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Applying lean principles to order-to-delivery process for spare parts with embedded software

Master's Thesis
Espoo, October 3, 2016

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ABSTRACT OF MASTER'S THESIS

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AC drive manufacturers promise product support for their products for decades. In AC drives there are components which are installed with software and providing product support includes being able to supply these components as spare parts. To ensure that these operations are efficient, we apply the lean principles to them. Because the range of product variants in this case is extremely vast, it is not reasonable to focus on improving the process of all products equally.

The goal of this thesis is to find out, on which products the improvement efforts should be focused, how the lean principles can be applied to the process and what kind of effect applying lean principles to this process has. As a result, suggestions for the case company are given in order to improve their performance.

The products are divided into four product groups that are prioritized according to their sales volumes. By using 80/20-principle, we decide to focus on two product groups which account for 77% of total sales volume. In the order-to-delivery process customer values short delivery time and high product quality. During the process there are interruptions caused by insufficient order information. As there is no continuous improvement process in place for this process, these problems keep on recurring. We form a picture of perfection which describes the future state of the process. In this picture we ensure that high quality products are delivered to the customers with no interruptions in the process flow by applying poka-yoke to the software installation process, practicing 5S, implementing continuous improvement process to the order-to-delivery process and maintaining and improving standards.

Keywords: Lean, AC drive, 80/20-principle, order-to-delivery process, embedded systems, Lean principles, Lean tools

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Taajuusmuuttajavalmistajat lupaavat tuotetuen tuotteilleinsa kymmeniksi vuosiksi. Taajuusmuuttajat sisältävät komponentteja, joihin tulee asentaa ohjelmisto, ja tuotetuki sisältää näiden komponenttien tarjoamisen varaosina. Varmistaaksemme, että näiden varaosien tilaus-toimitusprosessi on tehokas, sovellamme siihen Lean-periaatteita. Koska tuotevalikoima on tässä tapauksessa erittäin laaja, ei ole järkevää keskittyä parantamaan prosessia kaikkien tuotteiden osalta tasapuolisesti.

Tämän diplomityön tarkoituksena on selvittää, minkä tuotteiden tilaus-toimitusprosessin parantamiseen tulisi keskittyä, miten Lean-periaatteita voidaan soveltaa prosessiin ja millainen vaikutus Lean-periaatteiden soveltamisella tässä prosessissa on. Näiden tulosten pohjalta kohdeyritykselle annetaan ehdotuksia, joilla he pystyvät parantamaan tilaus-toimitusprosessin tehokkuutta.

Varaosat ovat jaettu neljään tuoteryhmään, jotka priorisoidaan niiden myyntimäärien perusteella. Käyttämällä 80/20-periaatetta päätämme keskittyä kahteen tuoteryhmään, joiden osuus on 77% kokonaismyyntimäärästä. Tilaus-toimitusprosessissa asiakas arvostaa lyhyttä toimitusaikaa ja tuotteiden korkeaa laatua. Tilaus-toimitusprosessin aikana tapahtuu pysähdyksiä, jotka johtuvat riittämättömistä tilaustiedoista. Koska tilaus-toimitusprosessiin ei ole otettu käyttöön jatkuvan parantamisen prosessia, nämä ongelmat toistuvat. Muodostamme kuvan täydellisyydestä, joka nyt kuvaa prosessin tulevaisuuden tilaa. Tässä kuvassa varmistamme, että korkealaatuisia tuotteita toimitetaan asiakkaille ilman keskeytyksiä käyttämällä poka-yokea ohjelmiston asennuksen yhteydessä, harjoittamalla 5S:ää, ottamalla käyttöön jatkuvan parantamisen prosessin tähän tilaus-toimitusprosessiin ja ylläpitämällä sekä kehittämällä standardeja.

Asiasanat:	Lean, taajuusmuuttaja, 80/20-periaate, tilaus-toimitusprosessi, sulautetut järjestelmät, Lean periaatteet, Lean-työkalut
Kieli:	Englanti

Preface

The thesis in front of you, "Applying lean principles to order-to-delivery process for spare parts with embedded software", was written to fulfill the graduation requirements for Master's Degree Programme in Electronics and Electrical Engineering at Aalto University School of Electrical Engineering. This thesis kept me busy from March to October 2016.

This thesis was conducted for ABB Drives service. I would like to thank Mikael Qvikström for arranging me this excellent opportunity. I would also like to show my gratitude to Mika Erkkilä for sponsoring this thesis and Vesa Vanhatalo for instructing me throughout the thesis. I am also grateful to all other colleagues at ABB who have helped me during this thesis writing process.

I would like to thank professor Seppo Ovaska for supervising my thesis and giving valuable insights. I would also like to thank RWTH Aachen University where I learned a lot of useful things during my exchange semester.

To my family and friends, thank you for helping me endure through this thesis writing process. And finally, I would like to express my gratitude to my girlfriend Tiina who has been supporting me all along and has found time for proofreading and discussion. Thank you for being there for me.

Espoo, October 3, 2016

Joel Alander

Abbreviations and Acronyms

ABB	Asea Brown Boveri
BOL	Business-Online
DIB	Drives installed base
FPY	First pass yield
IOT	Internet of things
JIT	Just-in-time
MTO	Make-to-order
OEE	Overall equipment effectiveness
PDCA	Plan-Do-Check-Act
SDCA	Standardize-Do-Check-Act
SMED	Single-minute exchange of die
QCD	Quality, Cost and Delivery
QFD	Quality function deployment

Contents

Chapter 1

Introduction

1.1 Description of the problem

AC drive manufacturers promise customers product support and spare part availability for their products for decades. Because the life cycle of an AC drive can be tens of years, there are numerous product families that need to be supported simultaneously. As the product structures are different for each product family, the range of spare part variants is vast.

AC drives contain components that require software installation. In this study we focus on the order-to-delivery process for such spare parts. The challenges in this case environment lie in the product information structures and different types of order-to-delivery processes for each product family.

1.2 Objectives and scope

The main objective of this case study is to map and analyze the order-to-delivery process for spare parts with embedded software. The focus will be in product families with highest sales volumes. For mapping and analyzing we use lean principles and lean tools. In the end we should have a good understanding of the process and by using lean principles and tools, have some improvement suggestions for the case company. Lean principles and tools, such as kaizen, were chosen because they are low-cost, effective [Imai, 1997] and they suit well on environments with large amount of different products [Womack et al., 1990].

The research questions of this thesis are:

- On which products should the effort of applying the lean principles be focused on?
- How can the lean principles be applied to the case environment?
- What kind of effect does applying the lean principles have on the order-to-delivery process performance?

1.3 Structure

This thesis consists of introduction, background description, order-to-delivery process description, literature review of lean manufacturing and 80/20-principle, analysis, discussion and conclusions. In the background Section we take an overall look at the case company, AC drives, service products for AC drives and ABB Drives service workshop. After the background Section, current order-to-delivery process is described. In the literature review we take a look at the lean manufacturing in general, lean principles, lean tools, waste and 80/20-principle. The analysis starts with prioritizing the products. After that we apply the lean principles to the case environment. Finally, we discuss what kind of effect application of lean principles has and make conclusions.

Chapter 2

Case background

2.1 Case company

The case company in this study is Asea Brown Boveri (ABB). ABB is a global technology company with focus on power and automation which enables utility, industry, transport and infrastructure customers to improve their performance and to lower their environmental impact. ABB group operates in roughly 100 countries and has about 135 000 employees. ABB's revenue was 35 481 million dollars in 2015 [ABB, 2016a]. ABB group has four divisions: Electrification Products, Discrete Automation and Motion, Process Automation, and Power Grids. This study was conducted for ABB Drives service which is part of ABB's Discrete Automation and Motion division. Each country where ABB has operations has its own local ABB unit. These local ABB units are responsible for sales in that area. Orders received by ABB Drives service are created by these local ABB units or ABB's partners who eventually deliver the product to the end customer.

2.2 AC drives

Electrical motors play an essential role in our everyday business and lives as they move and run almost everything we need for business and pleasure. AC and DC drives can be used to control these motors. AC drives, also known as variable frequency drives, adjustable speed drives, adjustable frequency drives, variable speed drives, frequency converters, inverters and power converters [Danfoss, 2016a], convert fixed frequency AC power to variable frequency and variable voltage AC power. To do this, the rectifier of an AC drive first converts the input AC voltage to a DC voltage. Then the resulting DC voltage is smoothed with capacitors. When the DC voltage is smooth, the AC drive calculates the required voltage and current for the motor and feeds DC power to inverter producing AC power at the precise current and voltage required. An example of the main circuit of an AC drive is shown in Figure 2.1. [ABB, 2016c]

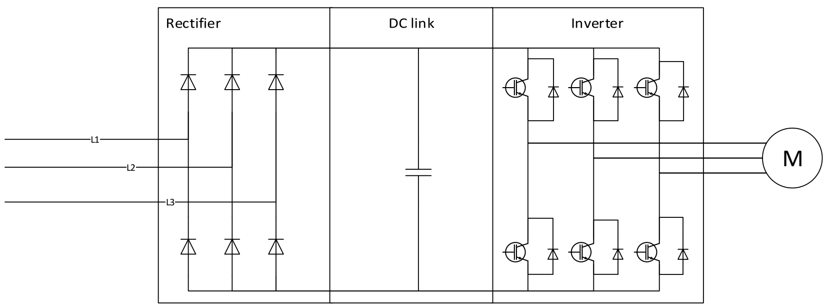

Figure 2.1: The main circuit of an AC drive

Significant energy savings can be achieved with AC drives. This is a result of running motors based on the current demands of the process instead of running them at full speed and using mechanical controls, such as throttles, to reduce the output. [ABB, 2016b] For example, one of the most common AC drive applications are pumps which consume approximately 1850 TWh of energy annually. If all these pumps were controlled by AC drives with average saving potential of 40 percent, the total savings would be 740 TWh every year. ABB's AC drives saved 445 TWh of energy in 2014. [ABB, 2016d]

2.3 Service products for AC drives

Service business offers new sources of revenue and often has higher profit margins than product manufacturing. That is why industrial manufacturers focus on developing services in addition to their core business in order to secure their future growth and maintain their position in the marketplace. [Jacob and Ulaga, 2008; Wise and Baumgartner, 1999] AC drive manufacturers offer many different types of service products for their drives. In Table 2.1 are shown service products which are offered by some AC drive manufacturers [ABB, 2016e; Siemens, 2016; Danfoss, 2016b; GE, 2016].

In this case we mostly focus on spare parts although we may also face some issues related to the drive exchange service. Spare parts in this case can be sold separately or in kits. For some products the software is a spare part article itself.

2.4 Drives service workshop

The Drives service workshop, which consists of multiple workstations and a warehouse, is located in Vantaa, Finland. Among other things, AC drive repairs, small scale AC drive module production and software installation operations take place there. The operations at the workshop are small scale because the sales volumes are relatively low and the amount of product variants is high. As the warehouse for spare parts for AC drives and software installation operations are located in the workshop, the picking-to-delivery part of the order-to-delivery process is carried out there.

Table 2.1: Service products offered by AC drive manufacturers

Service product	Description
Drive exchange service	Customer getting a functioning drive in exchange for an old drive
End-of-life services	Assisting customer with disposal and recycling of an old drive
Engineering and consulting	Analyzing production, safety and energy efficiency of customers' machines and systems
Installation and commissioning	Installation and commissioning of AC drives
Life-cycle assessment	Analyzing customers' installed base and providing customers information of the life-cycle of their drives
Maintenance	Maintenance of AC drives
Remote condition monitoring	Remote monitoring of AC drives giving accurate information in real-time about drive's condition
Repairs	Repair service for AC drives
Retrofits	Installing a new drive into frame of an existing drive so that the original cabeling and motor do not need to be changed
Service agreements	Predefined services that are included in an agreement
Spare parts	Spare parts for AC drives
Training	Training customers safety, troubleshooting skills and drive usage
Upgrades	Upgrading an existing drive with new technology

Chapter 3

Order-to-delivery process

3.1 General

In this section we describe the order-to-delivery process for spare parts with embedded software. The process consists of five phases:

1. Ordering process
2. Order picking
3. Software installation
4. Labelling
5. Packaging and delivery of the product.

A flowchart of the process is presented in Figure 3.1. As we can see from the flowchart, repair engineers are responsible for software installation and labelling, external logistics workers are responsible for collection and packaging and naturally the customer does the ordering of the product. A repair engineer is assigned for "software installation duty" for each day which means that they are responsible for software installations during that day. This repair engineer works from 9.30 AM to 6.00 PM. External logistics workers work in two shifts and they are on the premises from 7.00 AM to 7.00 PM.

