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Improving manufacturing processes by value stream mapping in a make to order environment

Case Oilon Oy

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TIIVISTELMÄ:

Yritysten on kehitettävä tuotantoprosessejaan pysyäkseen mukana globaalin teollisuuden kilpailussa. Kilpailukykyä parannetaan uudelleenmäärittelemällä ja -suunnittelemalla tuotantojärjestelmää. Yritykset ympäri maailmaa ovat ottaneet käyttöön lean-konseptin kehittääkseen tuotantoprosessejaan. Lean koostuu periaatteista, menetelmistä ja työkaluista, jotka poistavat hukkaa ja lisäävät prosessien tehokkuutta. Arvovirtakuvaus (VSM) on osoittautunut tehokkaaksi työkaluksi tuotantojärjestelmien uudelleenmäärittelyssä sekä -suunnittelussa. VSM-analyysiä voidaan soveltaa tilaustyöympäristöön sovelletulla viitekehyksellä.

Tutkielma on suoritettu tapaustutkimuksena Oilon Oy:lle. Tutkielman tutkimuskysymys on: Miten Oilon Oy:n tuotantoprosesseja voidaan kehittää arvovirtakuvauksen avulla? Tutkielman tavoitteet ovat: 1) määritellä arvovirtakuvauksen prosessi, 2) määritellä, miten tuote virtaa nykyisessä tuotantoprosessissa, 3) määritellä tuotantoprosessin tuleva tila ja 4) määritellä parannukset ja vaatimukset tulevan tilan saavuttamiseksi. Näiden tavoitteiden saavuttamiseksi on suoritettu VSM-analyysi Oilon Oy:n Kokkolan tuotantolaitoksessa.

Tämän tutkielman teoreettinen viitekehys sisältää teoriaa leanistä sekä arvovirtakuvauksesta. VSM:n teoria koostuu perinteisen VSM-analyysin suorittamisesta sekä VSM:n implementoinnista tilaustyöympäristöön. Tutkielma on suoritettu kvalitatiivisena tapaustutkimuksena, joka käyttää aineistotriangulaatiota käytetyn datan validoinnissa. Tutkielman ensisijaiset tiedonkeruumenetelmät ovat kirjallisuuskatsaus, haastattelut, havainnointi sekä työpajat. Tapausyrityksen ERP-järjestelmän raportit ovat toissijaisia kvantitatiivisia tietoja, jotka toimivat kerätyn ensisijaisen aineiston tukena.

Tutkimuksen tuloksena tunnistettiin neljä VSM-analyysin vaihetta. Kuhunkin vaiheeseen sisältyi useita alavaiheita, jolloin luotu viitekehys soveltui tilaustyöympäristöön. Tuotantoprosessin nykytila määriteltiin ensimmäisessä työpajassa. 16 erilaista hukkaa ja useita muita ongelmia tunnistettiin heikentävän tuotantovirtausta. Tuleva tila suunniteltiin ja määriteltiin toisessa työpajassa. Tulevalle tilalle määriteltiin 16 eri ehtoa. Kolmannessa ja viimeisessä työpajassa suunniteltiin ja määriteltiin työsuunnitelma tulevaisuuden tilan implementointia varten. Seuraavat luvut esittävät tulevan tilan potentiaalia: tuotannon läpimenoaika lyhenee 35 %, ei-arvonlisäysaika lyhenee 62 %, arvoa lisäävän ajan osuus tuotannon läpimenoajasta kasvaa 13 prosenttiyksikköä ja First Pass Yield:n arvo nousee 40 prosenttiyksikköä.

AVAINSANAT: Arvovirtakuvaus, Lean, Prosessien parantaminen, Oilon, Tilaustyö

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ABSTRACT:
Companies need to develop their manufacturing processes to keep up with the competition of the global industry. Competitiveness is improved by redefining and redesigning the manufacturing system. Companies worldwide have implemented the concept of lean to develop their manufacturing processes. Lean consists of principles, methods, and tools which eliminate waste and increase the efficiency of processes. Value stream mapping (VSM) is proven to be an effective tool for redefining and redesigning the manufacturing system. A VSM analysis can be applied to a make to order (MTO) environment with a fitted framework.

The thesis is conducted as a case study to Oilon Oy. The research question for the thesis is as follows: How can Oilon Oy's manufacturing processes be developed by value stream mapping? The objectives for the thesis are: 1) define the value stream mapping process, 2) define how the product flows in the current manufacturing process, 3) define the future state of the manufacturing process, and 4) define the improvements and requirements to achieve the future state. To address these objectives, a VSM analysis is conducted on Oilon Oy's manufacturing plan in Kokkola, Finland.

The theoretical framework of this thesis includes theory of lean and value stream mapping. The theory of VSM consists of conducting a traditional VSM analysis as well as implementing VSM to a MTO environment. The thesis is conducted as a qualitative case study which uses data triangulation in validating the data used. Primary data collection methods for the thesis are a literature review, interviews, observation, and workshops. Reports from the case company's ERP system are secondary quantitative data that act as a support for the collected primary data.

In the results of the study, four phases of the VSM analysis were identified. Each phase included several steps to make a suitable framework for applying it to a MTO environment. The current state of the manufacturing process was defined in the first workshop. 16 different wastes and several additional issues were identified to be impairing the manufacturing flow. The future state was designed and defined in the second workshop event. 16 different terms for the future state were defined. The working plan for the implementation of the future state was planned and defined in the third and final workshop. Following figures present the potential of the future state: production lead time is reduced by 35 %, non-value adding time is reduced by 62 %, the share of value adding time of the production lead time is increased by 13 percentage points, and the value of First Pass Yield is increased by 40 percentage points.

KEYWORDS: Value stream mapping, Lean, Process Improvement, Oilon, Make to Order

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List of abbreviations

CI	Continuous Improvement
CSF	Critical Success Factor
MTO	Make to Order
NNVA	Necessary but non-value adding
NVA	Non-value adding
SIPOC	Supplier, Input, Process, Output and customer
SME	Small and Medium-sized Enterprise
TPS	Toyota Production System
VA	Value adding
VSM	Value Stream Mapping

1 Introduction

The global industry forces companies to develop their manufacturing processes to stay competitive (Nasser et al., 2009, pp. 1). Competition triggers the need for redefining and redesigning the production system (Serrano et al., 2008a, pp. 39-40). To redesign a more competitive production system companies need either to reduce or eliminate waste to increase the efficiency and competitiveness of their operations (George, 2002). Nasser et al. (2009) argue the implementation of lean to be the best answer to accomplish the aforementioned factors. According to Abdullah and Rajgopal (2003, pp. 1) companies around the world that have implemented lean to progress their competitiveness have received a great growth in profit.

The process of redefining and redesigning a production system requires practical tools to be used (Serrano et al., 2008a, pp. 39-40). In this case value stream mapping (VSM) has proven to be a very effective and practical method for redefining and redesigning a production system (Manjunath et al., 2014, pp. 477). VSM is based on the concept of lean therefore it has the same objectives and goals of reducing and eliminating waste (Seth et al., 2017, pp. 398). A VSM analysis provides a straightforward and simple method for improving a mass production system (Manjunath et al., 2014, pp. 477; Mudgal et al., 2020, pp. 826). However, the implementation of VSM to a make to order (MTO) environment requires a more systematic approach.

1.1 Purpose of the research

The purpose of the research is to review and re-evaluate the current manufacturing process of the case company through a VSM project. The research aims to optimize and redesign the manufacturing process by implementing VSM. The VSM analysis is conducted for Oilon Oy’s manufacturing plant in Kokkola, Finland, where industrial heat pumps and chillers are manufactured.

The research question of the study is: *How can Oilon Oy's manufacturing processes be developed by value stream mapping?*

To be able to achieve an answer for the research question, four objectives are set to be defined in the study: (1) define the value stream mapping process, (2) define how the product flows in the current manufacturing process, (3) define the future state of the manufacturing process, and (4) define the improvements and requirements to achieve the future state. The first objective includes defining the phases and procedures for completing a VSM analysis. The second objective includes defining the values and wastes of the current manufacturing process. The third objective includes redesigning the flow of the manufacturing process. The fourth object includes generating the development ideas, terms, and working plan for achieving the future state.

1.2 Delimitations

The scope of the study focuses on two product series of industrial heat pumps and chillers manufactured at Oilon Oy's manufacturing plant in Kokkola. The two product series focused on are the S-series and P-series. The RE-series and double S-products are excluded from the study. The scope includes only in-house processes. Therefore, operations from receiving material and starting the production to packaging the product and shipping it are included in the scope. The scope of the study excludes seeing through the planning and implementation phase of the VSM process. Only the generation of the working plan is included in the scope.

1.3 Oilon Oy

Oilon Oy is a global energy and environmental technology company (Oilon, 2022b). Oilon was founded in 1961 and it specializes in producing industrial heat pumps and chillers, ground source heat pumps, burners, and combustion systems. Including the manufacturing of these products, Oilon emphasis on research and development of environmental technology solutions. Oilon's products and systems are used for heating and cooling large buildings, and heating houses of private consumers. The most important industrial customers include for example power plants, marine operators, district heating plants, and waste incineration plants. Oilon has a revenue of 70 million euros and a staff of 380 employees. It has manufacturing operations in Finland, the USA, China, and Russia. In addition, it has sales offices in Brazil and Germany, and over 70 dealers globally.

This case study focuses on Oilon's manufacturing plan in Kokkola, Finland. The Kokkola plant manufactures industrial heat pumps and chillers whose product name is Oilon ChillHeat (Oilon, 2022a). The ChillHeat product family consists of three product series: P-series, S-series, and RE-series. According to the plant, in year 2022 it is estimated that approximately 165 products are produced. The products manufactured in Kokkola are manufactured based on an order. Most of the products manufactured are customized based on the need of the customer. According to the development manager, the concept of lean is familiar to most of the employees at the manufacturing plant in Kokkola. Some lean projects have been conducted during the past years, for example, implementing 5S to the production. Also, the employees at the plant have received some lean training.

