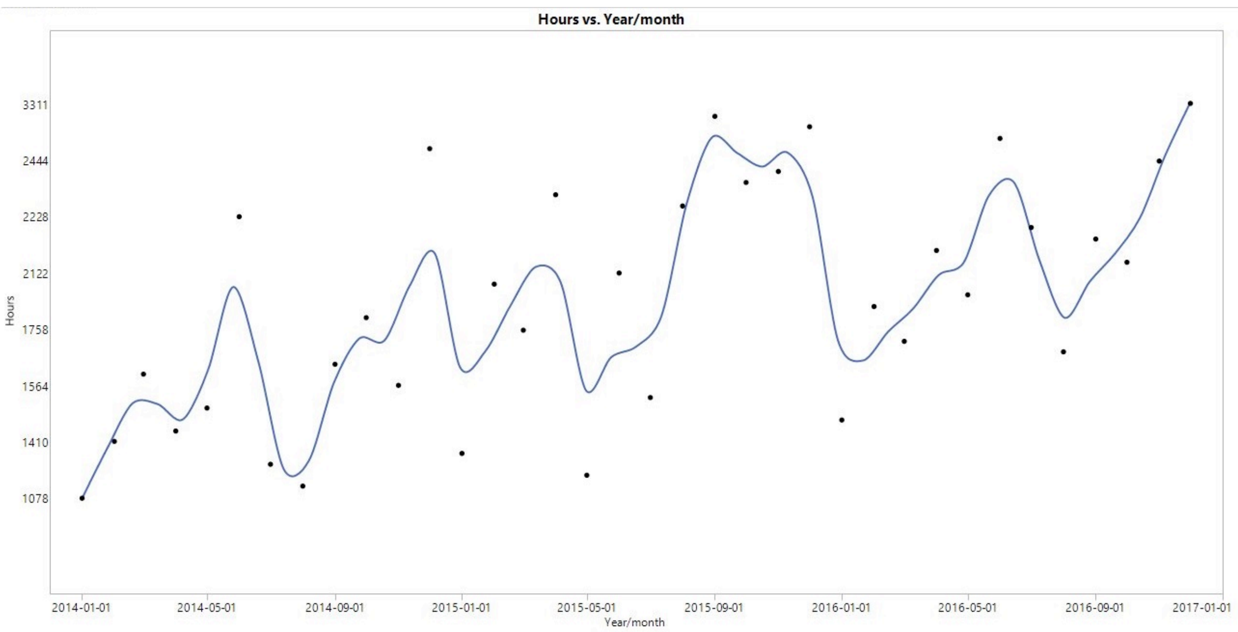

Figure 9

9 Results

During the DMAIC cycle, an estimated waste of over 6000 hours per year was found within the operational part of the company. This was mostly due to rework activities and over-processing. It was found that the lack of standardization amongst the units was the cause of several problems. The effect of this cause is that all the units have developed their own processes, methods and tools for the engineering projects. This was seen to hinder a smooth cooperation between the units.

This report resulted in concrete improvement recommendations, new control metrics and expanded knowledge within problematic areas that might become future projects in the LSS organization. Three concrete improvement recommendations were formulated as a result of the findings during the DMAIC cycle. The recommended improvements focused on utilizing IT tools to improve the engineering process and standardize work tasks between the units. The improvements "Automated spare part list" and "Automated assembly time calculation" were suggested in order to eliminate the process steps for the small engineering projects, and reduce cycle time for the engineering projects containing external material. They were estimated to save 2519 hours annually, which corresponds to 151 100 €, as well as eliminated hidden costs of all units maintaining their own tools and information connected with these process steps. The direct benefit will however come in the form of increased capacity. The third concrete improvement suggestion focused on using a knowledge base as a communication channel in order to communicate standards, guidelines and information in order to reduce waste, lower communication barriers and increase standardization. The knowledge base was believed to contribute to lower learning periods when shifting personnel between units as well as less time required to train new employees. It is intended as the backbone of a broad possibility of applications.