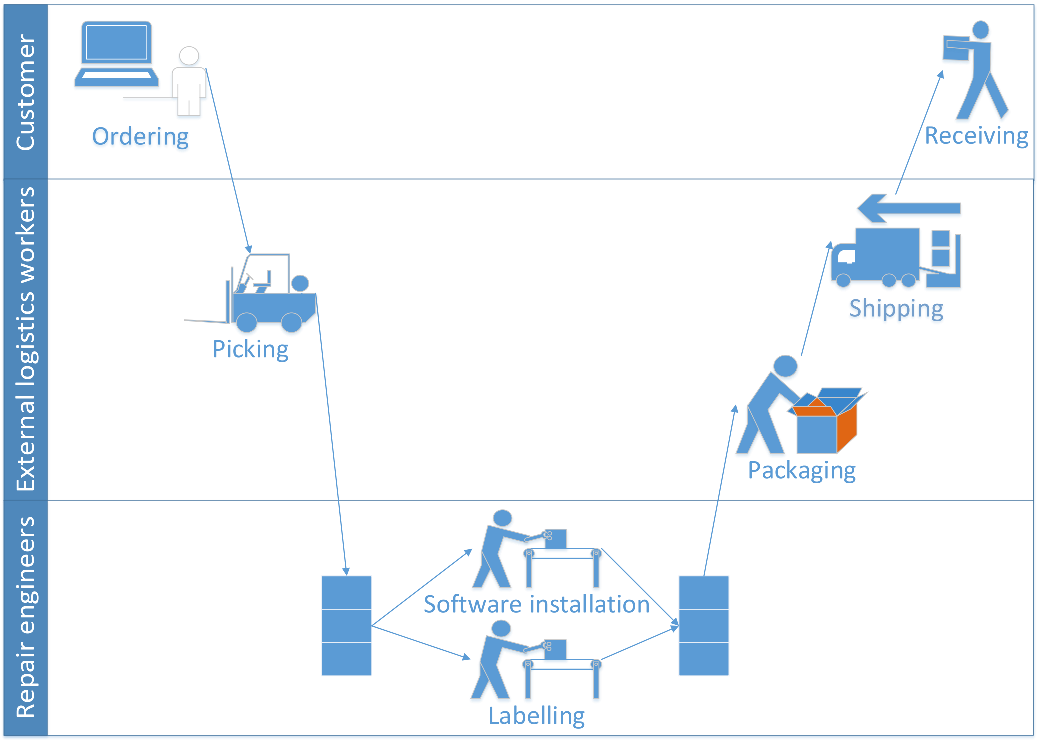

Figure 3.1: The order-to-delivery process for spare parts with embedded software

3.2 Ordering process

In this section we discuss the ordering process shown in Figure 3.2. The ordering process starts with the customer having a need for a product. Customers in this context are usually ABB's service partners or internal customers who work for ABB's local organizations. When customer knows which product is needed, they can make an order themselves in Business-online (BOL) which is a web store for spare parts of ABB's products. If customer does not know which products are needed they can contact the sales, support which helps them to choose the right products.

Once the order is made and is correct, it proceeds automatically to the company's ERP system. However, if there is information missing or if some detail in the order requires additional attention, the system assigns the order to one of the customer service employees who checks the order, fills the missing information and if necessary, asks customer

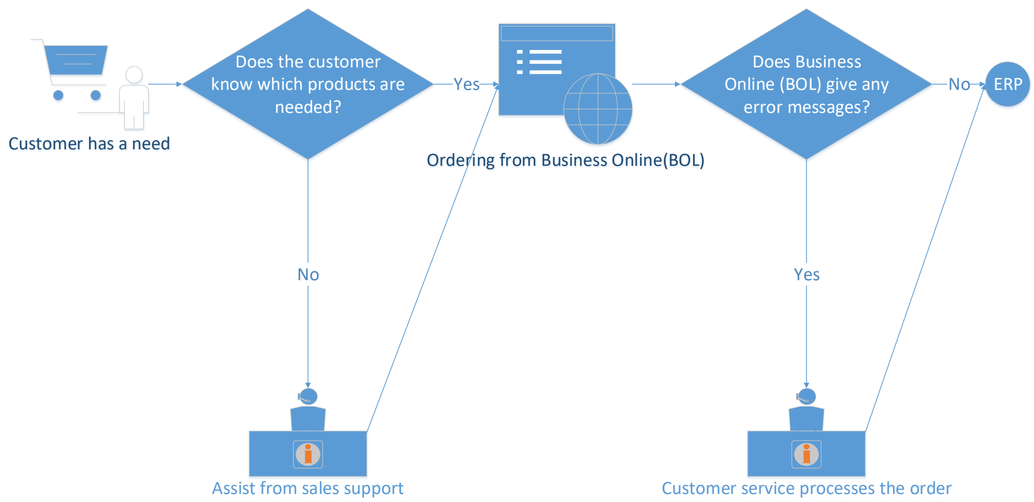

Figure 3.2: Ordering process for spare parts for AC drives

for additional information.

ABB has developed a system called Drives installed base (DIB). This system is a database of installed base of ABB's drives. Among other things, DIB helps ABB's partners and local organizations to choose correct spare parts for their customers by providing information about the assembly of their customer's drives. The system contains a list of components for each drive and clicking the material code of one of these components directs the user to the BOL page for equivalent spare part.

3.3 Order picking

At the workshop the delivery process starts with picking the product from the warehouse. ABB has promised a certain delivery time for each order. The ERP system sets a delivery date for each order based on the promised delivery time and customer's possible preferences. This delivery date is the piece of information which triggers the delivery process. When the delivery date is close, a picking list prints out automatically at the warehouse's picking station. The background program (which is an ERP system extension) for printing the picking list runs every 15 minutes. If none of the picked products require software installation, they are delivered to the packaging area after picking.

The need for software installation can be indicated in the picking list in three ways:

1. Software is ordered as a separate product and it has its own line in the picking list
2. There is an automatically generated special note in the picking list which states that software installation is required
3. Customer has mentioned the need for software installation in open text field.

If there is a need for software installation, the product is delivered to the software installation area which has its own buffer for the picked products. If the order includes multiple different products, some of which require software installation, there are two ways of doing the picking. The first way is to pick everything and deliver the cart to the software installation area with a note which tells the repair engineer to return the cart to the warehouse worker who finally delivers the cart to packaging. The other way is that the warehouse worker tells the repair engineer the location of the cart at the packaging station and asks them to bring the product there when the installation is complete.

The picking process itself is simple. Once a picking list prints out, a warehouse worker reads a bar code from the picking list with a small hand held computer which is connected to the ERP system. Then the ERP system tells the warehouse worker where the product can be picked. After picking the product, the bar code of the product is read and the quantity of the picked products is typed manually into the system. After this, the ordered products proceed to the next step which is packaging or software installation.

3.4 Software installation

The software installation area is located in the same building as the warehouse. Products with need for software installation are collected to a buffer with their picking list. The repair engineer starts the software installation process with checking from the picking list, which software needs to be installed. Then they set up the installation system and install the software.

The amount of product variants which are installed with software at the software installation station is high because ABB offers spare parts for products that have been sold during the last three decades. This means that product support exists for some products which have been designed in the 1980's as well as for products which are sold today. Each product family has its own product structure which means that each product family has its own way of how the software is installed.

The software installation station consists of five computers from which one runs Windows XP and other the four run Windows 7 operating system. These computers are used for the software installation. Windows 7 computers are practically identical so the software installation can be done the same way on any of them. The computer with Windows XP operating system is used for specific products on which the software installation is significantly faster on Windows XP than on Windows 7. At the software installation station there are also other tools which are used for software installation. The instructions for software installations are located in binders which have their own shelf. There is a designated specialist working at the workshop who is responsible for keeping the instructions and software installation systems up to date.

3.5 Labelling

Labelling is carried out at the software installation area. The labels for the products are printed using printers which are connected to computers which are also used for software installation. The printers print labels of different sizes. Company's ERP system has a feature for printing labels but it is not compatible with labels of smaller size.

A major issue with printing labels is that it requires a lot of manual work. The labels are usually designed and printed while the software is installing. The design of the label is made with a software which came with the label printer. According to the software operations specialist, it is not possible to automate this process as the ERP system does not support that kind of label machines. After the software installation and labelling of the product is complete, the product proceeds to the packaging station.

3.6 Packaging and delivery

After the software is installed, the products are delivered for packaging. Before the packaging operation, the product waits in a buffer. Once the product is packed, it is moved into another buffer where it waits until it is loaded into a truck. From then on the delivery process is handled by an external logistics company. ABB uses services of multiple different logistics companies and there are trucks leaving from the workshop multiple times a day.

Chapter 4

Lean production

4.1 Introduction to lean production

In this chapter we take a look at the literature related to lean production. First we start with introduction to lean production moving on to Lean thinking, Waste and Lean tools.

According to Dahlgaard-Park and Pettersen [2009] there is no consensus on the definition of lean production among authors and the authors have different opinions on the characteristics of lean. Therefore we need to take a look at the origins of lean production. Lean production originates from the Toyota production system which was invented by Taiichi Ohno. The first book where lean production was introduced was "A machine that changed the world" [Womack et al., 1990].

In order to understand what lean production is, we must first take a look at mass production. Mass production was invented by Henry Ford and it was first implemented at Ford's production plant in the beginning of twentieth century. Mass production system had continuous flow which was reached through delivering parts to each work station, part interchangeability and moving assembly line. This continuous flow had significant impact on the production performance. For example, in 1913 when craft production was still practiced, the effort required to assemble major components into a complete vehicle took 594 minutes. In 1914 when mass production began, the same operation required only 226 minutes of effort. Since the parts were interchangeable, the skill requirements for assemblers decreased dramatically because now they only did a single task which could have been taught in five minutes instead of assembling the whole car by themselves. This decreased the cycle time of a single worker from 514 to 1,19 minutes. In mass production companies usually only the "white-collar" employees, such as engineers, had a career path. Shop-floor workers instead were practically stuck in their position for life. The weakness of mass production is its extreme inflexibility. Since the assembly line consists of machines that can produce only specific identical products at high volume, changing them takes a lot of time. [Womack et al., 1990]

Lean manufacturing started to develop in Japan in 1950's. The reason for the development of lean manufacturing was that mass production was simply not possible there. New labor laws in Japan had strengthened the position of workers and as Japanese economy was not doing well, they could not afford any western mass production technology. [Womack et al., 1990]

The first lean manufacturing concept was fast setup time of machines. This concept is commonly known as Single-minute exchange of die (SMED) which was first introduced by Shingo [1985] (even though the term of lean manufacturing was introduced in 1990, the lean manufacturing concepts existed before that). Single minute here does not refer to changeover within one minute, it means being able to do it in one digit minutes (less than ten). Fast machine changeovers made lean production extremely flexible. Also producing small batches instead of large batches was a major difference between lean production and mass production. Running small batches developed later into one-piece flow and Just-in-time (JIT) system. [Womack et al., 1990]

In lean manufacturing, problems are handled immediately. When abnormality occurs, the whole production line stops and everyone starts to work on the problem. Usually at the lean production line a technique called "five why's" is used for solving problems. The idea of the technique is to ask "why" five times in order to identify the root cause for a problem. After the root cause has been identified its recurrence is prevented. This way the production system is improved continually. This concept of continuous improvement is known as Kaizen. [Womack et al., 1990]

Liker [2004] introduces fourteen management principles in his book "The Toyota way". These management principles can be seen as guidelines for managing a lean organization. These principles are:

1. Making management decisions based on long-term philosophy

2. Creating continuous flow to make the problems visible
3. Usage of pull systems to avoid overproduction
4. Leveling out the workload
5. Building a culture of stopping to fix problems and getting the quality right the first time
6. Standardizing tasks, making Kaizen and employee empowerment possible
7. Usage of visual controls
8. Usage of only reliable technology which serves people and processes
9. Grow leaders who understand the work, live company's philosophy and teach it to others
10. Development of exceptional people and teams who follow company's philosophy
11. Respecting extended network of partners and suppliers by challenging them and helping them to improve
12. Going to the place where the action occurs and seeing what is happening to thoroughly understand the current situation
13. Slow decision-making by consensus considering all options and rapid implementation
14. Becoming a learning organization through relentless reflection and Kaizen

These principles give a good idea what kind of characteristics lean companies have. Even though lean originates from manufacturing, it can also be applied to other industry segments, such as cost accounting [Huntzinger, 2007].