1.4 Structure of the thesis

The thesis obeys a scientific structure, and it consists of five main chapters. The structure of the thesis aims to proceed systematically to provide a logical review of the study. The five chapters of the thesis are introduction, theoretical framework, research methodology, results, and summary and conclusions. The introduction chapter presents the background of the study and the definition of the purpose, that is the research question and objectives of the study. Also, it defines the delimitations and the scope of the study, as well as introduces the case company. In general, the introduction chapter covers the outline of the entire study.

The second chapter provides a theoretical framework for conducting the empirical study. The chapter is divided into two subchapters. The first subchapter presents the theory of the concept of lean, its principles and tools, as well as the implementation to small and medium-sized enterprises. The second subchapter consists of theory dealing with value stream mapping and its implementation. The process of conducting a VSM analysis is reviewed including factors concerning the implementation of VSM to a make to order environment. Finally, the critical success factors for VSM implementation are defined.

The research methodology is presented in the third chapter of the thesis. It presents the methods for conducting the study. The research methodology defines the methods used for the data collection and data analysis for achieving answers to the research question and objectives of the study. Also, the reliability and validity of the research and the framework for conducting the empirical study are reviewed.

The fourth chapter presents the results of the empirical study and offers the answer to the defined research question and objectives. The results are presented in chronological order how the VSM analysis was conducted, that is in four phases. The procedures and results of each phase of the VSM analysis are presented.

The final chapter five summarizes the results of the empirical study. It also includes discussion and conclusions between the theory and results of the study. Additionally, possible future research is considered.

2 Theoretical framework

This chapter will present the theoretical framework for conducting the empirical study. The first part of the theoretical framework will cover the theory of lean and its implementation to small and medium-sized enterprises. The second part of the theoretical framework will cover theory of VSM including its implementations and practices for conducting a VSM analysis. In addition, the second section will include factors concerning the adaption of a VSM analysis to a make to order environment.

2.1 Lean overview

Lean is a data-driven concept and methodology for improving companies' processes (Bradley, 2012, pp 28). There is not an agreed definition for lean and yet the definition for its purpose is divergent (Pettersen, 2009, pp. 133-134). Pettersen (2009, pp. 136-137) argues this to be because lean is constantly evolving and as well lean is a very broad concept thus it is very hard to define all the attributes in a single definition. However, there is a common agreement on the characteristics that define the concept of lean. Chaudhari and Raut (2017, pp. 168) define lean to be a methodology that pursues to minimize the resources required for production. This is accomplished by eliminating non-value adding activities or also known as waste, from the processes. Locher (2008, pp. 12) defines lean as a systematic method to maximize value and minimize waste in a company's processes. Eliminating waste decreases costs, lead times, process times and inventory requirements, and improves flow efficiency, quality, and effectiveness (Chaudhari & Raut, 2017, pp. 168-169). This results in processes that produce as much added value for the customer as possible with the least possible resources. According to Krishna Jasti and Sharma (2014, pp. 91) at first lean was a set of principles that converted to a manufacturing strategy and now it is a management philosophy.

Lean is originated from Toyota's production philosophy called Toyota Production System (TPS) (Womack et al., 1991). TPS concentrated on customer satisfaction and producing solely what the customer wants, thus eliminating waste from the manufacturing processes. Lean was introduced to the world to describe the management techniques used by the Japanese automotive industry (Abdi et al., 2006, pp. 191). Lean encases the same principles, tools, and methods which are included in the TPS. A central philosophy for both TPS and lean is continuous improvement (CI) (Thangarajoo & Smith, 2015, pp. 1). The concept of CI is constantly developing and improving the performance of processes by systematically identifying and eliminating non-value adding activities, thus removing waste. This means that companies must understand and define which activities are value adding (VA) and which non-value adding (NVA).

Cutcher-Gershenfeld (2003, pp. 3) argues lean approach to be a central success factor for many large global companies. (Chaudhari & Raut, 2017, pp. 168-169) states that lean can address a wide range of competitive demands simultaneously to achieve high level of process and product quality, low cost, short lead times, and high flow efficiency. Lean approach aims to serve customers with precisely the product they wish along with higher quality, lower prices, and shorter lead time (Thangarajoo & Smith, 2015, pp. 1). Central features of lean are zero waiting times and inventory, flow, and line balancing (Chaudhari & Raut, 2017, pp. 168-169). Originally the concept of lean was used in the manufacturing industry (Thangarajoo & Smith, 2015, pp. 1). Today lean is applied to various other industries.

2.1.1 Principles of lean

In 1996 Womack and Jones introduced five principles of lean. These five principles are commonly applied when implementing lean to a company (Womack & Jones, 1996). According to Höök and Stehn (2008, pp. 20-31) these five principles can be applied to any business. The goal of the principles is to generate an efficient value stream in which it is constantly improved by eliminating activities that do not add any value for the customer. The five principles of lean are presented in figure 1.

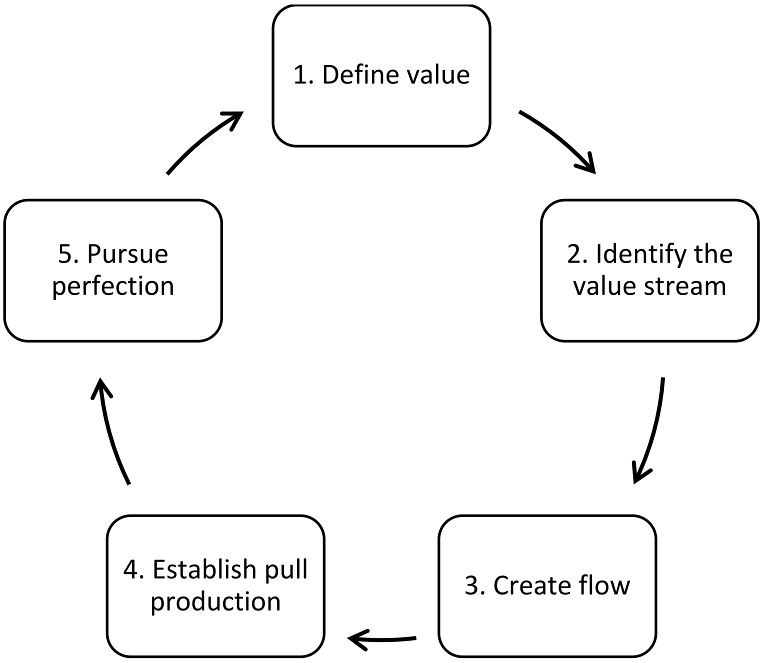

Figure 1. The five principles of lean (Adaption from Thangarajoo & Smith, 2015, pp. 2).

The first principle of lean is to define value from the perspective of the customer (Thangarajoo & Smith, 2015, pp. 2). It is essential to determine who are the actual customers and what the customer considers to be value for them and for which they are willing to pay. Hence companies can establish objectives for each activity in producing a product (Howell & Ballard, 1998, pp. 4).

The second principle of lean is to identify the value stream (Thangarajoo & Smith, 2015, pp. 2). This is a process in which a company need to map and identify all activities of a specific process or processes. As a result, all VA and NVA activities are determined (Maleyeff, 2006, pp. 682-683). VA activities are activities the customer is willing to pay for (Manjunath et al., 2014, pp. 477). NVA activities are such activities that add costs and time but do not add any value for the customer (Maleyeff, 2006, pp. 682-683, 688). Some of the NVA activities are so-called necessary but non-value adding (NNVA) activities.

These activities are such that cannot be eliminated from the process but possibly shortened (Bicheno, 2004). NVA activities are to be eliminated and NNVA activities minimized from the value stream (Thangarajoo & Smith, 2015, pp. 2-3). Value stream mapping (VSM) is an effective tool for identifying the value stream (Masuti & Dabade, 2019, pp. 609).

The third principle of lean is to create a flow to the mainly remaining value adding process, as the possible NVA activities are eliminated and NNVA activities minimized (Thangarajoo & Smith, 2015, pp. 3). The goal is to create a process that flows as efficiently as possible without interruptions (Womack & Jones, 1996). The flow does not concern only materials and products but also the flow of information.

The fourth principle of lean is to establish pull production (Thangarajoo & Smith, 2015, pp. 3-4). Pull production is established once the upstream production is triggered by the downstream (Womack & Jones, 1996). According to Thangarajoo and Smith (2015, pp. 3-4) pull production ensures that the customer receives the product it wishes. Pull production is not possible to achieve if the first three principles are not engaged.

The final principle of lean is to pursue perfection (Thangarajoo & Smith, 2015, pp. 4). This refers to continuous improvement of the prior four principles. Gupta (2015) states that the final principal challenges companies to continuously find new methods and opportunities to develop their processes and activities based on the four principles. The effort of improving processes and activities is complete only after perfection is achieved.

2.1.2 Waste in processes

There are three types of waste that strain processes (Smith, 2014, pp. 36). These three types are *muda*, *mura* and *muri*, which are Japanese terms for waste, inconsistency, and overburden. By concentrating on eliminating these three types of wastes the goals of lean can be achieved. Originally waste (*muda*) was categorized into seven different waste types. One type of waste was later added to the list. The eight wastes are overproduction, excess motion, waiting, inventory, transportation, defect correction, overprocessing, and lost creativity (Munro et al., 2016, pp. 41-42). Any these wastes do not add value to the product.

Overproduction – Producing products more, faster, or earlier than is needed (Munro et al., 2016, pp. 41). Smith (2014, pp. 36) states overproduction to be a cause of several other wastes. Overproduction increases for example inventory amounts and the need for space (Munro et al., 2016, pp. 41).

Excess motion – The excess motion of personnel and information (Munro et al., 2016, pp. 41; Harrington et al., 2014, pp 87). This can be caused by poor layout and ergonomic planning. The location of material and tools should be planned so that motion is minimized.

Waiting – Waiting is defined to be the time to wait for something to happen (Munro et al., 2016, pp. 41). The waiting factor can be a product, employee, or machine. Waiting has a direct impact on the lead time. There are several causes of waiting, such as poor production schedule and layout planning, raw material and resource shortage, and process bottlenecks (Munro et al., 2016, pp. 41 Harrington et al., 2014, pp 83-84).

Inventory – The storing of raw material or product do not add value to the product (Munro et al., 2016, pp. 41-42). Some inventories may be necessary, however excess inventory requires, for example, additional space or resources which increases the costs and lead time. Poor demand forecasting and product complexity are examples of the causes of excess inventories (Munro et al., 2016, pp. 41-42; Harrington et al., 2014, pp. 72).