Control parameters were suggested based on the improvement recommendations. The control parameters were focused on measuring if the solutions were used to the desired extent rather than measuring the gains. The new KPI sales/hour was proposed, which can be used to measure the gains of several LSS projects and improvement actions regarding engineering projects. When the sales/hour was plotted for historic data, it was evident that the company had been unable to improve their engineering processes significantly during the last two years, and that the initial problem background is valid; they could only grow by spending more hours. This result is important since it visualizes the problem for the first time and it is thus easier for higher management to take decisions.

10 Analysis

The three point estimation was used several times throughout the thesis. More importantly, the results were based on the three point estimation. This means that there is a potential error in the numbers based on the standard deviation. As mentioned by several authors, one of the most common challenges with Six Sigma projects in service operations is the gathering of quality data (Antony et al., 2007; Hensley and Dobie, 2005; Neves and Nakhai, 2011). This statement was also confirmed by this thesis. Cycle time data was not possible to gather, which meant that the basis of the report had to be based on estimations. The thesis conducted by Gerremo (2017) also found that the engineering time was not reported to the desired extent, which makes it hard to use the data for analysis. This thesis proposed to introduce reporting of cycle times in engineering projects as a recommendation for future improvement projects. Having access to this data facilitates future improvement projects within the LSS organization in the company. Another challenge mentioned by Neves and Nakhai (2011) is that data in service operations lack reliability since it is often collected by verbal communication. This statement was also confirmed during the thesis. Situations occurred when different interviewees had contradicting statements, which made it hard to rely on the data.

Another encountered issue was the difficulty to define waste within the process. Many waste modes found were hidden within the process and thus hard to discover. There were frequent discussions with stakeholders on which activities that could be classified as waste, since there were often disagreements. This connects with the statement from Åhlström (2004), that defining waste in service operations is subjective, in contrast to manufacturing. What one considers waste may be value-adding to someone else.

The major gains of this thesis was decreasing of non-value adding activities, increased standardization amongst the units and increased efficiency in the operations. These were also some of the benefits of Six Sigma in service operations mention by Antony (2006). This case study thus confirms both reported benefits and challenges with using Lean Six Sigma in service operations.

11 Conclusion

This project had the aim to increase capacity for FlexLink by reducing the time required to complete engineering projects. The thesis was performed according to the DMAIC cycle known from LSS methodology. Furthermore, the thesis was a part of the global LSS program deployed by Coesia and followed the internal LSS procedures adopted by the organization.

The research questions focused on the factors affecting the engineering time for small projects, enhancement of engineering tools and alignment of this report with LSS theory in service operations. It was found that the engineering time was mostly affected by the assembly drawings and repetitive tasks such as assembly time calculation and project documentation. Producing the assembly drawings was expected to be a time consuming task in the engineering projects, since it is the main delivery of the process. There were also ongoing larger improvement projects regarding this area. The focus was therefore directed to the repetitive tasks. These tasks were also highly relevant with respect to the research question of how to enhance the engineering tools. All the repetitive tasks with a high amount of manual information transfer were candidates for automation. Concrete improvement recommendations were formulated on how to enhance the engineering tools so that two process steps could be automated. It was estimated that this would bring savings of 1.5 MSEK. The savings would be noticeable as increased capacity in the organization. This thesis also started discussions on automating other process steps. There were also several other benefits of process automation besides the savings. Automation of repetitive tasks received positive feedback from the engineers, since they all agreed on that these tasks were the least stimulating in their daily work. Furthermore, it would remove hidden waste by standardizing process between the different units.

12 References

Ahlstrom, P. (2004). Lean service operations: translating lean production principles to service operations. *International Journal of Services Technology and Management*, 5(5/6), p.545.

Antony, J., Jiju Antony, F., Kumar, M. and Rae Cho, B. (2007). Six sigma in service organisations: Benefits, challenges and difficulties, common myths, empirical observations and success factors. *International Journal of Quality & Reliability Management*, 24(3), pp.294-311.