Shah and Ward [2007] conducted a study on defining and developing measures of lean production. They took a sample of companies which were identified as practicing lean manufacturing and characterized, by using data analysis, which are the distinct dimensions of lean system. They ended up with following ten dimensions:

1. Providing regular feedback to suppliers about their performance
2. Ensuring that suppliers deliver the right quantity at the right time in the right place
3. Developing suppliers so that they can be more involved in the production process of the focal firm
4. Focusing on customers and their needs
5. Facilitating JIT production including kanban cards which serve as a signal to start or stop production
6. Establishing mechanisms that enable and ease the continuous flow of products
7. Reducing process downtime between product changeovers
8. Addressing equipment downtime through total productive maintenance and thus achieve a high level of equipment availability
9. Ensuring each process will supply defect free units to subsequent process
10. Employees are involved in problem solving and they have cross-functional character

To summarize this section I quote Oppenheim [2011]: "it is useful to think of lean simply as "creation of best value with minimum waste"".

4.2 Lean principles

4.2.1 General

In this section we discuss the five lean principles introduced by Womack and Jones [2003] in their book "Lean thinking: Banish waste and create wealth in your corporation". These five lean principles are:

1. Value
2. Value stream
3. Flow

4. Pull
5. Perfection.

Oppenheim [2011] has added a sixth principle, respect for people, which can be also seen as a major characteristic of a lean organization. In this thesis we focus only on the five original principles.

4.2.2 Value

The first of the five lean principles is value. Defining value is usually hard because most producers are used to producing what they have been producing all the time and customers only know how to ask for a product variant they have been purchasing all the time. Value creation usually goes through multiple companies, each of which have their own way of defining value. In these cases, when the value defined by each company is summed together the sum accounts for more than the product's value is to the customer. [Womack and Jones, 2003]

Producers and customers usually rethink value by using simple formulas such as lower cost, increased product variety through customization or instant delivery. Instead of doing the value rethinking the conventional way, they should analyze the value together and challenge the old definitions of what is really needed. If a company finds a mechanism for rethinking the value, they can reach higher sales by finding new customers and boosting the sales of existing customers. Value rethinking needs to be continuous process. [Womack and Jones, 2003]

After value has been properly defined, a target cost must be set. The target cost should be based on the amount of resources and effort needed to make a product with given specifications and capabilities when all waste is removed from the process. This is very different from the conventional way of defining value by thinking which price the markets can take and define the target cost using the market price with sufficient profit margin. Because the target cost of lean enterprise is always lower than conventional company's, lean enterprise can reduce prices to increase sales in order to utilize freed-up resources, add features to a product to increase sales, add services to a physical product to create more value, expand the distribution and service network or take profits to design new products. [Womack and Jones, 2003]

4.2.3 The value stream

The second lean principle is the value stream. Value stream means all the actions currently required to bring the product through the production flow from raw materials to a product in customers' hands or through the product development process from concept to launch [Rother and Shook, 1999]. According to Rother and Shook [1999] there is always a value stream behind a product for a customer but it is challenging to see it. If the activities which are necessary to design, order and produce a specific product are not clearly identified, analyzed and linked together, they cannot be challenged, improved and eventually perfected. In order to really understand the value stream, one has to draw a value stream map in which all the actions are divided into three different categories:

1. Actions which create value to customers
2. Actions which do not create value to customers but cannot be eliminated yet because product development, order filling or production system needs them
3. Actions which do not create value to customers and can be eliminated immediately

Usually lean producers notice during benchmarking their operations that their operational efficiency is superior to their competitors and thus they have natural tendency to relax. Mass producers usually have hard time realizing why they are lacking in performance and they try to find answers from factors like factor costs, scale or company culture. The real answer lies in understanding the hard-to-see value streams. [Womack and Jones, 2003]

4.2.4 Flow

When customer pays for a product, the price also includes all waiting between process steps and rework which do not add any value. Designing, ordering, and delivery of a good or service need to be made flow in order to eliminate these non-value adding steps. Flow is achieved when all necessary steps are lined into a steady, continuous flow without any unnecessary motions, interruptions, batches or queues. Applying flow to human activities is not easy as for some managers it is even hard to identify the value stream behind a product or service. Once managers learn to see the value stream behind a product, there are many practical problems that need to be tackled in order to fully introduce and sustain a flow. The good thing with flow is that it can be applied to any activity with good effect. Usually the amount of human effort, time, tools, and inventories needed to design and produce a specific good or service can be cut in half very quickly, and steady progress can be achieved from that point onward. This way the amount of resources needed should be halved again within a few years. [Womack and Jones, 2003]

In order to reach flow there are three things that need to be kept in mind. First, once value has been defined and the whole value stream has been identified, the focus must be kept on the actual thing which is a specific order, design, or the product itself. Second, the traditional boundaries of jobs, careers, functions and firms must be ignored in order to build a lean enterprise eliminating all barriers preventing continuous flow of a specific product or service. Third, specific work practices and tools must be rethought to eliminate backflows, scrap and stoppages so that design, order, and production of a specific product can proceed continuously. [Womack and Jones, 2003]

In lean product development, teams are formed around a product. Each of the teams does value specification, general design, detailed engineering, purchasing, tooling and production planning in one room in a short period of time using Quality Function Deployment (QFD) method. This way the design process is standardized and the team can follow the same approach every time making it possible to measure the throughput time of the design process and improve it continuously. This is how a company makes its design process flow. [Womack and Jones, 2003]

In production, flow can be reached by taking critical concepts of JIT and level scheduling and carrying them to their logical conclusion of making everything flow continuously. In order to reach continuous flow, the production areas must be designated for each product family and the production steps should be set in a sequence without any buffers in between in a continuous-flow layout, usually located in a single cell. This way a single piece flow is reached. The production systems need to have a "everything works or nothing works"-quality which means that the machinery and people need to be available all the time. The work needs to be standardized and the machines and people need to monitor their own work through poka-yoke (fool-proof system) and this way make it impossible for a defective part to proceed to the next production step. Also visual controls must be in place through 5S. Unfortunately there are some tools that cannot be easily modified into continuous flow and they need to be run in batch mode for an extended period of time. In these cases it is important to focus on reducing tool changeover times and minimizing batch sizes. These actions are usually easy and almost never require investments. [Womack and Jones, 2003]

The right location is an essential factor in reaching flow. Design and physical production should be located optimally for serving the customer. If the production processes are remotely located, a continuous flow throughout the value stream is not possible. For example, if a factory is located in China, the finished products are loaded into large shipping containers which means large batches. This leads to high costs of logistics and massive unit inventories which lead to obsolete goods which are eventually sold at large discounts. When carefully analyzed, these costs and revenue losses are often greater than the savings of production costs from low wages. [Womack and Jones, 2003]

4.2.5 Pull

Pull principle means simply that no good or service should be produced until the the next process step or customer asks for it. In practice this is more complicated. The best way to understand the logic and challenge of pull is to start with a real customer ordering a product and go backwards through all the steps required to bring the product to the customer. When a company learns how to pull products through its system it can respond to customer's orders instantly. Because of company's ability of quick changeovers the production can be started within minutes from customer's order. When pull and flow are in place, product quality usually increases. [Womack and Jones, 2003]

4.2.6 Perfection

The last of the five lean principles is perfection. Even though perfection is impossible to reach, the effort of trying to reach it provides essential inspiration and direction towards making progress. When pursuing perfection, every enterprise needs both radical and incremental continuous improvement approaches. Every process step in a value stream can be improved in isolation with a good effect and there is rarely any reason for investing to improve a process step which may be replaced later anyway. Once the managers learn to see the value stream, flow of value and the value being pulled by the customer, they can learn to see the picture of perfection which ironically is never perfect. That is why once the "perfection" is reached, a new picture of perfection which goes even further needs to be formed. After a picture of perfection has been formed it is important to form a vision and select two or three most important steps which will get you there and leave the other steps to be taken later. The general principle of doing one thing at a time applies to the improvement activities as much as it applies to design, order-taking and production activities. [Womack and Jones, 2003]

When pursuing perfection, managers need to decide which forms of waste they attack first by means of policy deployment. In policy deployment the top management agrees on simple goals and selects a few projects to achieve these goals. To get the projects done, people and resources need to be designated for these projects. Finally, numerical improvement targets need to be set and they need to be reached on time. Most organizations create an annual lean policy deployment matrix which summarizes the goals, projects and targets for those projects for that year so that anyone in the organization can see them. [Womack and Jones, 2003]

4.3 Waste

In this section we discuss about waste. According to Imai [1997] there are eight types of waste:

1. Overproduction
2. Inventory
3. Repairs and rejects
4. Motion
5. Processing
6. Waiting
7. Transportation

8. Time.

Trent [2008] has defined the previous waste types as "traditional waste" and has added "other waste" category with following waste types: too many bits and bytes, untapped creativity, poor measurement, excessive overhead, overdesign, duplication of effort and poor planning. Burton and Boeder [2003] have added human potential into the "traditional waste" category because they feel that it is one of the most important types of waste within an organization. Waste elimination costs nothing which makes it the easiest way for the company to improve the efficiency of its operations [Imai, 1997].

Overproduction results from getting ahead of production schedule. Producing more than is necessary results in large amounts of waste since it consumes raw materials before they are needed, wastes manpower and utilities, requires additions to machinery, increases interest burdens, requires additional space to store excess inventory, adds transportation needs and increases administrative costs. Overproduction is the worst type of waste as it gives false sense of security, covers up all sorts of problems and hides information that could provide clues for continuous improvement. [Imai, 1997]

Inventory consists of final products, semi-finished products, parts and supplies. Excessive material in inventory does not add any value and thus is waste. It increases the cost of operations by occupying space, requiring additional equipment and facilities such as warehouses. Also the quality of items in inventory deteriorates over time. Inventory is a result of overproduction. By lowering the inventory levels, problems are uncovered which gives possibility for improvement. [Imai, 1997]

Repairs and rejects interrupt the production and require expensive rework. Rejects must sometimes be discarded which is a great waste of resources and effort. They can also damage expensive jigs or machines. Any motion that does not add value and any additional processing of information or work piece is waste. Waiting is also waste since if operator is put on hold because of line imbalance, lack of parts or machine downtime, the operator does not add any value. [Imai, 1997]

Transportation is an essential part of operations. Unnecessary transportation does not add any value which is why it is waste. Also there is a risk of the material being damaged during transportation. Time as a waste is critical to be taken into account specially in the service sectors. By eliminating the non-value-adding time, great increases can be achieved in both efficiency and customer satisfaction. [Imai, 1997]

In lean literature, usually Japanese word muda is used for waste. Also words mura and muri are used with the word muda. Mura means irregularity which appears when the smooth flow of operations is interrupted. Muri means strenuous work conditions for workers and machines. [Imai, 1997]

4.4 Lean tools

4.4.1 General

In this section we discuss some of the lean tools. Dirgo [2005] defines following tools as lean tools: Kaizen, Plan-do-check-act (PDCA), Value stream map, 5S, 5 why's, Kanban, Pull, Standard work, One-piece flow, Poka-yoke, Total productive maintenance, Visual factory and Policy deployment. The lean tools that we discuss in this section are Kaizen, 5S, Just-in-time system, Poka-yoke, Total productive maintenance and Value stream mapping. The reason for choosing these tools is that PDCA can be seen as part of Kaizen process and One-piece flow, Pull and Kanban can be seen as part of Just-in-time system. [Imai, 1997]

4.4.2 Kaizen

Kaizen is Japanese and means continuous improvement. It is one of the most frequently used terms in lean world [Dirgo, 2005]. Kaizen should involve everyone - from managers to shop-floor workers. Even though single improvements are small and incremental in Kaizen, it brings great results over time. Imai [1997] introduces following Kaizen concepts:

- Kaizen and management
- Process versus result
- Following the PDCA/SDCA cycles
- Putting quality first
- Speaking with data

- Seeing the next process as customer.