Transportation – The transportation of material is typically the cause of poor layout planning and overproduction (Smith, 2014, pp. 36). Transportation increases costs, lead time, and the number of resources required (Munro et al., 2016, pp 42-43).

Defect correction – The quality defects of products is entirely a NVA activity, as the effort to correct the faulty product is wasted. The reason for the need for defect correction is for example poor equipment maintenance, quality system, product design, and training of workers (Munro et al., 2016, pp. 43).

Overprocessing – Processing the product more than the customer is willing to pay for it, thus the process of producing a product includes NVA activities (Munro et al., 2016, pp. 43). Hence, the process includes more activities than required to produce a product that satisfies the customer. Overprocessing is caused by for example unclear customer requirements and poor communication (Harrington et al., 2014, pp. 80).

Lost creativity – The inability to exploit the skills, creativity, ideas, or other potential and capabilities of the employees (Munro et al., 2016, pp. 44). According to Harrington et al. (2014, pp. 92-94) the waste of lost creativity is unavoidable in all companies. Lost creativity is caused for example due to the lack of training and poor hiring process.

In addition to the eight categories of waste, inconsistency and overburden are forms of waste that strain processes. Inconsistency refers to the unevenness and irregularity of a company's processes (Smith, 2014, pp. 37). Inconsistency in processes can generate waste, thus inconsistency should be dealt with and minimized to make the processes more predictable. Overburden refers to a situation in which an activity is not able to manage the workload which is assigned for it (Smith, 2014, pp. 37). However, overburden is more of a symptom than a cause. Inconsistency is one cause for overburden.

2.1.3 Implementation of lean to SMEs

As stated before, the implementation of lean is argued to be the best response to the competition of the global industry. However, small and medium-sized enterprises (SMEs) do not have the same capabilities and resources as large companies when it comes to implementing lean (Elkhairi et al., 2019, pp. 566). The implementation of lean and the structure of lean is complex. Thus, SMEs do not have the essential resources to determine the appropriate structure for them. Elkhairi et al. (2019, pp. 566) state that SMEs often are unsuccessful in selecting and evaluating the right methods and tools for their use. Large companies do have their problems and barriers for lean implementation, but smaller companies have more of these problems and barriers.

Bajjou and Chafi (2018) classify the barriers to lean implementation of SMEs into three categories: economic barriers, managerial and technical barriers, and social barriers. Economic barriers include limited resources. Managerial and technical barriers include lack of planning, lack of experience, lack of commitment from top management, lack of strategic perspective, and misunderstanding of the lean. Finally, social barriers include resistance to change. Almanei et al. (2017, pp. 753) list the common root causes of the failed implementation of lean in SMEs to be lean suppliers, leadership, employee involvement, tools and techniques, and business systems.

To overcome the barrier of lean implementation SMEs should concentrate on the critical success factors (CSFs) for lean implementation in SMEs (Elkhairi et al., 2019, pp. 568). CSFs are factors that play a key role in the successful implementation. These factors should be taken into account in the company's different functions and day-to-day work. Elkhairi et al. (2019, pp. 568) list the CSFs for lean implementation in SMEs to be: leadership, cultural change, competence and expertise, commitment from top management, education and training, and communication. In another study conducted by Bakås et al. (2011, pp. 5-6) the CSFs for lean implementation in SMEs were summarized into seven categories: leadership and management involvement, employee involvement and sufficient participation, change in organizational culture and the time factor, motivation and learning, performance evaluation systems, communication of goals and objectives with improvement initiatives, and linking improvement initiatives to business strategy and customers.

2.1.4 Lean tools

Based on the five principles of lean, presented in chapter 2.1.1., lean aims to identify and remove the non-value adding activities or wastes and then optimize resources to be able to produce as much as possible with the minimum number of resources (Belhadi et al., 2016, pp. 340). To be able to accomplish this lean consists of a set of diverse tools and methods. Different tools have different purposes and objectives (Zhao et al., 2016, pp. 79). Thus, companies should choose the correct tools based on the purpose. Belhadi et al. (2016, pp. 340) argue that only a few SMEs have managed to implement lean successfully and have benefited from its result. Nasser et al. (2010, pp. 3) state that the main difficulties SMEs faced when implementing lean are the use of wrong tools, use of one tool to solve all the problems, use of the same set of tools to solve problems, and lack of understanding.

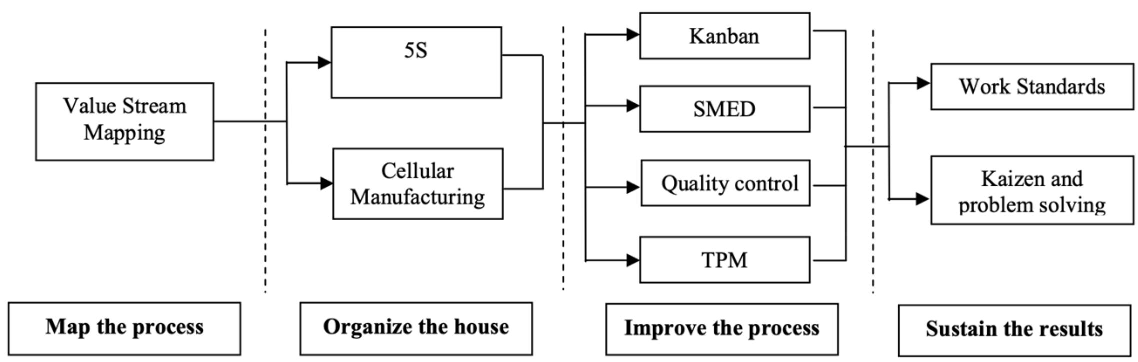

Figure 2. Roadmap of lean tools implementation in SMEs (Adaption from Belhadi et al., 2016, pp. 344).

Belhadi et al. (2016, pp. 340-344) carried out a study to form a roadmap of lean tool implementation for SMEs. As a result of the study, a proposed roadmap was created. This roadmap is presented in figure 2. The roadmap acts as an optimal sequence of lean implementation in SMEs. The roadmap contains four phases:

Map the process – The aim of the first phase is to see and identify the production process (Belhadi et al., 2016, pp. 344). In this value streams and wastes are located. The recommended tool to be used is Value Stream Mapping (VSM). VSM consists of several lean practices, such as visual control, time study, and 7 wastes. The output of this phase is the locations of existing wastes and a design of a future state which is in line with the philosophy of lean.

Organize the house – The purpose of the second phase is to lay a solid foundation so that other lean practices can be implemented with fewer difficulties (Belhadi et al., 2016, pp. 344). Recommended lean tools to be used are 5S and Cellular Manufacturing. The implementation of 5S is quite easy and does not require a big financial investment. Similar to VSM, 5S consists of several lean practices. Cellular Manufacturing pursues the implementation of Just-In-Time (JIT) to the production and culture of the company. JIT accomplishes continuous flow and flexibility in the processes.

Improve the process – The third phase is the main phase of the implementation process of lean tools (Belhadi et al., 2016, pp 345). The aim of the third phase is to implement a set of pilot projects that acts as trial implementations. The purpose of the pilot project is to experiment the implementation and ensure that the actual implementation is based on accuracy, effectiveness, and efficiency. In this phase, the SMEs can study different tools and methods to ensure that they are the correct ones to be implemented. The decision of choosing lean tools should be based on the company's operating environment, for example, depending on the company's production volume and products repetitiveness.

Sustain the results – The purpose of the final phase of the roadmap is to establish new work standards based on the own experience of the SME (Belhadi et al., 2016, pp. 345). In addition, SMEs should implement a CI culture to tackle the existing and future problems.

2.2 Value stream mapping

The second principle of lean is to identify the value stream by determining the VA, NVA and NNVA activities of the process. The first phase of the roadmap developed by Belhadi et al. (2016, pp. 344) is fulfilling the second principle of lean by mapping the process. Both Belhadi et al. (2016, pp. 344) and Masuti and Dabade (2019, pp. 609) state that value stream mapping (VSM) is the most effective tool to use in mapping the process and thus identifying the value stream. VSM is defined as a powerful tool that helps to identify different activities, wastes, the flow of material, information, and resources of the process (Krishna Jasti & Sharma, 2014, pp. 92; Mudgal et al., 2020, pp. 826). By identifying the mentioned factors, the process can be redesigned in a way that the NVA activities are minimized and VA activities maximized. Serrano et al. (2008b, pp. 4412) state that no tool or method is comparable to the effectiveness and the efficiency of VSM. VSM concentrates on describing the physical and informational flows of a process. The main goal is to find out the areas for improvement to redesign the process based on the concept of lean and ultimately achieve it (Locher, 2008, pp. 1-2; Masuti & Dabade, 2019, pp. 607).

A traditional VSM visualizes all material and information flow from supplier to customer covering wastes, bottlenecks of the process, and their impact on the cycle times (Seth et al., 2017, pp. 400). It shows the relationships between different processes and stakeholders, such as production scheduling, prioritization of work, inventory, and production rates. VSM is well applicable, thus necessary data and information can be included depending on the need and the industry in question. Seth et al. (2008, pp. 542) state that VSM can be implemented for any industry and activity. It can also be expanded upstream and downstream if seen necessary. Locher (2008, pp. 93) VSM process and especially the mapping events are learning opportunities. The VSM project participants learn about the existing processes and the ways to develop them.

Locher (2008, pp. 1-2) states that there is a recommended four-phase process for applying VSM. This recommended process is presented in figure 3. These four phases, (1) preparation, (2) mapping the current state, (3) mapping the future state, and (4) planning and implementation, are defined and assessed in the chapters from 2.2.2 to 2.2.5. Rother and Shook (1999) suggested a five-phase process for applying VSM. These five phases are selection of a product family, current state mapping, future state mapping, definition of a work plan, and achievement of the work plan. The differences between these two frameworks are minor as the content is essentially the same.