Antony, J. (2006). Six sigma for service processes. *Business Process Management Journal*, 12(2), pp.234-248.

Assarlind, M., Gremyr, I. and Bäckman, K. (2013). Multi-faceted views on a Lean Six Sigma application. *International Journal of Quality & Reliability Management*, 30(4), pp.378-402.

Bañuelas, R., Antony, J. and Brace, M. (2005). An Application of Six Sigma to Reduce Waste. *Quality and Reliability Engineering International*, 21(6), pp.553-570.

Bergman, B. and Klefsjö, B. (2010). *Quality from Customer Needs to Customer Satisfaction*. 3rd ed. Lund: Studentlitteratur AB, pp.37-45, 51-52, 567-580.

Bryman, A. and Bell, E. (2003). *Business research methods*. 1st ed. Oxford: Oxford University Press.

de Koning, H., Verver, J.P.S., van den Heuvel, J., Bisgaard, S., & Does, R.J. (2006) Lean Six Sigma in Healthcare. *Journal for Healthcare Quality*, Vol. 28, No 2. Pp. 4-11

Declaration of Incorporation - Work equipment and machinery. (n.d.). [online] Hse.gov.uk. Available at: http://www.hse.gov.uk/work-equipment-machinery/declaration-incorporation.htm [Accessed 4 Nov. 2016].

Gerremo, E. (2017) *Improving Engineering Process productivity when visualizing waste and mitigating variation*. Gothenburg: Chalmers University of Technology. (Diploma work at Department of Materials and Manufacturing Technology)

Griffin, R. and Pustay, M. (1999). *International business: A Managerial Perspective*. 2nd ed. Addison-Wesley Publishing Company, Inc, pp.327-329, 347-356.

Hammersberg, P. (n.d.). *3 point estimate*.

Hensley, R. and Dobie, K. (2005). Assessing readiness for six sigma in a service setting. *Managing Service Quality: An International Journal*, 15(1), pp.82-101.

Kerzner, H. (1998). *Project Management, Sixth Edition*, Wiley & Sons, 1998, pp. 660-661.

Leung, K., Bhagat, R., Buchan, N., Erez, M. and Gibson, C. (2005). Culture and international business: recent advances and their implications for future research. *Journal of International Business Studies*, 36(4), pp.357-378.

Liker, J. (2004). *The Toyota way: 14 Management Principles from the World's Greatest Manufacturer*. 1st ed. New York: McGraw-Hill.

Machinery - Growth - European Commission. (2017). [online] Growth. Available at: http://ec.europa.eu/growth/sectors/mechanical-engineering/machinery [Accessed 4 Nov. 2016].

Neves, J. and Nakhai, B. (2011). Six Sigma for services: a service quality framework. *International Journal of Productivity and Quality Management*, 7(4), p.463.

Pacheco, D., Pergher, I., Vaccaro, G., Jung, C. and ten Caten, C. (2015). 18 comparative aspects between Lean and Six Sigma. *International Journal of Lean Six Sigma*, 6(2), pp.161-175.

Psychogios, A., Atanasovski, J. and Tsironis, L. (2012). Lean Six Sigma in a service context: A multi-factor application approach in the telecommunications industry. *International Journal of Quality & Reliability Management*, 29(1), pp.122-139.

Schroeder, R., Linderman, K., Liedtke, C. and Choo, A. (2008). Six Sigma: Definition and underlying theory. *Journal of Operations Management*, 26(4), pp.536-554.

Slack, N., Chambers, S. and Johnston, R. (2010). *Operations management*. 6th ed. Harlow, England: Financial Times Prentice Hall.

The new improvement frontier. (2005). *Strategic Direction*, 21(11), pp.33-35.

Wedgwood, I. (2006). *Lean sigma: a practitioners' Guide*. 1st ed. Upper Saddle River, N.J.: Prentice Hall.