Kaizen and management concept has two major functions: maintenance and improvement. Maintenance is about activities that are directed towards maintaining current technological, managerial and operational standards. It ensures that everyone follows the standard operating procedure. Improvement is about activities directed towards enhancing current standards. Kaizen forsters process-oriented thinking. It means that errors in the process must be identified and corrected in order to improve results. Identifying and correcting process-based errors is management's responsibility. Establishing plan-do-check-act (PDCA, shown in Figure 4.1) or standardize-do-check-act (SDCA) cycle is the first step of Kaizen. In PDCA, "Plan" refers to establishing target for improvement. Since Kaizen is a way of life, there should always be a target for improvement. "Do" refers to implementing a plan to achieve that target. "Check" refers to making sure that the implementation stays on track and that it has brought planned improvement. "Act" means performing and standardizing new procedures to prevent recurrence of the original process-based errors and setting new targets for improvement. [Imai, 1997]

In the beginning a new work process is unstable. Before PDCA, the current process needs to be stabilized using SDCA. In case of abnormality following things should be checked:

- Did it happen because there was no standard?
- Did it happen because the standard was not followed?
- Did it happen because the standard was not sufficient?

Only after the standard has been stabilized, proceeding to PDCA is possible. [Imai, 1997]

According to Imai [1997] quality should always be put first in Kaizen. This means that from quality, cost and delivery (QCD), quality should always have highest priority because products and services that lack in quality are not competitive. Achieving and maintaining high quality requires commitment from management because they often face situations where low prices or meeting delivery requirements tempt them to make decisions which have negative impact on quality. When a company produces products which lack in quality, it puts its entire business at risk. [Imai, 1997]

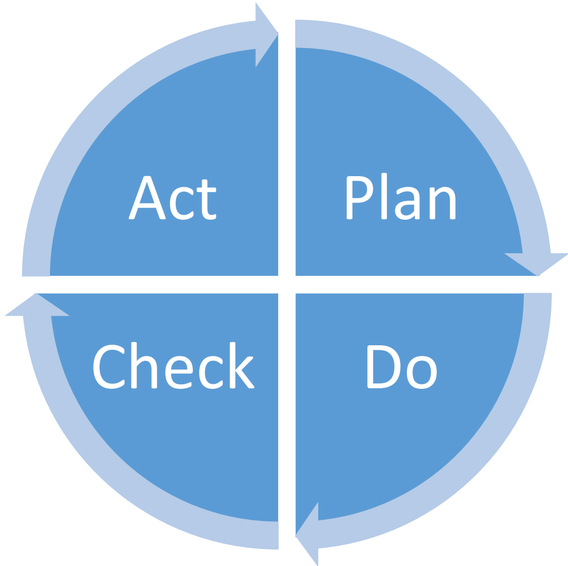

Figure 4.1: Plan-Do-Check-Act cycle

One of the Kaizen concepts is speaking with data. Speaking with data means that in order to correctly understand a problem and solve it, the problem must to be recognized and the relevant data needs to be gathered and analyzed. The focus of improvement efforts should be based on the analysis. [Imai, 1997]

A good way to promote Kaizen is a suggestion system. Suggestion system encourages employees to provide suggestions for improvement. It does not matter how small these suggestions are because they bring great results over time. In Japan employees are often encouraged to discuss the suggestions with their managers right away, even before submitting the suggestion forms. This way the improvement suggestions can be put into action immediately. The main goal of suggestion system is to develop Kaizen-minded and self-disciplined employees. [Imai, 1997]

Small-group activities are informal and voluntary. In small-group activities an intracompany group carries out tasks in a workshop environment. One type of small-group activity is called Quality circle. Quality circle is designed to focus not only on quality issues but also on issues, such as cost, safety and productivity. Management plays a leading role in small-group activities. It builds quality assurance systems, provides employee training, establishes and deploys policies and builds cross-functional systems for quality, cost and delivery. [Imai, 1997]

When talking about Kaizen at shop-floor, in lean literature one faces the term Gemba Kaizen. Gemba is Japanese and means "real place", the place where the real action occurs. In business Gemba means the place where the value-adding activities take place. In businesses there are three major activities which are directly related to making profit: Developing, producing and selling. Gemba can mean all these activities but in this context we regard Gemba as the place where products or services are produced. At Gemba the customer-satisfying value is added to the product or service which makes it possible for the company to survive and prosper. [Imai, 1997] In this Thesis Gemba is both the Drives Service workshop in Vantaa and also the web store where the orders are made (BOL).

When a problem occurs, managers should always go to Gemba first to see what has happened. At Gemba they should examine the object where the problem occurs and implement temporary countermeasures on the spot to make the operations run again. Once the countermeasures have been implemented, they should identify the root cause of the problem and standardize the new process by implementing SDCA. This way recurrence of the original problem can be prevented. Problems which are spotted at Gemba may reveal problems of other supporting departments, such as Research and Development (R&D), quality management, sourcing and sales as well. [Imai, 1997]

Management usually uses more sophisticated tools, such as Quality Function Deployment (QFD) and Design Review. At Gemba, on the other hand, problems are usually easy to solve. As long as the quality level of a company stays in percentile figures, a company can achieve major improvements through basic activities, such as reviewing standards, housekeeping, collecting data on rejects and conducting group activities for problem solving.

Standards are business activities which operate according to written-down agreed-upon formulas. They can be seen as the best, easiest and safest way to do the job. Standards give basis for continuous improvement as they represent the current work process. When standard a is improved, SDCA should be used first to standardize the improved work process. Then PDCA should be used to stabilize the new standard. Since standards are written down, they offer a good way to preserve know-how and expertise in the company. For example when new employees start working in a new company, they do not have to learn everything through trial and error as standards offer the current best way to do the job. Because standards help the workers to do the job the same way every time, they make it possible to measure the performance of the process. Standards should be visible at every workstation because they help the worker to do the job right as the worker can check if the job is carried out in accordance with the standards. Standards should include instructions of what to do when abnormality occurs. [Imai, 1997]

Continuous improvement requires that problems are made visible. If the abnormalities in the process cannot be detected, corrective actions cannot be implemented and the work procedure cannot be improved. The best thing to do when abnormality occurs is to stop the production because then the problem is visible to everyone. Visual management should be used to help employees to follow company's performance as well. This can be achieved by keeping following trend charts visible at shop-floor [Imai, 1997]:

- Number of suggestions
- Production schedules
- Targets for quality improvement and current quality level
- Productivity improvement
- Setup-time reduction
- Reduction of accidents
- Delivery information
- Machine downtime
- Overall equipment efficiency (OEE).

4.4.3 5S

5S is a methodology for housekeeping in an organization. The 5S's stand for Japanese words Seiri, Seiton, Seiso, Seiketsu and Shitsuke.

Practicing 5S indicates good employee morale and self-discipline. According to Imai [1997], lack of 5S indicates inefficiency, waste, insufficient self-discipline, low morale, poor quality, high costs and ineptitude to meet the delivery terms. Suppliers that do not practice 5S will not be taken seriously by prospective customers [Imai, 1997]. For example Honda and Toyota have acknowledged that twenty-five to thirty percent of all quality defects are related to safety, orderliness and cleanliness [Burton and Boeder, 2003]. Even though 5S originates from manufacturing environment it can be applied to other environments, such as offices as well [Sarkar, 2006]. Sometimes "safety" is used as sixth S [Zelinski, 2005; Gnoni et al., 2013] but in this thesis we only discuss the original 5S's.

Seiri means sorting. Sorting starts with categorizing items at the workplace into two categories: necessary and unnecessary. The unnecessary items should be removed. A good rule of thumb is to remove everything that has not been used within thirty days. Seiri is the first step when implementing 5S. Usually Seiri is carried out in form of a red-tag campaign. The campaign starts by selecting the area for sorting. Once the area has been selected, red tags are placed on all unnecessary items. When the red tags are placed, the 5S implementation team goes through every item with a red tag. The items that are not needed are removed from the workstation. [Imai, 1997]

Seiton means straightening and it is done by putting the necessary items in good order. This way the effort for searching items is minimized. Each item needs to have its designated address. For example, the floor of a factory should be painted so that there is just enough space for the items that are be placed there. This way deviation from the designated number of items shows up instantly. Hallways should be clearly marked and they should be clear of items as they are used for transportation. [Imai, 1997]

Seiso means scrubbing or sweeping and it is carried out by cleaning the work environment including machines, tools, floors, walls, and other areas of the workstation. By keeping everything clean flaws that have been covered by dirt can be detected. Also when cleaning, operators can make discoveries and learn new things. [Imai, 1997]

Seiketsu means systematizing. Systematizing is done by keeping employees clean by using correct clothing as well as maintaining a clean, healthy working environment. Also it means continuous work on Seiri, Seiton and Seiso. [Imai, 1997]

Shitsuke means standardizing. It requires self-discipline and when it is in place, employees do things spontaneously. Visual management of shitsuke includes making sure that 5S duties are specified, instructions for duties are visible and that standards are established and followed. [Imai, 1997]

Introduction of 5S is a project which has to be carefully planned, organized and executed. The 5S project should always start with preparing the employees to mentally accept 5S. Imai [1997] lists following arguments for implementing 5S:

- Creates clean, sanitary, pleasant and safe working environment
- Improves employee morale, self-discipline and motivation
- Eliminates waste by minimizing the time it takes to search tools, reducing physically strenuous work, and freeing up space
- Improves communication between shifts, work areas and organizational levels
- Reduces workflow problems, increases product quality and productivity
- Aligns employee efforts with goals and strategies for eliminating waste
- Improves appearance of the facility
- Establishes standards for operating equipment
- Reduces equipment breakdowns

Also management should understand the benefits of 5S. First, 5S helps employees to develop self-discipline. When employees are self-disciplined, they engage in 5S, take positive interest in Kaizen and can be trusted to follow standards. Second, 5S highlights waste at the workplace which makes the first step of waste elimination (recognizing the problems) easy. Third, it reduces unnecessary movement. Because every tool and part at the workstation has its own designated address, it takes less effort to search them. Fourth, it makes problems visible, such as shortage of materials, line imbalances, machine breakdowns and delivery delays. When the problems are visible, they can be solved. Fifth, it improves working efficiency leading to reduced costs of operation. At last, it reduces the amount of accidents caused by disarray. [Imai, 1997]

4.4.4 Poka-yoke

Poka-yoke is a concept of mistake-proofing and is critical for reducing variation in the process. In poka-yoke, a device or procedure is used for preventing defects or equipment malfunction during processes. It enforces correct operations by eliminating choices which lead to incorrect actions and gives a signal or stops the process if an error is made or a defect created. Poka-yoke also prevents from damaging the product or the machine. [Burton and Boeder, 2003] Ethernet cable is an example of a product where poka-yoke has been applied. Because Ethernet ports and cables can only be connected in one orientation, it is impossible to connect them the wrong way.

Burton and Boeder [2003] list the benefits of poka-yoke as follows:

- Promotes individual responsibility for product quality
- Is equivalent to a hundred percent inspection but requires only little investment
- Detects and eliminates defects as early in the process as possible
- Gives immediate feedback and thus reduces the duration of corrective actions
- Establishes a system for successive checks for each operation
- Ensures that proper conditions exist for production and prevents mistakes from occuring in the first place
- Focuses on elimination of error causes
- Improves First pass yield (FPY).

4.4.5 Total productive maintenance

Burton and Boeder [2003] define Total productive maintenance as a comprehensive, team-based approach that utilizes a series of methods for the design, selection, correction, and maintenance of equipment to ensure that every machine or process is always able to perform its required tasks of defect-free production without interruptions. McCarthy and Rich [2004] identified six categories of equipment losses which can be reduced by using total productive maintenance:

1. Breakdowns due to equipment failures
2. Set ups and unnecessary adjustments
3. Idling and minor stops
4. Running at reduced speed
5. Start-up losses
6. Rework and scrap

According to Smith and Hawkins [2004] total productive maintenance cannot be applied on unreliable equipment. When measuring total productive maintenance, a measure of overall equipment effectiveness (OEE) is used. The formula for OEE is [Smith and Hawkins, 2004]:

$$OEE = Availibility \times Performance \times Quality. \tag{4.1}$$

.