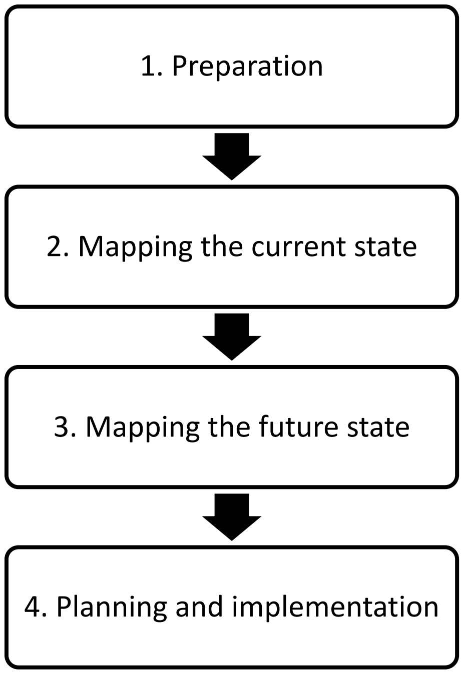

Figure 3. Phases of the VSM process (Adaption from Locher, 2008, pp. 2).

2.2.1 Implementing VSM to a MTO and complex product environment

The VSM tool was developed for the high-volume-low-mix industry (Rother & Shook, 1999). Over the history of VSM, it has successfully been used in a mass-production or Make to Stock (MTS) manufacturing environment (Mudgal et al., 2020, pp. 826). However, the use of a traditional VSM in a make to order (MTO) or complex product environment generates problems and is must be fitted to be applied for these types of manufacturing environments (Mudgal et al., 2020, pp. 826; Seth et al., 2017, pp. 398).

The concepts of MTS and MTO are very different (Koch & Lödding, 2014, pp. 2). A MTS production usually manufactures products based on forecasting while a customer's order triggers the production of MTO (Deep et al., 2008, pp. 434-435). MTS companies usually produce standard products thus the customer has a very limited number of products from which to choose (Koch & Lödding, 2014, pp. 2). MTO products are influenced by the customers thus the products are often customized to match the need of the customer. As MTS companies produce a standard product the flow of the production is also standard (Koch & Lödding, 2014, pp. 2). The production of a MTO product is often complex as it may require different parts and production phases than another product. The production of a MTO product tends to have a complex non-standard material flow (Stamm & Neitzert, 2008, pp. 5). As MTO products have a complex design and production flow thus the requirements of the product vary from product to product including the required due date of the product (Stamm & Neitzert, 2008, pp. 5). Based on these factors the takt time, or the required production time, changes constantly. Mudgal et al. (2020, pp. 827-828) state that an average takt time is an appropriate tool in a MTO environment. The formula for calculating takt time is presented in formula 1.

$$Takt\ time = \frac{Availabe\ production\ time}{Customer\ demand} \quad (1)$$

It can be realized, MTS and MTO production strategies differ in several factors. However, Alves et al. (2005, pp. 1) state that VSM can be applied to a complex manufacturing environment when used in a flexible manner. In the following chapters 2.2.2 to 2.2.4 the implementation of VSM to a MTO environment aspect will be included.

Braglia et al. (2006, pp. 3932-3933) were able to specify how VSM should be applied for a complex manufacturing environment by creating a framework. The framework includes seven steps which are presented in figure 4. Braglia et al. (2006, pp. 3951) state that the framework has three main advantages, which are: it serves as a structured way of selecting the key elements of a complex manufacturing process and can complete an analysis of the whole value stream, it can deal with multiple products which may not have the same manufacturing path, and it can deal with complex bill of materials which have multiple levels and flows.

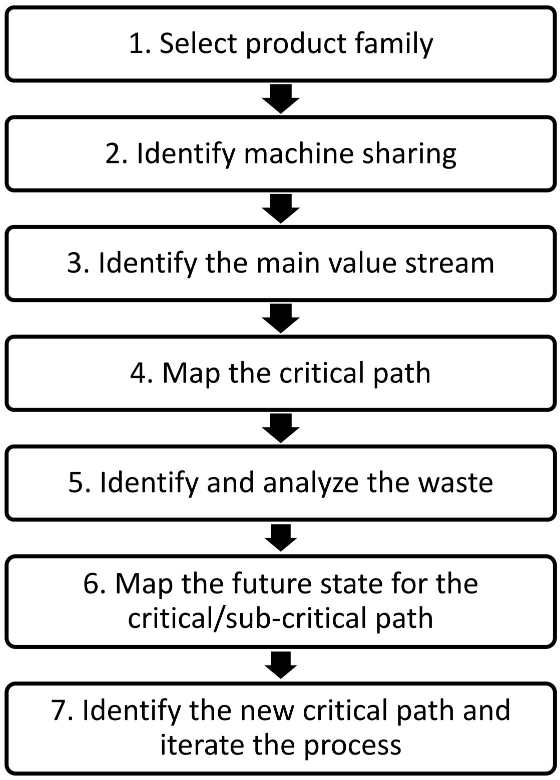

Figure 4. Framework for applying VSM for a complex manufacturing environment (Adaption from Braglia et al., 2006, pp. 3932-3933).

When comparing the VSM framework created by Braglia et al. (2006, pp. 3932-3933) to the traditional VSM frameworks of Locher (2008, pp. 2) and Rother and Shook (1999) resembles can be identified. The first three steps of the framework of Braglia et al. can be seen as the first phase of the frameworks of Locher and Rother and Shook. The fourth and fifth steps are comparable to the second phase of Locher and Rother and Shook. The sixth step is practically the same as the third phase of Locher and Rother and Shook. The seventh step of the framework of Braglia et al. cannot be compared to the other frameworks. The purpose of this phase is to choose the next value stream to target improvement on (Braglia et al., 2006, pp. 3943-3944).

2.2.2 Preparation

The first phase of the VSM process is preparation for the mapping process. The main aim of the preparation phase is to define the scope of the VSM. The scope is defined by the selection of a specific product of a product family which is then mapped in the next phase (Ertay et al., 2001, pp. 5). As mentioned before MTO products are usually complex and may not obey the same path of production flow. If this is the case should the common operations or critical path of the specific product family be identified (Braglia et al., 2006, pp. 3939-3041; Mudgal et al., 2020, pp. 828). Possible process and machine sharing should also be identified.

Necessary goals and objectives and also possible delimitations for the VSM project should be defined (Locher, 2008, pp. 1-8). As the product or product family and possibly the common operations have been identified the participants of the mapping team should be identified. These participants should be based on the selected product or product family and the objectives of the VSM process. The preparation phase includes all planning activities that concern the practical mapping work. These include the possible training of the project participants. Serrano et al. (2008a, pp. 50) state that one of the main issues or pitfalls of a successful VSM is not training the VSM project participants with necessary lean concepts. Thus, every participant should have the necessary knowledge to achieve the goals and objectives of the VSM project. All information and decisions made in the preparation phase can be summarized in a SIPOC (Supplier, Input, Process, Output and Customer) -diagram. The SIPOC-diagram acts as a guideline throughout the VSM project.

2.2.3 Mapping the current state

The second phase of the VSM process aims to map how the existing process works (Locher, 2008, pp. 23). Zahraee et al. (2014, pp. 120) highlight that the value stream map should be a representation of the actual events, not the supposed events. The current state map acts as a baseline for the development of the future state map (Mahlo & Chiromo, 2020, pp. 12). The mapping events should be based on the scope which was determined in the preparation phase (Locher, 2008, pp. 23). Thus, the scope should be kept in mind though out the whole mapping event. This way the objectives and goals of the project will be achieved.

Locher (2008, pp. 23) suggests a six-step process for mapping the current state. The six steps are identifying the customer’s current needs, identifying the main process, selection of process metrics, preforming the value stream walk-through and filling in the data boxes, identifying how work is prioritized, and calculating the value stream summary metrics. There are also other frameworks and processes for mapping the current state. For example, Lee and Snyder (2006, pp. 53-60) suggest a 16-step process for mapping the current state. However, the six-step process suggested by Locher (2008, pp. 23) is very clear and comprehensive, so it is reviewed below in more detail.

Identify current customer needs – The aim of the first step is to identify the external customer’s needs (Locher, 2008, pp. 24). The customer needs are identified by determining the demand rate. The demand rate tells the number of products needed to be manufactured in a specific period of time.

Identify main process – In the second step of the process, the processes are identified and documented in the order in which they take place (Locher, 2008, pp. 24-25). The extent of the processes identified in this step should be based on the scope determined in the preparation phase. Possible subprocesses are also to be identified and documented if included in the scope.

Select process metrics – The aim of the third step is to decide the suitable metrics for the current state map (Locher, 2008, pp. 26-30). There are various possible metrics available, but it is important to choose the metrics which are useful and to benefit from. One role of the metrics is to display waste in the process. The metrics should describe the current state as well as possible and in the desired way. Based on the analysis of the chosen metrics decisions regarding the future state are made. When selecting the metrics, the process of acquiring the data for the metric is to be taken into consideration.

As mentioned, there are various possible metrics available. The metrics can measure for example time, quality, resources, and inventory (Locher, 2008, pp. 18-19, 26-30). Common time metrics are for instance process time, lead time, takt time, VA time, NVA time, and NNVA time. Examples of quality metrics are for instance first pass yield-%, complete and accurate-%, and uptime-%. First pass yield-% indicates the average percentage of produces products that flow through the value stream without any additional work completed to it. As the first pass yield-% metric indicates the quality of the whole value stream complete and accurate-% indicates the quality of a specific production phase. Thus, complete and accurate-% indicates the average percentage of produces products that flow through a specific production phase without any additional work completed to it. Uptime-% indicates the average percentage of the available time that a machine is up and running when taking into account the possible breakdowns or service times (Lee & Snyder, 2006, pp. 61). Therefore, the metric indicates the operation reliability and quality of a machine. Resource metrics can indicate the number of employees or machines available (Locher, 2008, pp. 26-30). Inventory metrics can indicate the number of materials in stock or the time a material is stored.

Perform value stream walk-through and fill in data boxes – In this step the value stream is reviewed phase by phase (Locher, 2008, pp. 30-32). The aim is to understand and analyze what happens in the value stream, what activities are made, and how the product flows through the value stream. All necessary metrics and data are to be documented. All VA, NVA, and NNVA activities should be documented.

Establish how each process prioritizes work – The aim of the fifth step of the process is to identify how different processes prioritized work (Locher, 2008, pp. 32). This step determines how products and materials flow into a process phase and what happens between process phases. This step also identifies the possible information flows between the production phases and the work management.