13 Appendix

Process step	m, most likely	a, optimistic	b, pessimistic	e, expected	s, standard deviation	v, variance
Concept design FLDT	1	0,3	5	1,55	0,7833	0,6136
Calculate assembly time	0,3	0	1,5	0,45	0,25	0,0625
Familiarize with quotation	2	0,3	5	2,2167	0,7833	0,6136
Detailed layout design	5	1	40	10,1667	6,5	42,25
Book workshop time (+time spent in workshop)	1	0,2	6	1,7	0,9667	0,9344
Order FlexLink material	0,5	0,2	1,5	0,6167	0,2167	0,0469
Prepare purchase of external material	1	0	4	1,3333	0,6667	0,4444
Make project documents	2,5	1	5	2,6667	0,6667	0,4444
Send documents to customer	0,3	0,1	0,5	0,3	0,0667	0,0044
Total (Hours)				**21**	**6,7390**	**45,4144**

Three point estimation of cycle times

Input	Class	Step	Output	Notes
Concept drawing Excel calculation tool	C C	Calculate assembly time	Budgeted assembly time	
Quotation Concept drawing Customer order	S C S	Familiarize with quotation	Project knowledge	
Project knowledge Concept drawing	C C	Detailed layout design	Assembly drawing Customer drawing BOM list (External material drawing)	
Budgeted assembly time	C	Book workshop time	Workshop template	
Customer drawing	C	Approve FDR	Approved FDR	
Approved FDR Assembly drawing BOM list	N C C	Order Flexlink material in webshop	Internal material for assembly	
Approved FDR External material drawing BOM list	N C C	Prepare purchase of external material	Information to purchasing department	
Assembly drawing BOM list European Machine directive standards	C C S	Make project documents	Spare part list Risk analysis Operating manuals	
Assembly drawing Budgeted assembly time Internal material External material	C C C C	Assembly	Finished conveyor system	

P-Map

	Waste type	Transport	Motion	Inventory	Waiting	Over-processing	Overproduction	Rework	
Process Step/Origin	**Process Input**								**Total**
Detailed layout design	Assembly draw ings (C)	0	3	0	1	9	0	9	**220**
Detailed layout design	Know ledge (C)	0	1	0	1	9	0	9	**200**
Make production binder	Production binder EOPL (C)	3	3	0	0	9	0	0	**150**
Make project documents	Spare part list (C)	0	0	1	0	9	0	0	**100**
Calculate assembly time	Assembly time calculation (C)	0	0	0	0	9	0	0	**90**
Approve FDR	Approved FDR (N)	0	0	0	9	0	0	0	**90**
Send documents to custo	Declaration of incorporation (C)	1	1	1	1	0	0	0	**40**
Book w orkshop time	Workshop template (C)	1	3	0	0	0	0	0	**40**
Make project documents	Operating manual (C)	0	0	1	0	3	0	0	**40**
Make project documents	Risk analysis (C)	0	0	1	1	1	0	0	**30**
Assembly	External material (C)	0	0	0	3	0	0	0	**30**
Assembly	Internal material (C)	0	0	0	1	0	0	0	**10**
Familiarize w ith quotation	Quotation (S)	0	0	0	1	0	0	0	**10**
Approve FDR	Customer draw ing (C)	0	0	0	0	0	0	0	**0**
Familiarize w ith quotation	Concept draw ing (C)	0	0	0	0	0	0	0	**0**
Familiarize w ith quotation	Customer order (S)	0	0	0	0	0	0	0	**0**
Make project documents	European machine directive standards(S)	0	0	0	0	0	0	0	**0**
Order Flexlink material in w	BOM list (C)	0	0	0	0	0	0	0	**0**
Prepare purchase of exte	External material draw ing (C)	0	0	0	0	0	0	0	**0**
	Waste category total	5	11	4	18	49	0	18	

Cause and Effect matrix