Total productive maintenance consists five different components [Burton and Boeder, 2003]:

1. Predictive maintenance
2. Preventive maintenance
3. Autonomous maintenance
4. Early equipment management
5. Focused equipment improvement

Predictive maintenance means performing maintenance before the equipment is predicted to malfunction. This method is based on equipment history and data-acquisition-based equipment knowledge. Preventive maintenance means machine maintenance which is performed at predetermined intervals which are based on machines' critical operating characteristics. The goal of preventive maintenance is to ensure smooth and continuous operation of the machine. Autonomous maintenance means using equipment users for activities which ensure optimum conditions for the machine to operate. These activities include tasks, such as cleaning and inspection, establishing standards for taking care of the equipment and training employees to use the machine correctly. Early equipment management means selecting the optimal value adding features for new equipment when its entire life-cycle is taken into account. In focused equipment improvement the parameters and capabilities of equipment are identified and optimized to improve OEE. [Burton and Boeder, 2003]

4.4.6 Just-in-time

Just-in-time (JIT) system is a way to reduce cost and meet customer's needs. It can be defined as "making only as many products, and in the same sequence as ordered." In JIT system each process is connected to the next one and there is no buffer in between which means that only one work piece at a time flows through the processes. This is called one-piece flow. Although JIT is often referred as a system without stocks it is not always practical or possible to keep zero inventory. In these cases a company might use a small stock for products with the highest demand. For products which are made to stock, there is a Kanban system in place. Kanban is Japanese and means a card or a signal. When a product with Kanban tag is sold, that Kanban tag is brought to the beginning of production where it gives a signal to start producing that product. This way it is ensured that the stock level of these products stays at an optimal level. Kanban system can be manual or automatic. [Imai, 1997; Burton and Boeder, 2003]

If a large order is received it can be spread so that a given number of products are produced each day. This is called leveling. [Imai, 1997] Burton and Boeder [2003] lists following benefits of production leveling:

- Transition from large lot production to small lot production
- Provides better distribution of inventory to meet customers' demand
- Allows quicker response to changes in demand
- Reduces inventory of raw materials, subassemblies, finished goods and work-in-processes
- Improves schedule linearity
- Provides linkage between cycle time of demand and production

- Supports the ultimate objective of making small quantities of every product every day in ratios that matches with incoming demand
- Daily level production is synchronized plant wide

In JIT systems one can see a clear line connecting the customer and the production process. Because companies that have implemented JIT system have short lead times, they can start production after customer has placed an order. This system allows great flexibility in meeting customer's needs. JIT system can also respond to abnormalities on the line instantly. If a reject is produced, the whole line stops because there is no replacement for that reject. This is why keeping continuous flow on the production line requires constant efforts from management in tackling the problems. JIT requires Kaizen and self-discipline from both shop-floor workers and managers. [Imai, 1997]

When trying to reach the JIT system, one must take into account the takt time of the products and production's cycle time. Takt time is a theoretical figure which tells how much time is given to each process step to produce one product in order to answer customer demand. The formula for takt time is [Imai, 1997]:

$$takt\ time = \frac{Available\ working\ time\ per\ day}{Customer\ demand\ per\ day} \tag{4.2}$$

Cycle time means the actual time it takes for a process step to produce a product. In conventional companies cycle time is usually significantly shorter than the takt time. This results in producing work-in-processes and inventory surplus of finished goods. This is why the production lines should be reviewed for uniformity of cycle times since the process step with the longest cycle time determines the performance of the whole production process. [Imai, 1997; Rother and Shook, 1999]

4.4.7 Value stream mapping

According to Trent [2008] the ability to model or map a process should be a tool which is part of every organization's lean arsenal. In this section we discuss value stream mapping which is a lean tool for mapping company's processes. Value stream mapping was first introduced in book "learning to see" [Rother and Shook, 1999]. In value stream mapping, the focus is in the big picture, not small single improvements. It helps to see and understand the information and material flow between the supplier and the customer. In order to create a value stream map, one needs to follow the production path of the product from customer to supplier and carefully draw a visual drawing from every process step in material and information flow. An example of value stream map is shown in Figure 4.2. Burton and Boeder [2003] list following things to be the benefits of value stream mapping:

- Illustrates the material and information flows and the linkages between these flows
- Identifies waste in the value stream
- Forms the basis of an implementation plan for identifying and eliminating waste
- Helps to identify non-value adding steps and provides information about lead time, distances traveled, and inventory

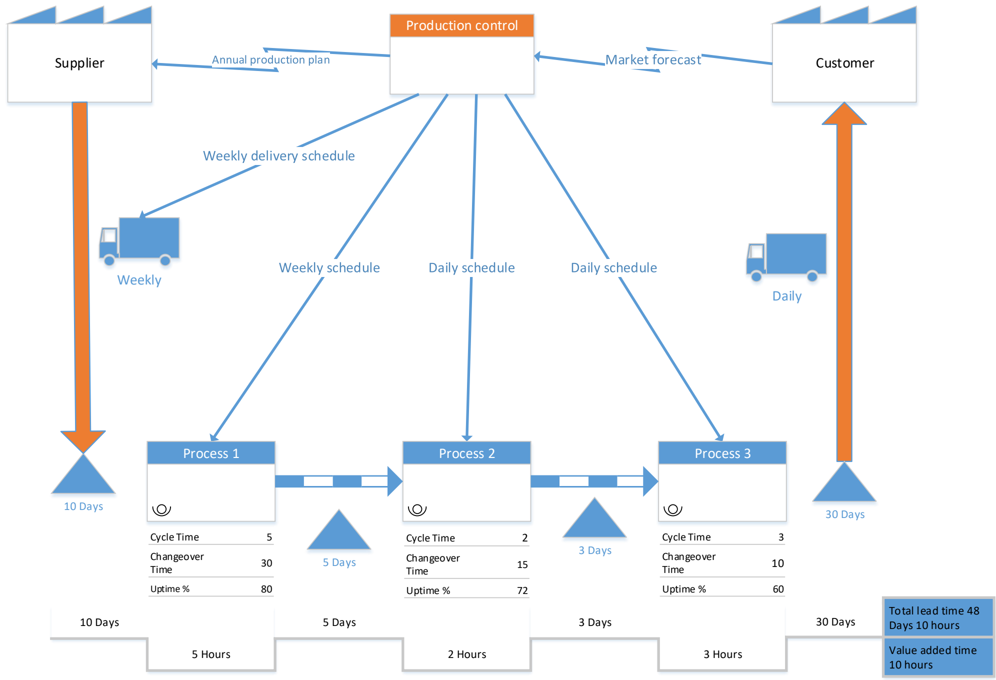

Figure 4.2: An example of a value stream map

When the current state map is drawn, the next step is to draw a future state map. It is important to draw a value stream map for each product group separately. When creating a value stream map, one needs to write down clearly what the selected product group is, how many different parts there are in the product group, how much is wanted by the customer and how often. If the product mix is complicated, a matrix can be created with assembly steps and equipment on one axis and the products on the other axis. Usually the future state ideas come to mind while creating the current state map. The final step is to prepare and implement a plan that describes how the future state will be achieved. When the future state is achieved, previous steps are repeated. This way continuous improvement is implemented on value stream level. [Rother and Shook, 1999]

The value stream mapping should always be started on big picture level. When the big picture has been mapped, the level of magnification can be increased. Rother and Shook [1999] give following tips for drawing the value stream map:

- Collect information about the current state while walking along the actual pathways of material and information flows
- Begin drawing by taking a quick walk through the value stream. After that go back and gather information about each process separately
- Start mapping from the shipping process and work upstream. This way the focus is in the processes that are close to the customers
- All throughput times should be measured with own stopwatch. The ability to envision the future state depends upon going to where the action takes place and understanding and timing what is happening
- Value stream map should be done by one person as understanding what is happening is what value stream mapping is all about
- Always draw by hand.

In value stream mapping data needs to be gathered from different process steps. Rother and Shook [1999] list following data as typical measures in value stream mapping:

- Cycle-time
- Changeover time
- Uptime
- Production batch sizes
- Number of operators
- Number of product variations
- Pack size
- Working time
- Scrap rate

In lean value stream, products should be produced to takt time, continuous flow should be applied wherever it is possible, production of different products should be evenly distributed over time and producer should have the ability to make "every part every day". Although producing to takt time sounds simple, it takes effort to provide fast response to problems, eliminate causes of unplanned downtime and to reduce the changeover time. Continuous flow should be created wherever possible as it is the most efficient way to produce goods. However it is not always possible because of following reasons [Rother and Shook, 1999]:

- The process is designed to operate at very slow or very fast cycle time and there is a need for changeover in order to serve multiple product families
- The physical distance between processes is long and shipping one piece at a time is not realistic
- The process has too long lead time or it is too unreliable to be directly integrated to continuous flow of other processes.

By developing the ability to produce every product every day, the producer is able to respond to changing demand more quickly. This ability can be reached by shortening the changeover time and running smaller batches. [Rother and Shook, 1999]

Chapter 5

80/20 Principle

In this chapter we discuss the 80/20 principle which is used for prioritizing products later in the thesis. 80/20 principle, also known as Pareto principle and the Pareto law, was discovered by Vilfredo Pareto in 1897. He discovered that there is a constant mathematical relationship between the proportion of people and the amount of wealth this group of people enjoys. He also noticed that this pattern exists in different time intervals and in different countries, and realized that this imbalance is predictable. 80/20 principle states that *minority of causes, inputs and efforts result in majority of results, outputs and rewards.* This relationship is shown in Figure 5.1. This means that there is an inbuilt imbalance between causes and results, inputs and outputs, and efforts and rewards. Typically the causes, inputs and efforts divide into two categories: the majority that has a minor impact and the minority that has a major impact. An example of this relationship in business is that 20 percent of products account for 80 percent of the sales. Of course the exact relationship might not be 80/20 but these numbers represent the uneven distribution and give useful hypothesis. [Koch, 1997]

80/20 analysis examines the relationship between two data sets. One set consists of a large number of people or objects and the other set consists of interesting characteristics of those people or objects. Both numbers can be converted into percentage. 80/20 analysis can help to focus on the key inputs of the relationships that lead to the greatest output which is much easier and more rewarding than focusing on all inputs with equal effort. It can also help find the underperforming inputs which can be improved. However, improving these inputs takes a

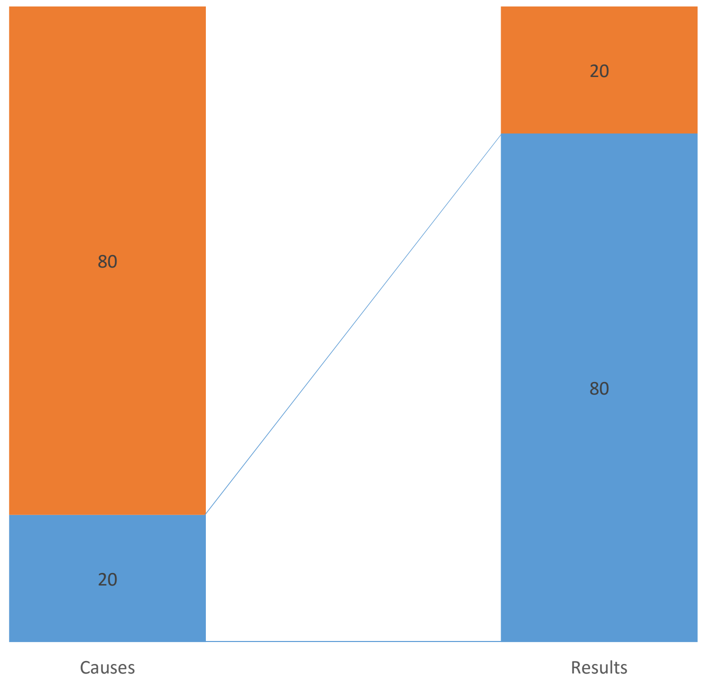

Figure 5.1: 80/20 principle

lot more effort than eliminating them and focusing on the better performing inputs. [Koch, 1997]

The reason why 80/20 works can be found in simplicity. In business, complexity increases the overhead costs which is why increased returns can be achieved by simplifying the business. When trying to get competitive advantage from economies of scale, one needs to make sure that the increased scale does not add complexity. The increased scale always increases profits if the complexity does not increase. Whenever something has become complex, it should be simplified or if simplification is not possible it should be eliminated as effectiveness requires simplicity. Most of the activities will always be pointless, poorly conceived, badly directed, wastefully executed and also nothing that customers need. On the other hand there is a small portion of activities which will always be very effective and valued by the customers. All organizations have a mix of these productive and unproductive activities. Usually poor performance hides behind a small amount of excellent performance. Major improvements can always be achieved by doing things differently and by doing less. [Koch, 1997]

One major application for 80/20 principle is cost reduction. In cost reduction one should not focus on everything with equal effort. It is important to understand that all equal cost does not lead to equal customer satisfaction. When using 80/20 principle to reduce costs, one should use three 80/20 insights:

1. Simplification through elimination of unprofitable activity
2. Focus on a few key drivers of improvements
3. Comparison of performance

80/20 principle can also be used for tackling problems. As 20 percent of the causes create 80 percent of the problems, by tackling these 20 percent of causes, 80 percent of problems are solved. [Koch, 1997]

Chapter 6

Analysis

6.1 General

In this chapter we select the products for the analysis by using 80/20 principle and apply lean principles to order-to-delivery processes for those selected products. We have divided the spare parts with embedded software into four product groups. Products within the same product group have similarities in the way they are ordered from BOL and in their information structures.