Calculate value stream summary metrics – All summary metrics are calculated in the final step of the process (Locher, 2008, pp. 32). Summary metrics describe the whole process on large scale. There are various summary metrics, such as total lead time, total process time, and First Pass Yield. The summary metrics can describe different factors such as time and quality. As well as in the third step of selecting the process metrics, it is important to select the right metrics which is most useful.

After these six steps, a map of the current state is established. The process of mapping the current state has room for fitting it for one's use (Locher, 2008, pp. 33). Thus, there is no one right way of conducting it. For example, in a MTO environment there is often no inventories (Stamm & Neitzert, 2008, pp. 8). However, the symbol for inventory can be used to illustrate the waiting time of a product between two process phases. In addition, in a MTO environment for example the process time and lead time of a product vary from product to product as the products are produced based on the need of the customer (Koch & Lödding, 2014, pp. 2). Thus, there is no standard metric data for a process phase. In these cases, an average time is sufficient data (Mudgal et al., 2020, pp. 828).

2.2.4 Mapping the future state

The process of creating and mapping the future state is the key to why VSM is such an effective tool in the concept of lean (Locher, 2008, pp. 55). The future state map shows the future of the production after implementing lean tools (Masuti & Dabade, 2019, pp. 608). This VSM phase aims to create and map the most effective value stream possible in which NVA activities are eliminated, NNVA activities are minimized, and the share of VA activities are maximized.

The goal of VSM is to find out the areas for improvement to redesign the process based on the concept of lean. Authors and researchers have introduced guides for analyzing the current state and finding the areas for improvement. Locher (2008, pp. 55) lists seven questions that are intended to act as a guide for the creation of the future state map. The seven questions are:

1. What does the customer really need?
2. How often will the performance compared to the customer's needs be checked?
3. Which steps create value and which steps are waste?
4. How can work flow with fewer interruptions?
5. How to control work between interruptions, and how will work be triggered and prioritized?
6. How will the workload and/or different activities be levelled?
7. What process improvements are necessary?

Stamm and Neitzert (2008, pp. 4) lists five features that a process phase should include. A process phase should be valuable from the perspective of the customer, capable, available in terms of utilizing the equipment, adequate in terms of machine capacity, and flexible. If a process phase does not include all these features Stamm and Neitzert (2008, pp. 4) states that it should be analyzed and improved. Serrano et al. (2008b, pp. 4411) introduce a six-feature guideline identifying the improvement for the future state. The six-feature guideline includes: (1) the production rhythm should be based on the customer demand also known as takt time, (2) continuous flow should be fulfilled as widely as possible, (3) pull system should be implemented where continuous flow is not possible, (4) one process should set the pace for other processes, (5) work scheduling should deal with the maximization of mix and volume production levelling, and (6) overall efficiency of the processes should improve. As the areas for improvement are identified they should be improved and developed. Bradley (2012, pp. 67-68) introduces eight tactics for eliminating waste and burden from processes. The eight tactics include simplifying the process, streamlining the process, standardizing the process, using visual systems in the process, making the processes mistake-proof, synchronizing the processes, collocating the process, and reducing changeover time in the process.

There is no guarantee that the future state will come true and every development idea will be implemented successfully (Locher, 2008, pp. 56). Therefore, all development ideas included in the future state map should be realistic. Locher (2008, pp. 56-57) introduces a ground rule technique which used to delimit the non-realistic ideas from the future state map. The ground rule defines as a rule, a development idea should be included if it is believed that it can be implemented with a certain probability within a certain period of time. For example, as a rule, a development idea should be included in the future state map if it is believed that the idea can be implemented successfully in one year's time with a probability of 70 percent. If it is not believed, the development idea should not be included in the future state map. The VSM project participants can produce their own ground rule, but the probability and the time period should be justified. Also, the development ideas included in the future state map should be in line with the objectives and goals of the VSM project.

2.2.5 Planning and implementation

The aim of the final phase of the VSM process is to create a working plan for the implementation of the future map and see through the implementation (Locher, 2008, pp. 89). A working plan is a scheme for the implementation of the development ideas (Wenchi et al., 2015, pp. 819-820). By following the working plan during the implementation process the future state is achieved and improvement targets are met. According to Jiménez et al. (2012, pp. 1899-1900) the creation of the working plan should begin by classifying the development ideas as wholes or loops. The implementation of the development wholes should be categorized into priorities and scheduled (Locher, 2008, pp. 89-93).

Also, the development should be assigned for different people to know who is responsible for implementing each improvement (Jiménez et al., 2012, pp. 1901).

The prioritization plays a major role in the outcome of the implementation. Locher (2008, pp. 89-91) suggests that the quality of the product should be improved and waste from the processes should be eliminated in the first steps of the implementation. After these improvements, the flow of the product can be developed. This is because waste and low-quality commit resources. Thus, after the development of quality and the elimination of waste is completed, there are more resources for improving the flow. Locher (2008, pp. 89-91) also states that development ideas that are not complex and not time-consuming are to be implemented in the first months of the implementation process.

The implementation process itself should be regularly reviewed (Jiménez et al., 2012, pp. 1892). There are several measures and metrics for monitoring the implementation, such as quality and time metrics. A successful implementation rests on the commitment of the VSM project participants. The next chapter 2.2.6 deals with the CSFs for VSM implementation. Many of the CSFs presented affect the implementation of the future state and working plan.

There are not many studies and literature dealing with the planning and implementation phase of VSM in the manufacturing industry. Therefore, there is not much theory available to review and present. (Wenchi et al., 2015, pp. 819) supports this argument and states that the VSM participants should focus on improvements and discovering of waste to be based on benchmarking and data collection.

2.2.6 Critical success factors for VSM implementation

Different factors affect the success of VSM implementation to a company. A study conducted by Shou et al. (2017, pp. 3913-3914) lists 12 CSFs for VSM implementation in the manufacturing industry. The study bases its findings on 14 different academic articles.

Based on these 14 articles the top CSF is the ability to refine theory and integrate it to the company and to the VSM process. 11 of 14 articles point out this factor as a CSF for VSM implementation. The second level of CSFs includes the use of an empowered inter-principle lean team, support from the top management, and the quality and extent of training and education. Each CSF included in the second level was pointed out by 4 of 14 articles. Other CSFs of VSM implementations are, for example, the level of skills and abilities of the company and the VSM participants, organization culture, and the level and quality of communication.

3 Research methodology

This chapter presents the methodology for conducting the study and achieving the answer to the defined research question and objectives. The methodology defines the methods for data collection and data analysis. Finally, the consideration for reliability and validity of the research and the framework for conducting the empirical study are reviewed.

3.1 Case study approach

A case study is a research strategy that carries out thorough research from several perspectives of a specific project, program, or system in a real-life context (Simons, 2009, pp. 21). Case studies investigate the questions of how and why and develop new theories and ideas (Voss et al., 2002, pp. 195-196). Also, it can be used for testing and refining theory. In addition to enhancing, theory case studies have a strong impact on improving and enhancing researchers themselves.

This thesis is conducted based on a case study research strategy. The case study is carried out to a manufacturing company called Oilon Oy and its manufacturing plant in Kokkola. As the study is performed for a specific company, manufacturing plant and product it can be defined as a single case study. To be able to answer the research question and to define the objectives listed in chapter 1.1 data is collected and analyzed. Table 1 shows the methods of data collection used in the study, methods of data analysis and, notes concerning the data collection.

Table 1. Data collection of the study.

Data collection	Data format	Analysis	Note
Literature review	Qualitative	Content analysis	Literature review of the theory of lean and VSM is based on scientific articles and books on the topic.
Interviews (3 white collar employees and 12 technicians)	Qualitative	Content analysis	Interviews were conducted with the manufacturing plant's white-collar employees and technicians of each production phase.
Observation (All manufacturing phases)	Qualitative	Content analysis	The manufacturing plant, production processes and the work of the technicians were observed.
Workshop (3 workshop events)	Qualitative	Content analysis	Three workshops were held to define and create the current state map, future state map and the working plan.
Report (From the years 2021 to 2022)	Quantitative	Trend analysis	Data from ERP-system.

3.1.1 Interviews and observation

The process of familiarizing the manufacturing plant, products, and production processes was based on interviewing employees and observing the plant, production processes, and the work of the technicians. The author did not have prior knowledge of the manufacturing plant, product, or production processes. Therefore, observations and interviews were conducted to achieve a good and broad understanding of the operations taking place in the manufacturing plant. All phases of the production were reviewed by observing the work of the technicians, facilities, and the features of the phase. In addition to observing the technicians were interviewed concerning the work processes, facilities, and features of the production phase. These interviews did not have a predefine interview framework. Thus, the questions were generated during the observation activity. The questions were open-ended questions. Interviews and observations of work were conducted for several technicians of the same production phase. Among the production interviewees were both new technicians and experienced technicians.

The white-collar employees, which included the plant manager, development manager, and foreman, were interviewed. These interviews supported the familiarization of the manufacturing plant, products, and production processes. Also, based on questions and the discussion with the plant manager and the development manager the scope of the VSM project was defined and the SIPOC document was generated. Similarly, to the questions for the technicians, the questions for the white-collar employees were open-ended questions. Except from the interview and discussion dealing with the scope definition and the SIPOC-diagram which were carried out via Microsoft Teams, all interviews were carried out face-to-face including the technician interviews.

3.1.2 Workshops

Three workshops were conducted during the study. The first workshop event dealt with the definition and creation of the current state map. The second workshop event dealt with the definition and creation of the future state map. The final workshop event dealt with the definition and creation of the working plan. All interviews were conducted before the workshops. The workshop events were carried out face-to-face in the manufacturing plan premise.

The plant manager, development manager, foreman, and two to three technicians per production phase attended the first and second workshop events along with the author who acted as a facilitator. Among the technicians were both new technicians and experienced technicians. The white-collar employees were present throughout the workshop events. The technicians were present when dealing with matters concerning their job or production phase. Only the plant manager, development manager, and foreman attended the third workshop event along with the author who acted again as a facilitator. The atmosphere of the workshops was neutral and every participant was encouraged to speak up and attend the discussions.