6.2 Prioritization of products

In Figure 6.1 we have summarized the sales volumes of each product group for year 2015. As we can see from the graph, the sales volumes are not evenly distributed which is in line with 80/20 principle. According to 80/20 principle we should focus on products groups which account for approximately 80% of the sales volume. As product groups 1 and 2 account for 77% of the total sales, we will focus on these product groups in order to maximize the result of our efforts.

6.3 Value

AC drives are used for controlling value-adding processes. This is why it is important that they operate without unexpected interruptions and

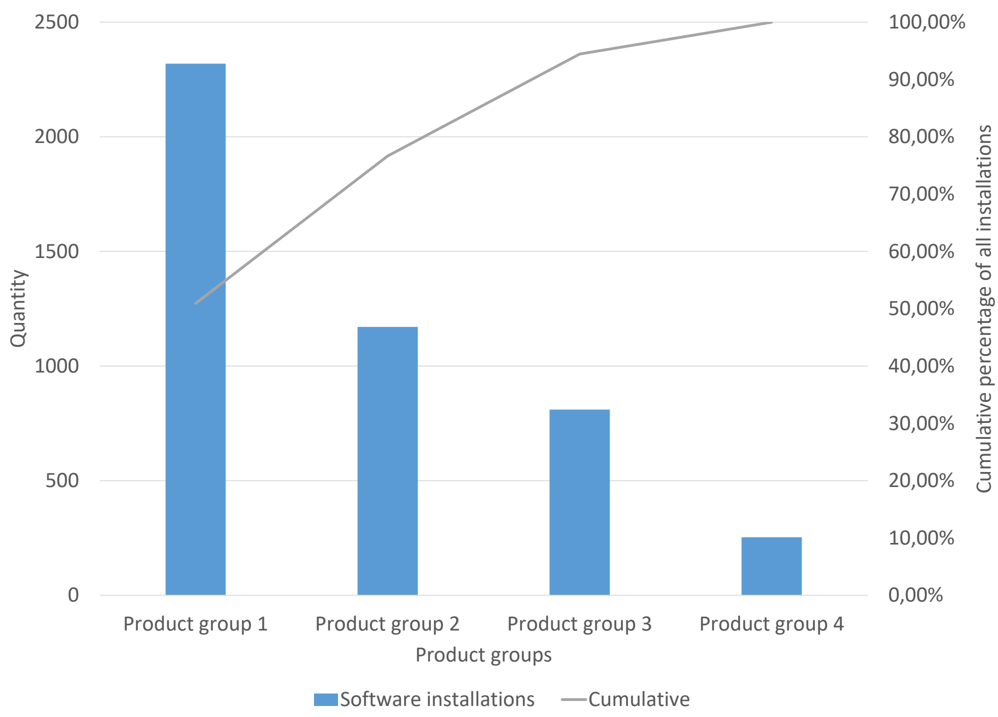

Figure 6.1: Products with software ordered in 2015 by product groups

customer's put high value on the reliability of these devices. Quality comes first in this case environment since when a spare part is needed, it is essential that the spare part is correct and it fixes the problem that customer is having. Also as sometimes customers face unexpected stoppages which are caused by malfunctioning AC drives, fast delivery time of spare parts is very important to them.

6.4 Value streams

6.4.1 General

In this section we map the value streams of spare parts with embedded software for each selected product group. Value adding time in the process was measured with a stopwatch at the Vantaa workshop. The data of non-value adding time was collected from company's ERP system which records a time stamp when an order is placed in BOL, order is registered to the ERP system, picking list is printed, the order is packaged and when the package is loaded into a truck. However, no time stamp is recorded when the software installation is complete which makes it impossible to define how long the products wait in each buffer. That is why cycle times for buffers in value stream maps are based on estimates of how the duration from picking to packing is divided between value-adding activities and buffers. The information flow data in value stream maps is based on data received from the customer service. In order to fully understand the order-to-delivery process performance, more data should be collected from the process. For example a time stamp could be recorded when the software installation is complete which would help us identify how long products wait in buffers.

6.4.2 Product group 1

Product group 1 consists of company's latest products. In this product group there are two spare part types which have significant demand and a need for software installation. From now on we call these two product types product A and product B. In this product group there are also other spare parts which require software installation or checking if the spare part contains the correct software version but we will leave them out of this analysis because they have low demand and they can be seen as exceptional cases.

Product A is mostly made to stock because it has just one type of software installation procedure and the further configuration can be done by the customer. This way the product can be sent to the customer right away. The stock level of this product is low and it is produced in low quantities. Because the customers do the configuration by themselves, the probability of wrong software installation at the Drives service workshop is low. It is also possible for the customer to order the product with configuration. In this case the customer selects the rating of their AC drive from a drop-down list when ordering the product. These products are MTO kits.

Product B is made to order and in BOL there is a product for each software hardware combination. This has made the quantity of product codes high and company has received complaints from customers that this makes ordering the correct product very difficult. On the other hand this is the best product structure for internal processes as there is a link between the software and the hardware making the software installations unambiguous. These products are small and cheap so stocking them does not increase the costs significantly. In addition, these products have different prices depending on the software.

6.4.3 Product group 2

Product group 2 represents company's products which have the highest installed base at the moment. In this product group we have two products which we will focus on. From now on we call these products product C and product D. For both of these products software has to be ordered separately. These products can also be ordered without software as local ABB units can download the software from company's database by themselves.

Since the software is ordered separately for both of these products, the delivery process does not go through the software installation work queue in company's ERP system and there is no informational link between the software and hardware. This means that at the software installation station the repair engineer has to find out to which product the software should be installed. On the other hand, company has received feedback from the customers that ordering products this way is a lot easier than finding the correct product from a list of over 200 products. The value stream maps for products A, B, C and D are presented in Appendix A.

6.5 Flow

In this order-to-delivery process, the area with greatest potential for improvement is found when observing the process flow. Interruptions during the process flow lengthen the average delivery time significantly. Reasons for these interruptions are easy to spot at the Vantaa workshop because a post-it note is attached to all products which for some reason wait in a buffer and cannot proceed to the next step. The reason for these interruptions is usually insufficient order information. In these cases the repair engineer who does the software installation contacts the customer service which will contact the customer and ask for the missing information. This increases the cost of order processing significantly and does not add any value. At the moment there is no continuous improvement process in place which is why these problems recur. That is why a standardized continuous improvement process, involving the entire ABB Drives service organization should be implemented to this order-to-delivery process in order to identify the root causes for these interruptions, prevent their recurrence and eventually make the process flow continuously. This way the average delivery time could be reduced thus creating more value to the customer and reducing the cost of reprocessing the data.

As we found out in Section 6.4, products within product group 1 are ordered differently than products within product group 2. According to ABB's sales manager, specially the way of ordering the product where customer has to pick the product they want from a list of over 200 products creates additional burden to the sales support department as they are the ones who have to find the correct product in case customer is unable to find it. This is waste because sales support department's main function is to provide the customer technical expertise when customers do not know which product they need.

6.6 Pull

In this case environment a certain stock level for hardware is required as fast delivery is essential to the customers. ABB has applied pull production to the product kits which include hardware and software as they are mainly made to order. This way the waste in form of excess inventory is eliminated while still ensuring fast delivery of the product. The hardware for these kits is ordered to stock in low quantities which is in line with JIT system. For some of the product A's variants that are made to stock there is an automatic Kanban system in place. In this system, the ERP system prints out a picking list when the stock needs to be refilled. In most cases product A does not need any information from the customer regarding the software so making these products to stock is reasonable in order to ensure fast delivery, as long as the cycle-time of products in inventory stays short.

6.7 Perfection

After making previous observations we have formed a picture of perfection which is from now on the future state of the process. This future state is illustrated in Figure 6.2. In this picture interruptions are eliminated from the process which leads to a continuous flow that creates value to the customer constantly. Ordering of these products is easy to the customer. The product structures are streamlined so the process works the same way for all product groups and the ordering system supports company's information structures while also keeping the user interface simple. The process is also transparent. A lot of data is collected from the process so that the process can be benchmarked and continuously improved. The software installation process itself is made easier. A poka-yoke system is in place eliminating the risk of mistakes caused by manual work. The work is standardized and these standards are continuously improved. There is a 5S system in place keeping the workplace clean, pleasant and safe. Once this picture has been reached, a picture of perfection which goes even further will be formed.

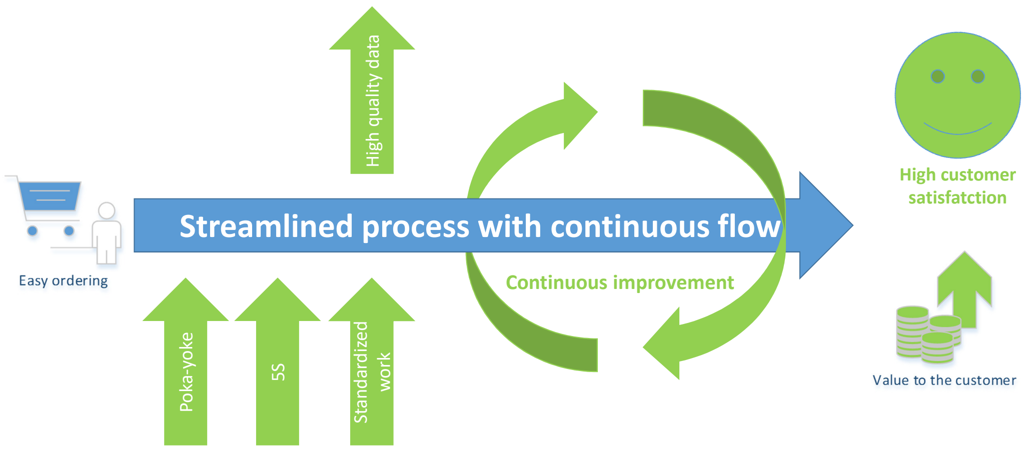

Figure 6.2: Picture of the future-state

Chapter 7

Discussion

This case environment is challenging as the demand of single products is low and the amount of variants is high. Since at the workshop there is no automated production system in place, the operations at the workshop have developed very much the same way as lean manufacturing developed in Japan. Because software installations are done in a small area for multiple different product families, the changeover times have become very short and the workshop is able to answer to changes in demand very effectively. In other words, the software installation operations at the workshop are very flexible. Also the repair engineers at the workshop are highly motivated. These kind of employees are just the ones that are needed for lean manufacturing since they are able to solve problems themselves and they can do various tasks.

The area where most of the waste in the process was found was in the ordering and order processing part of the order-to-delivery process. All additional sales support and customer service activities created by missing order information or challenges in finding the correct product from BOL not only make the delivery time of the product longer but also require ABB's resources. As this order reprocessing is done by white collar employees, it is expensive. By implementing a standardized continuous improvement process which involves the entire ABB Drives service organization, interruptions during the order-to-delivery process are eliminated and eventually continuous flow is reached. That frees up resources which can be used for value adding activities leading to improved customer satisfaction. It also shortens the average delivery time thus creating more value to the customer. Because customers value fast delivery, they are also ready to pay more for it. This way it is also possible to increase company's revenues.

For ABB Drives service quality is extremely important as spare parts are usually ordered when something has gone wrong. If there is something wrong with the spare part which is supposed to fix the customer's problem, customer satisfaction suffers significantly and that may lead to losing the customer and the potential revenues they could bring in the future. That is why also the software installation process should be continuously improved to ensure that maximum quality is delivered to the customer. As an example of how continuous improvement is practiced in order to improve product quality, we carried out a project where we developed a poka-yoke system for product A's software installation. This project is described in Appendix 2.

Recently there has been a lot of discussion about Internet-of-Things (IOT) [Gubbi et al., 2013]. IOT is mostly about connecting different things, such as devices, to the internet. Since some of the spare parts are mere memory sticks which deliver the software to the customer, all material flows in this order-to-delivery process could be eliminated for those products by connecting the AC drives to the internet and making ordering and delivery of the software possible via internet. That would be a very lean solution as all physical material flow would be eliminated. When implementing IOT to AC drives, cyber security has to be considered carefully since AC drives are also used in extremely critical processes.

At the moment ABB's Drives Installed base is in use and helps ABB's local organizations and partners to order correct products for their customers. With software there are still some issues to be fixed, such as linking firmware to MTO kits. Generally we can say that DIB is continuously improving the ordering process of spare parts for ABB's AC drives.

Chapter 8

Conclusions

In this thesis we reviewed the literature related to lean manufacturing and 80/20 principle and applied them to order-to-delivery process for spare parts with embedded software. In our analysis we first selected the most relevant product groups using 80/20 principle and then we applied the lean principles to products within these product groups. In Chapter 7 we discussed what kind of effect applying the lean principles to this case environment has. We also discussed what kind of effect new technological innovations have on the process in the future.

The first objective of this thesis was to find out, on which products the effort of applying the lean principles should be focused on. The products of this case were divided into product groups. The sales volumes of different product groups were not evenly distributed which was in line with 80/20 principle. Product groups 1 and 2 accounted for 77% of total sales volume so we focused on them in our analysis. This way we maximized the payoff of our analysis.

The second objective was to discover how the lean principles can be applied to the case environment. In Chapter 6 we analyzed which actions are required to make the case environment lean by applying lean principles. First, we started by recognizing what the customers value in the process. We found out that maximum value is created to the customer in the order-to-delivery process when the delivery time is short and spare parts have high quality. Second, we mapped the value streams behind the spare parts of chosen product groups. Third, we focused on the process flow and found ways to prevent the flow from stopping. Then we examined how pull production could have been applied to the case environment and noticed that the case environment followed pull principle already as much as it was reasonable. At last, we formed a picture of perfection which is now the target for future state.

Finally, we wanted to find out what kind of effect applying the lean principles has on the order-to-delivery process performance. Continuous improvement process and streamlining the order-to-delivery process would improve the process flow and eliminate interruptions during the process. This would be beneficial in two ways. First it would decrease the average delivery time of the product and that way add value to the customer. Second it would decrease information reprocessing done by expensive white collar employees. Since now ordering these products is challenging for the customer, improving the ordering system would decrease the burden of sales support team and increase customer satisfaction. Third, implementing poka-yoke systems and practicing standardized work would improve the product quality. In the future Internet of things (IOT) solutions may eliminate the entire material flow for some of these products. However, ABB supports products which have been designed decades ago and IOT will not eliminate material flows of spare parts for these products.

The research questions which were introduced in Chapter 1 were answered and the goals of the thesis were achieved. However, the effects of applying the lean principles to the order-to-delivery process were based on assumptions. In order to confirm the actual outcome, the process performance must be continuously measured.

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Appendices

Appendix A

Value stream maps

This Appendix consists of value stream maps for products from selected product groups. Figure A.1 shows the value stream behind product A. As we can see, product A has 7 different variants. These products are mostly made to stock since they are configured by the customer. Figure A.2 shows the value stream behind product B. These products are MTO kits and they have an information structure where there is a link between the hardware and software. The value stream behind product C is shown in Figure A.3 and behind product D in Figure A.4. Software is ordered separately for both of these products.