3.1.3 Other data

A literature review was conducted to learn the theory of lean and VSM. The data from the literature review acts as a base for the study. The literature review is based on scientific articles and books. Data from the case company's ERP-system was gathered in form of a report. The report consisted of data from a long period of time. The ERP-system conducted the trend analysis for the data. This data was used for supporting the creation of the current state map. The data from the ERP-system is a secondary source of data.

3.2 Reliability and validity

Reliability is defined as the extent to which the results of a study are consistent over time (Golafshani, 2015, pp. 598). This means that by applying the same methodology over different studies similar results are acquired. Validity is defined as the extent to which the methods and tools used in the study measure what they are intended to measure and how accurate the results are (Golafshani, 2015, pp. 599). Both reliability and validity are derived from quantitative context (Rose & Johnson, 2020, pp. 436). Therefore, reliability and validity are not so distinct in a qualitative context.

Due to the nature of this thesis, as it is almost entirely a qualitative study, ensuring reliability and validity is more difficult. Besides this, the study was conducted primarily to ensure good reliability and validity. One measure which was taken was data triangulation. The data was collected from several employees from different levels of the hierarchy. Also, data was generated by a discussion which led to a common outcome. The discussion was based on experience and facts, not assumptions. In addition, the interviewees and workshop participants were with a different amount of experience which brought a broader perspective on the matter at hand. Based on these measures and features of the study, it was assumed that the study could be repeated.

3.3 Framework of the research

The framework of the research is based on the traditional VSM framework, but it is fitted to suit a more complex environment. It consists of four phases and each phase consists of several steps. The frameworks used in the research is presented in figure 5. As stated in chapter 1.2 the research will not see through the implementation of the future state.

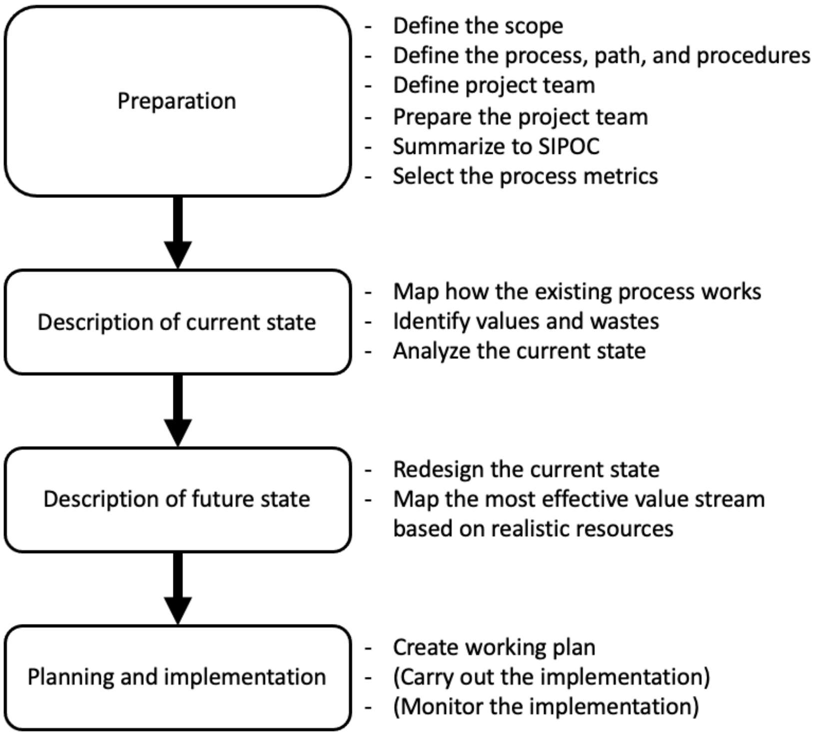

Figure 5. Framework of the research.

4 Results

This chapter presents the results of the empirical study which was conducted based on the framework presented in figure 5. The results of the research are based on the collected data from the case company. Before the VSM project itself started the author presented the framework of the research for the case company. This was conducted to discuss how the VSM process will progress. Some preliminary definitions were made for the scope. This concerned the extent of the VSM and possible targets and objectives. As the author and case company were satisfied with the framework and the preliminary definitions of the research the VSM project was kicked off.

4.1 Preparation for VSM

The process of defining activities was completed together with the plant manager and the development manager of the case company. These employees acted as the decision-makers for the project. The preparation phase was conducted in four days. The phase included six steps which are presented in the following subchapters.

4.1.1 Define the scope

The preparation phase was started by defining which products are included and which products are excluded from the scope. The aim was to define the scope to be clear and streamlined. Hence, excessive obscurity can be avoided at later stages of the VSM analysis.

It was decided that the P-series and S-series are included in the scope and the RE-series and double S-product are excluded from the scope. According to the employees of the case company, the P-series and S-series have a very similar manufacturing process and flow, unlike the double S-product. The RE-series is produced less frequently compared to the P-series and S-series. Because of these features, the RE-series and the double S-product were excluded from the scope.

4.1.2 Define the process, path, and procedures

As the products were defined to the scope the process, path, and procedures could be defined. As stated, the P-series and S-series complete a similar manufacturing process. It was defined that there are seven manufacturing phases: (1) picking, (2) mechanical, (3) pressure test, vacuuming and refrigerant filling, (4) electrification and insulation, (5) electrical and IO test, (6) trial run, and (7) packaging. In the first phase, all small materials are collected in a collection cart based on a pick list. In the second phase, all mechanical parts are installed. This includes the prefabrication and assembly of the body parts, installation of the heat exchangers, compressors, and all pipes. In the third phase, the product is tested in case of leaks. The product is then vacuumed and refrigerants are added. The fourth phase includes the prefabrication, installation, and connection of all electrical material. Insulations refers to the process of insulating all pipes and heat exchangers. In the fifth phase, the electrification of the product is tested, as well as the software is fitted and tested. The performance of the product is tested by conducting a trial run. The final phase includes the packaging of the product.

The path of the P-series and S-series products is defined in figure 6. Although the path of the products is quite clear the work performed in each manufacturing phase vary based on the product manufactured. P-series and S-series include different products that can be customized based on the needs of the customer. Therefore, the procedures performed in each step vary thus the process time and lead time vary as well. It was decided with the plant manager that the value stream map will present the best possible average including all customization of the products in the scope. It was seen that it is not worthwhile to describe only one product and one customization of it, as it does not give a good overall picture of the production.

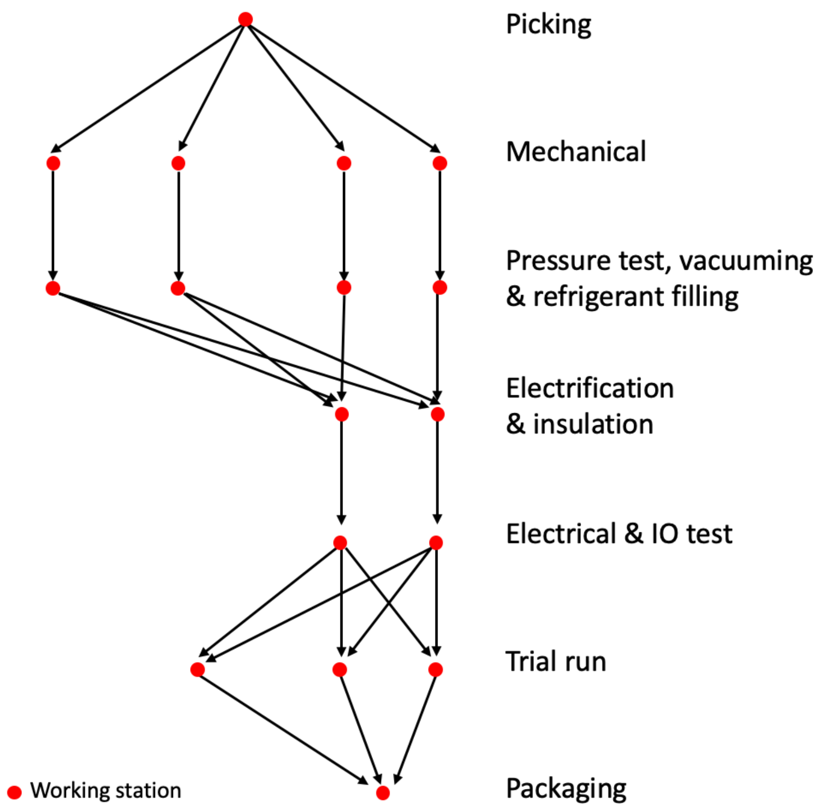

Figure 6. Path of the P-series and S-series products.

4.1.3 Define the project team

The definition of the process has a great influence on defining the project team. It was decided that the project team should consist of experienced technicians as well as fairly new technicians. It was seen that new technicians bring fresh ideas when more experienced technicians bring knowledge of the work and processes. It was decided that two to three technicians per each manufacturing phase along with the plant manager, development manager, and the foreman from the work management were included in the project team. Naturally, the author was included in the project team as a facilitator and the person bringing the knowledge of VSM.

4.1.4 Prepare the project team

The preparation of the project team was seen as a crucial element in a successful VSM analysis. The preparation of the project team included the training of the project team and the process of familiarizing the manufacturing plant, products, and production processes. The training consisted of theory of lean and VSM. The theory was tried to put into practice by examples and discussion of the subject. The practices and aims of each VSM process phase were presented. The training was conducted by the author and was fulfilled for each member of the project team. In addition, efforts were made to motivate team members. The motivation efforts were conducted during the training sessions as well as during the following workshop events. The motivation was conducted by the plant manager, development manager, and the author.

As mentioned in chapter 3.1.1 the author did not have prior experience of the products and the production of the products. Therefore, the author used two days to get familiar with the manufacturing plant, products, and production processes. This was carried out by interviewing and observing the technicians.

4.1.5 SIPOC-diagram

A SIPOC-diagram was used for summarizing the defined factors in the preparation phase. The SIPOC-diagram is presented in appendix 1. The SIPOC-diagram was used as a guideline tool during the process of defining the scope, process, path, procedures, and project team. Defining the suppliers, inputs, process, outputs, and customers helped to define the stakeholders of the production. In addition, objectives and goals were set for the VSM analysis. These included: a review of the current state of production practices, developing production chain, increasing the performance of production, reducing lead time, improving and developing quality, and identification of bottlenecks. The completed SIPOC-diagram presented in appendix 1 acted as a guideline for the whole VSM project.