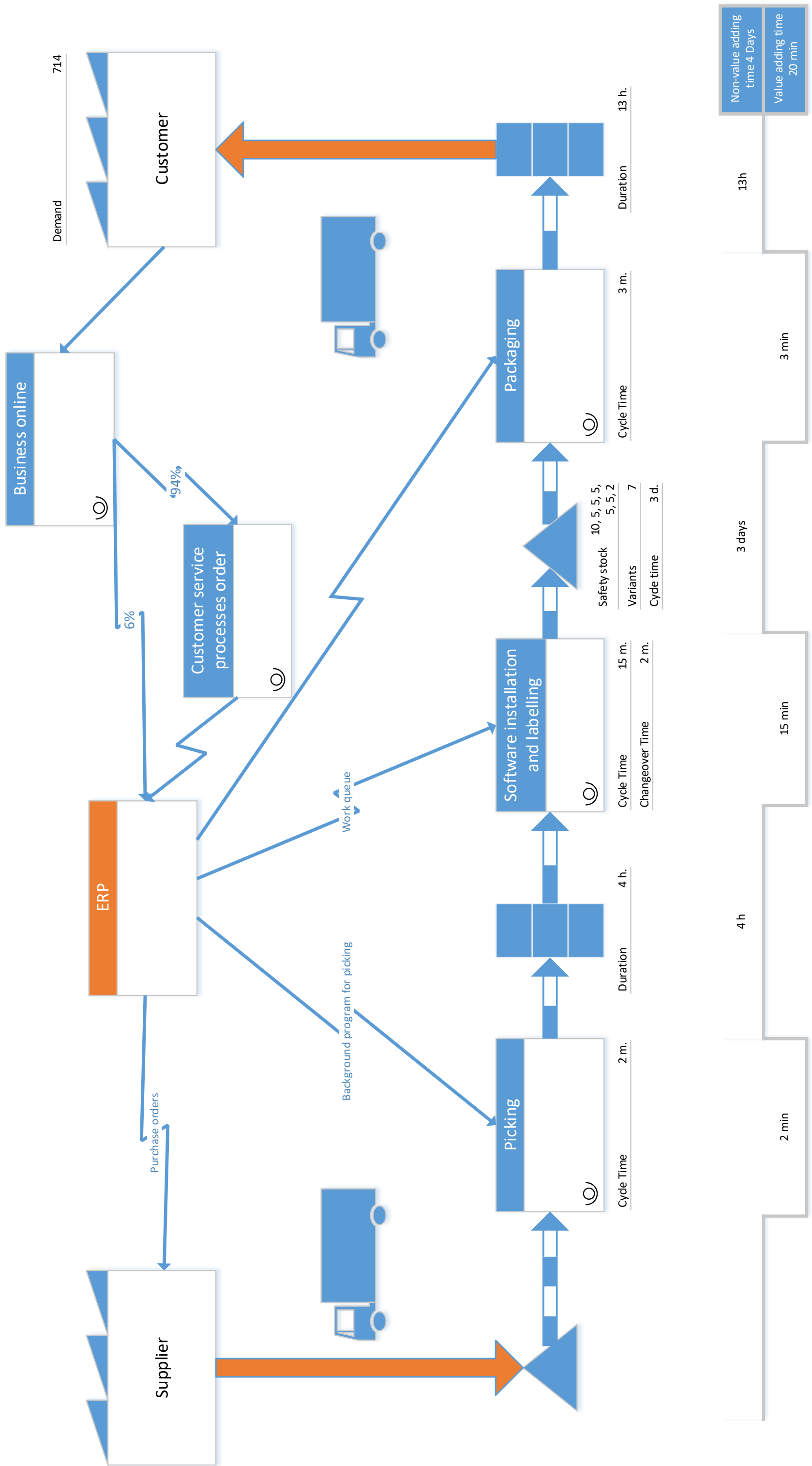

Figure A.1: Value stream map for product A

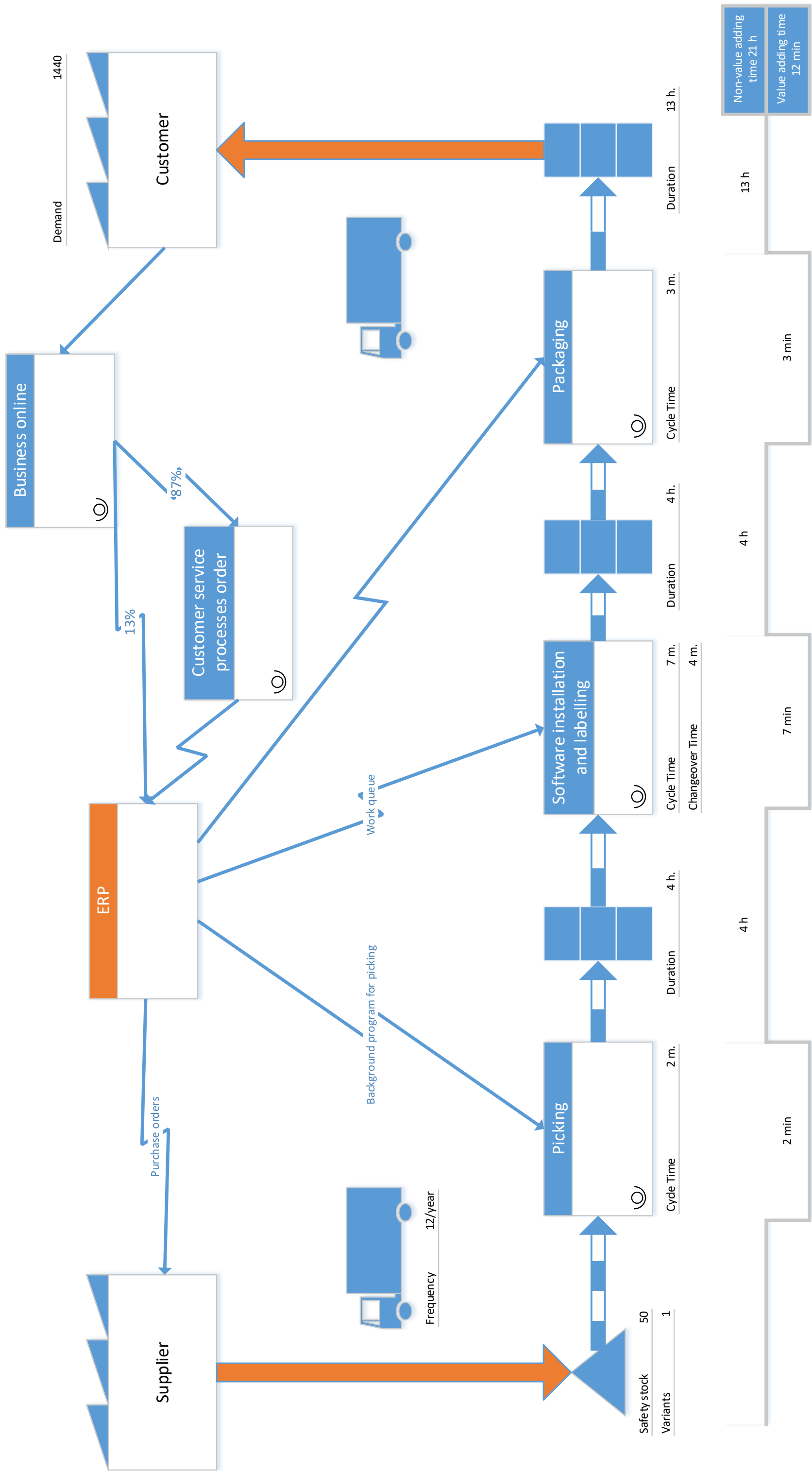

Figure A.2: Value stream map for product B

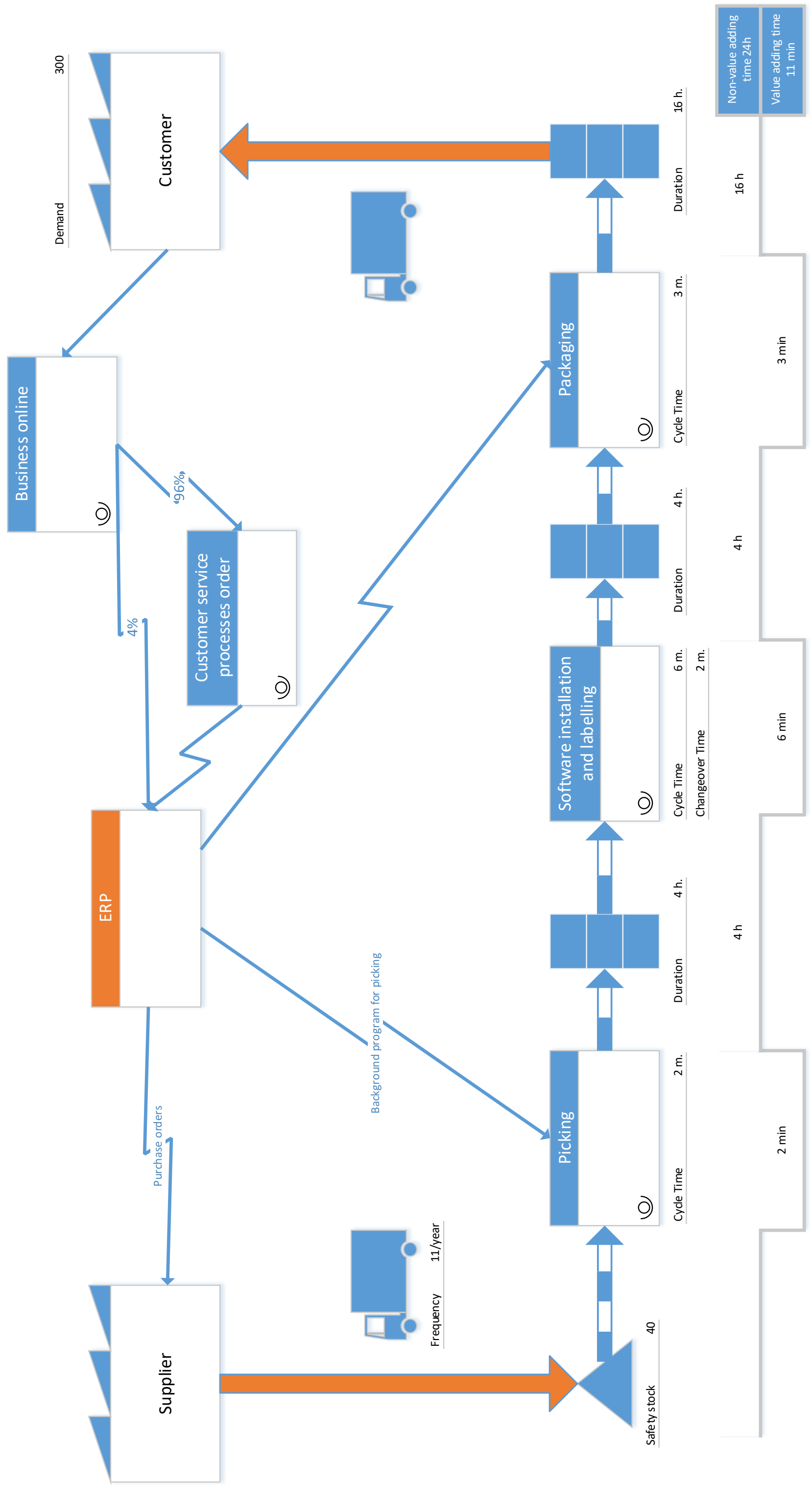

Figure A.3: Value stream map for product C

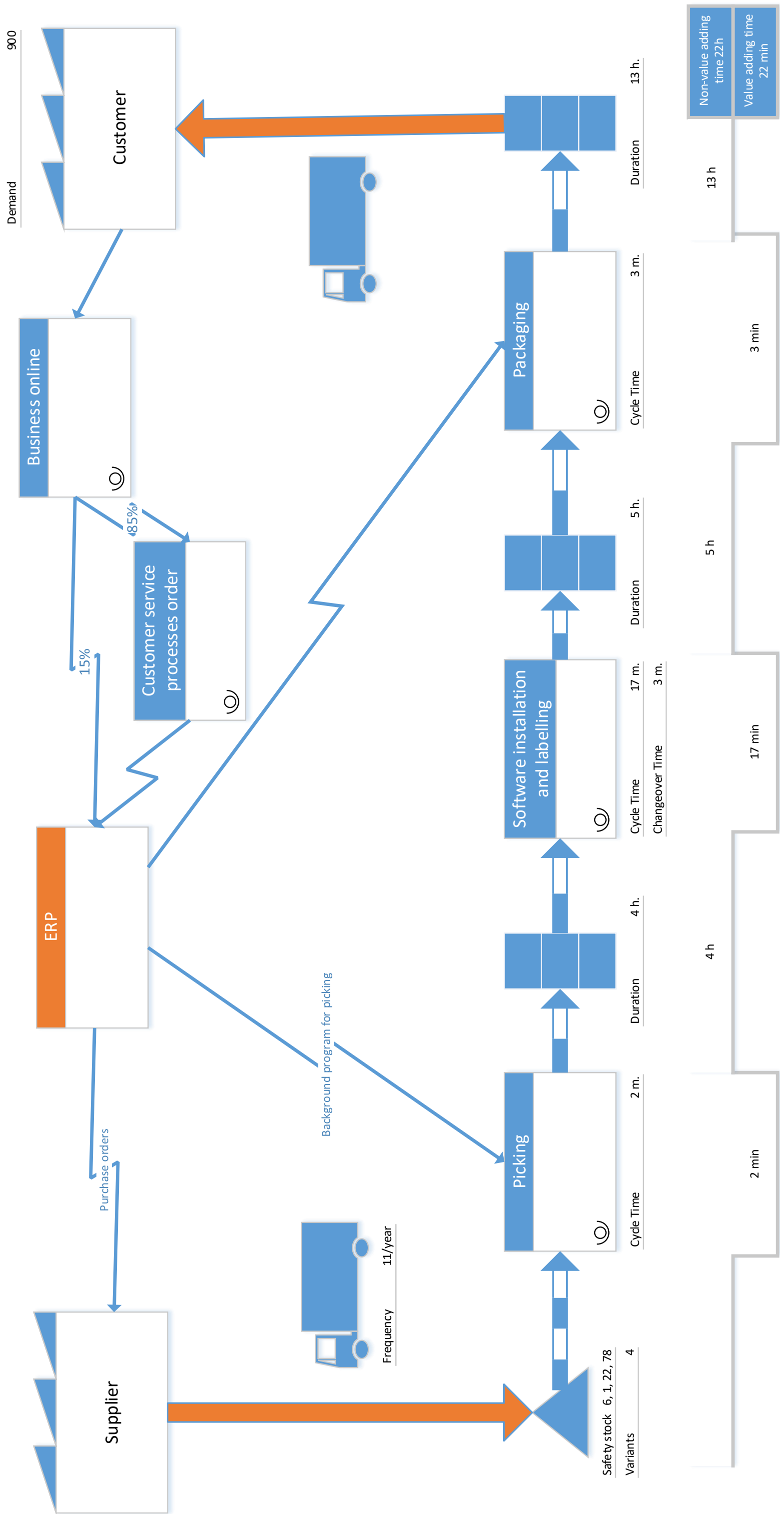

Figure A.4: Value stream map for product D

Appendix B

Continuous improvement project

In this Appendix we introduce a project which was carried out as an example of a continuous improvement case. ABB had received multiple reclamations concerning malfunctioning of product A. We started by finding out the root cause for these problems. It turned out that because same hardware was used in different AC drives but these AC drives used different software, in software installation phase there was a possibility to use wrong installation setup. These software installation operations also included a lot of manual work which gave possibilities for mistakes. A major problem was also that the software installation system did not record any data which made it impossible for us to verify which software had been installed to those malfunctioning products.

We decided to create a poka-yoke system for software installations of these products. First we identified requirements for this kind of system. We ended up with requirements which are presented in Table B.1.

Once we had identified the requirements for the system we designed a prototype of the system with Microsoft Excel. The functionality for the prototype was created with macros which were written with Visual Basic for applications (VBA) programming language. In Figure B.1 we have illustrated information flows of the new software installation system.

First, the system asks for product's material number. This material number is read from the product's package with a barcode scanner. Second, system opens a page which asks for all other information which is needed for the software installation to that specific product. When

Table B.1: Requirements for poka-yoke system for Product A's software installations

Requirement	**Description**
Connection to ERP system	Software installation to product A may require order specific information which needs to be collected from company's ERP system
Setup check	A barcode needs to be attached to every part of installation setup and poka-yoke system needs to verify that the setup is correct before software installation is executed
Automated software installation	The system needs to automatically recognize correct software which needs to be installed and trigger the software installation process.
Log	The system needs to record all software installations to a log.
Verification	After software installation the system needs to read the installed software from the product in order to verify that correct software was installed.

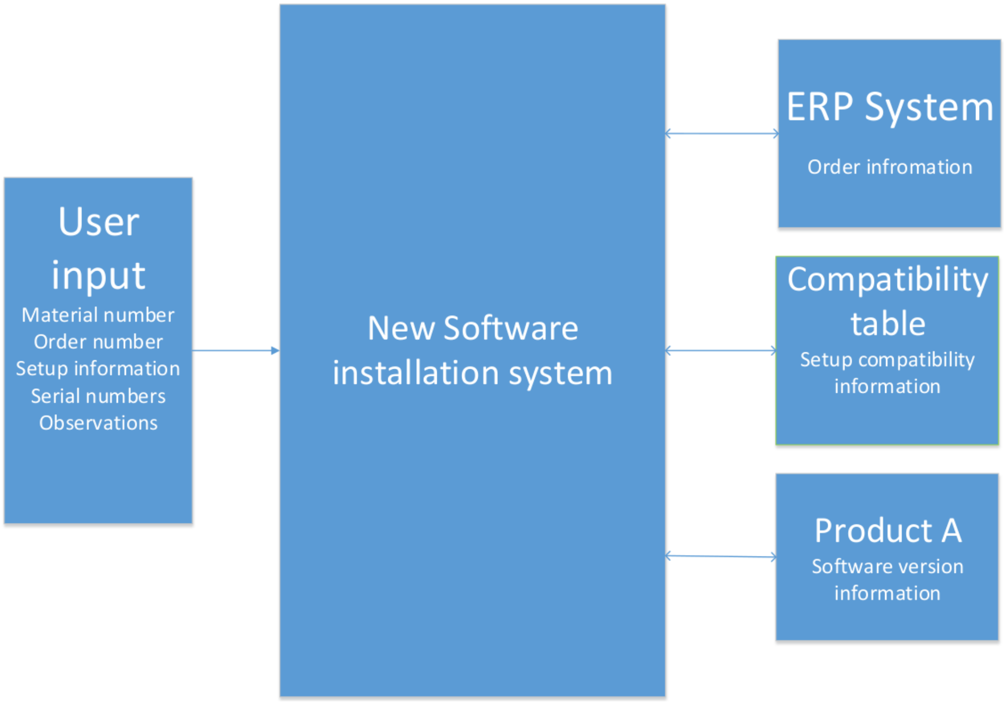

Figure B.1: Information flows of new software installation system

these information fields are filled, the system gives feedback about the filled information in real time. For example when the order number is inserted to the system, it checks immediately from company's ERP system which software package belongs to the given material in that order. Some of the fields are just for checking if the software installation setup is correct and some are for serial numbers which are used for tracing purposes. The system prevents user from inserting wrong information to any of the fields. If invalid information is inserted, system automatically empties the field and asks user to fill the field with correct information. This way system does not allow the process to proceed with incorrectly. Third, once all necessary information is filled, the system launches the software installation. After the software installation, the system asks user if the installation was successful. If installation was not successful, it is done again. Information from all failed installations is recorded to the software installation log. If problems with installations recur constantly, this log can be used to trace these problems. When the software installation is complete, the system checks from the product which software was installed and adds confirmation of the installed software to the software installation log.