4.1.6 Process metrics

Finally, suitable process metrics for the state maps were reviewed and selected. This process was conducted with the plant manager and development manager. It was seen by the author that the review and selection of the metrics are conducted in the preparation phase. This is because the author wanted to prepare and pre-define as much as possible so that the mapping event runs as smoothly as possible.

It was discussed that the metrics should be able to describe the subject as well as possible and there should be as few metrics as possible, thus only the most essential things are measured. The author presented a list of metrics for the plant manager and development manager. Based on the discussion the list of metrics was modified to be as sufficient as possible. The selected metrics were categorized into four categories: time metrics, quality metrics, resources, and number of pieces. The selected metrics are presented in table 2

Table 2. Selected metrics.

Time metrics	**Quality metrics**
VA time	First pass yield-%
NVA time	Complete and accurate-% (C&A)
NNVA time	Uptime-% (UT)
Prosess time (PT)	**Resources**
Lead time (LT)	Number of technicians
Waiting time	**Number of pieces**
Walking time (WT)	Frame part inventory
Deviating work time (DWT)	Demand amount
Demand rate	

The times defined in the current state and future state maps are estimates based on the knowledge of the employees of the case company. It was seen that estimates of times are sufficient in this case as it is impossible to produce an exact map of the production because of the variation of products produced.

4.2 Description of current state

The aim of the process of mapping the current state was to map how the existing production works. Before the mapping process, the author revised for the whole project team the aim of the phase and process of how the current state will be mapped. It was highlighted that the purpose is not to describe how operations should happen but how operations really happen. For the clarity of the map, different colours of Post-it notes were predefined to indicate a certain subject of the map. The value stream map itself was drawn to a wide piece of paper.

4.2.1 Mapping the current state

The current state workshop followed a six-step process of mapping the current state: (1) identifying the needs of the customer, (2) identifying the main process, (3) reviewing the value stream phase by phase and filling in data boxes, (4) establishing how work is prioritized, (5) calculating summary metrics, and (6) generating ideas throughout the mapping process. During the mapping process, it was recognized that it is essential that the content of the metrics is defined in the same way for each operation.

The author acted as a facilitator who asked questions during the mapping process to establish the content for the value stream map. The first two steps were conducted together with the plant manager, development manager, and foreman, who all were present during the whole mapping process. Steps three and four were conducted in a way that the technicians were called in turn when their work phase was reviewed. Thus, the whole project team was not present during the entire mapping process. This was because it was seen that the technicians had input only to issues concerning their work phase. Also, it was seen that fewer people would not create any extra fuss and would be able to focus on the subject at hand. The content of the map was reached through a joint discussion. The summary metrics were calculated after the whole value stream was reviewed. Throughout the mapping process, each participant was able to generate development ideas. The current state map was checked by all participants of the project team after the first draft was finished. The outcome of the workshop is presented in figure 7.

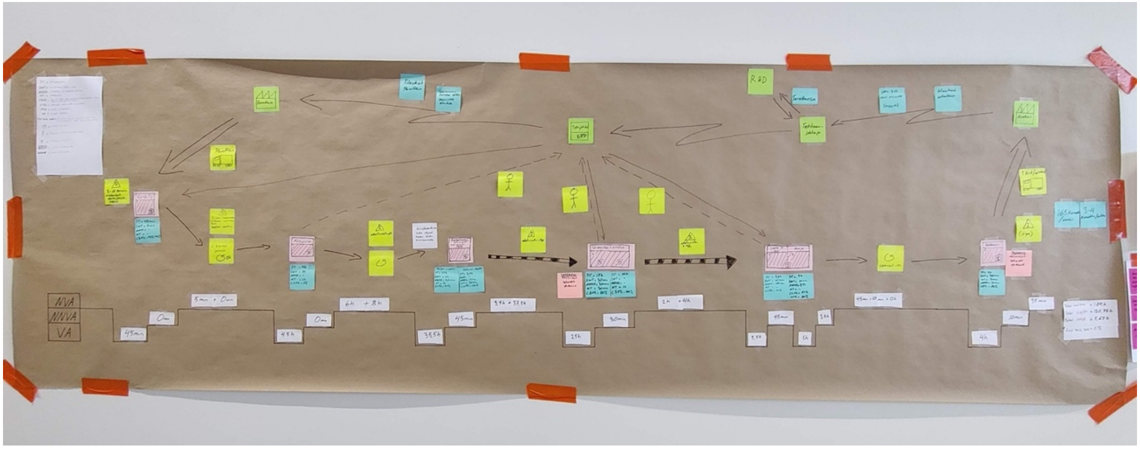

Figure 7. Outcome of current state workshop.

4.2.2 Key findings of the current state

The current state value stream map is presented in appendix 2. Table 3 presents different time metrics and the First Pass Yield metric of the current state. These values include all products and customization variations of the products which are in the scope of the project. The First Pass Yield metric imparts that 0 % of the products go through the value stream without any additional work. Therefore, every product which passes through the value stream includes additional work in some stage of the production. Figure 8 presents the shares of VA, NVA and NNVA activities. 1/3 of the total lead time is NVA time, nearly 2/3 of the total lead time is VA time, and 3 % of the total lead time is NNVA time.

Table 3. Current state metrics.

Production lead time	189 h
VA time	120,75 h
NVA time	62,58 h
NNVA time	5,67 h
First Pass Yield	0 %

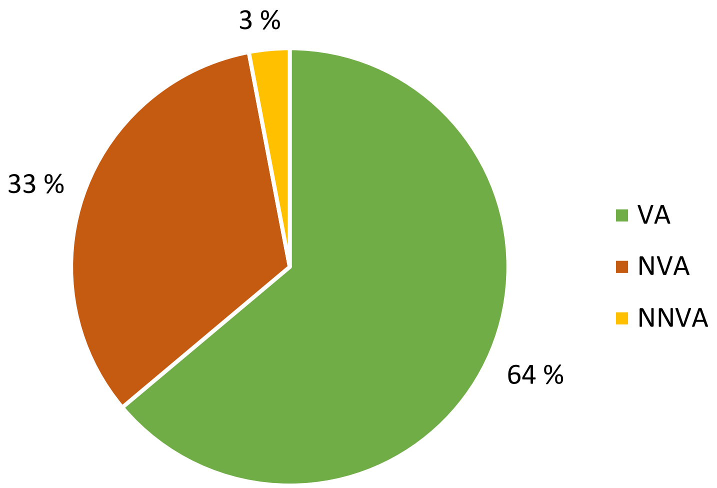

Figure 8. VA, NVA, and NNVA shares of the current state lead time.

The takt time of the current state is calculated in formula 2. Figure 9 presents the capability of the production phases compared to the takt time. It shows that every production phase except the mechanical and trial run phases can achieve the required production rate. This suggests that these phases are the most critical to be developed. As the mechanical phase has the lowest capability it is the bottleneck of the production process.

$$Takt\ time = \frac{1815\ hours/year}{165\ pieces/year} = 11{,}0 \tag{2}$$

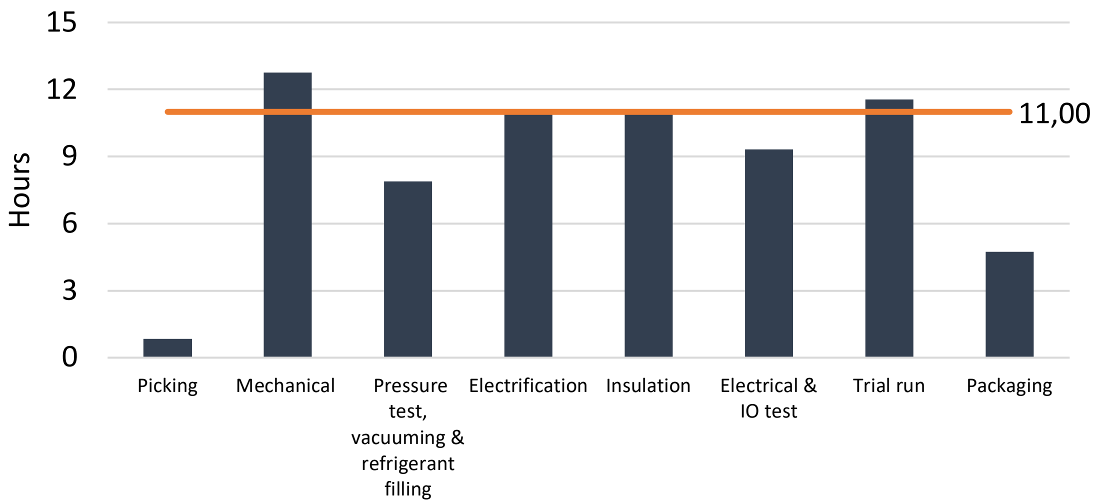

Figure 9. Current state production capability of each phase compared to takt time.

By analyzing the operations and activities in the current state value stream 16 different wastes were identified. Most of these 16 wastes occur in several activities. The 16 wastes which were identified are presented below.

1. Picking lists are delivered by the foreman after a technician from the mechanical phase triggers a notice for the foreman for needing a new product to work on.
2. The technician needs to physically give a notice for the need for new work to the foreman (mechanical, electrification, and electrical and IO test).
3. Material is left in the collection cart because technicians from the mechanical phase collect material from the inventory to speed up their work. The excess material is retrieved from the end of the production line back to the inventory.
4. Materials of the same product are in several storages. All material is not in one location.
5. Long walking distances for technicians.
6. Storage of small supplies is not in order.
7. Mistakes in product pictures and plans cause additional clarification.
8. Replenishment of storages is lagging, for example, compression storage.
9. No clear indicator informing at what stage of the production the product is.

10. Excess movement of products, for example, moving the product to the electrification phase.
11. Shortages in inventory due to Covid-19.
12. Correction of defects.
13. Extra work, for example, editing programs, applying labels, and getting the test bench working.
14. Outdated work instructions.
15. Dishevelled collecting cart due to a considerable amount of material.
16. Fetching missing material.

In addition to the 16 wastes, it can be stated that the process times of mechanical, pressure test and vacuuming, and electrification are very long. Most of the process time consumed in the pressure test and vacuuming phase is however conducted outside working hours. Both mechanical and electrification phases are time-consuming as almost all material is installed in these phases. The installation of the material also involves a lot of prefabrication. Work in the mechanical phase includes retrieval of larger materials such as compressors and heat exchangers which are stored in storage shelves and storage areas. The retrieval of these larger materials takes time from the mechanical phase technicians. In addition, both mechanical and electrification phases have only one workstation for the prefabrication. This produces a lot of walking time, especially for mechanical phase technicians.

The work of three out of seven production phases is triggered by the technicians themself. The need for new work is told to the work management which reacts. This requires physical movement from the technicians. The work management does not queue work orders for the production phases. As a result, pull production is not fulfilled. To summarize, the biggest issues of the current state are long process times, products will not pass through the manufacturing process without additional work, a lot of physical movement of technicians, and issues concerning material retrieval, shortages, and storage.

4.3 Description of future state

The aim of the process of mapping the future state was to redesign the current state and to create the most effective value stream possible. Similarly to the description of the current state, before the mapping process began the author revised for each team member the aim of the phase and the process of how the future state will be mapped. The same system of Post-it notes was used as in the description of the current state. The future state value stream map was drawn to a wide piece of paper.

A ground rule for the development ideas was generated together with the plant manager and development manager. The ground rule stated that a development idea is included if it is believed that the idea can be implemented successfully in two years' time with a probability of 70 %. This ground rule was seen as a good and realistic rule which was in line with the strategy of the plant. In this case, the future state was planned to be the state in two years from the mapping time.

4.3.1 Mapping the future state

The future state workshop followed a three-step process of mapping the current state: (1) analysis of the current state, (2) review of the issues and problems, and creation of development ideas, and (3) mapping the future state. This three-step process was carried out in the following order: identifying the needs of the customer, identifying the main process, reviewing the value stream phase by phase and filling in data boxes, and establishing how work is prioritized. Throughout the process, terms and conditions are generated that are to be fulfilled in order for the future state to be realized. The final phase of the mapping process is calculating summary metrics. The analysis of the current state was based on the following seven questions:

1. What does the customer really need?
2. How often will the performance compared to the customer's needs be checked?

3. Which steps create value and which steps are waste?
4. How can work flow with fewer interruptions?
5. How to control work between interruptions, and how will work be triggered and prioritized?
6. How will the workload and/or different activities be leveled?
7. What process improvements are necessary?

The second step of reviewing the issues and problems and creating development ideas was based on eight tactics for eliminating waste from processes, which are: simplifying the process, streamlining the process, standardizing the process, using visual systems in the process, making the processes mistake-proof, synchronizing the processes, collocating the process, and reducing changeover time in the process. The third step of mapping the future state was the process of putting the discussion of the first two steps into a value stream map. It was recognized that estimating the future state time and quality metrics would be difficult or nearly impossible to estimate precisely. However, truthful and realistic metric values were pursued to be generated.

Again, the author acted as a facilitator who asked questions during the mapping process to challenge the project participants to think of the most effective future state possible. During the whole mapping process, the ground rule was kept in mind. Applying the three-step process to the identification of the customer needs and the main process was conducted together with the plant manager, development manager, and foreman, again who all were present during the whole mapping process. Applying the three-step process to reviewing the value stream phase by phase and filling in data boxes and establishing how work is prioritized was conducted again in a way that the technicians were called in turn when their work phase was reviewed. Thus, similarly to the process of creating the current state map, the whole project team was not present during the entire mapping process. This procedure was justified in the same way as in the process of creating the current state map. The content of the map was reached through a joint discussion and every participant had an equal chance of producing an idea for the future state.

The number of resources per manufacturing phase was calculated based on the takt time. Finally, the summary metrics of the future state map was calculated. The outcome of the workshop is presented in figure 10.

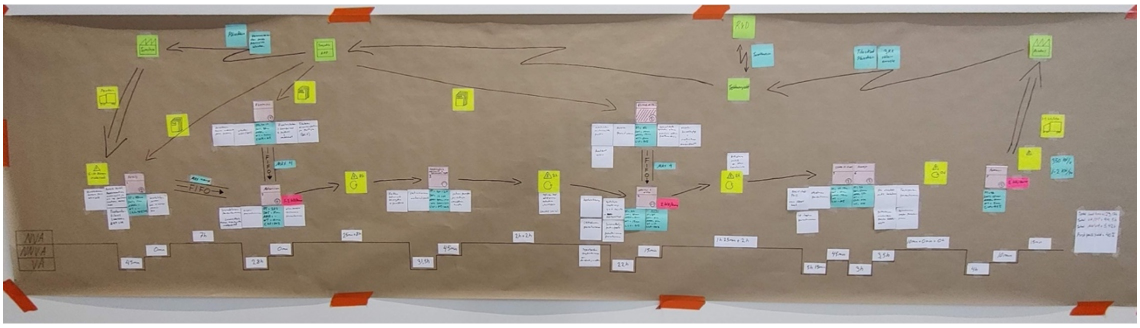

Figure 10. Outcome of future state workshop.

4.3.2 Key findings of the future state

The future state value stream map is presented in appendix 3. Table 4 presents different time metrics and the First Pass Yield metric of the future state. Similarly to the current state, these values include all products and customization variations of the products which are in the scope of the project. The value of the First Pass Yield metric improved by 40 percentage points as the value in the current state was 0 %. The future state First Pass Yield value is believed to be higher than presented below but in the workshop situation, the project team wanted to be careful about this.

Table 4. Future state metrics.

Production lead time	123,5 h
VA	94,5 h
NVA	23,58 h
NNVA	5,42 h
First Pass Yield	40 %

Figure 11 presents the shares of VA, NVA and NNVA activities of the future state lead time. The share of VA time increased by 13 percentage points to over 3/4 of the total lead time. The share of NVA time decreased by 14 percentage points to less than 1/5 of the total lead time. The share of NNVA time increased by 1 percentage point to 4 %.

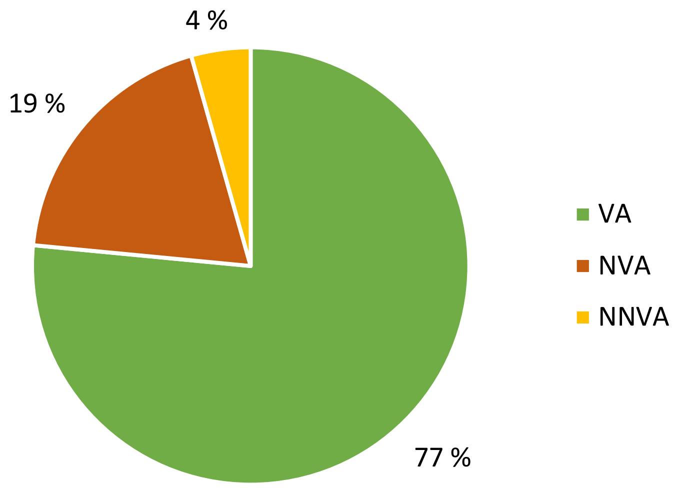

Figure 11. VA, NVA, and NNVA shares of the future state lead time.

As stated in chapter 4.3.1, the number of resources of the production phases were defined based on the takt time. The takt time for the future state is calculated in formula 3. Figure 12 presents the production capability of each future state phase when compared to the takt time. With the resources presented in appendix 3 all but the insulation phase are capable to achieve in the required production time. It was seen that as the difference to the takt time is not big, an extra permanent resource to the insulation phase is not required. This statement was based on the conception that the future state is based on an estimation thus it may be different compared to reality. In addition, if the mapped future state is the case in reality the required production time will be achieved with an extra part-time resource.

$$Takt\ time = \frac{1815\ hours/year}{350\ pieces/year} = 5{,}19 \tag{3}$$

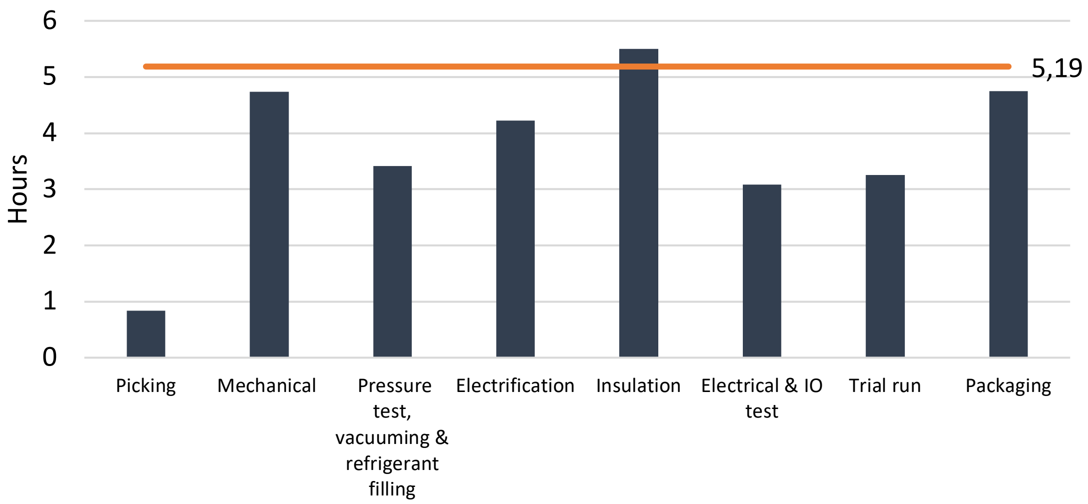

Figure 12. Future state production capability of each phase compared to takt time.

The takt time for the mechanical prefabrication phase is calculated in formula 4 and the takt time for the electrification prefabrication phase is calculated in formula 5. These calculations are based on the lead time and resource amount of the mechanical and electrification phases. Figure 13 presents that with the resources presented in appendix 3 the prefabrication phases are capable to achieve the required production time.

$$Takt\ time = \frac{28{,}42\ hours}{6} = 4{,}74 \tag{4}$$

$$Takt\ time = \frac{12{,}67\ hours}{3} = 4{,}22 \tag{5}$$

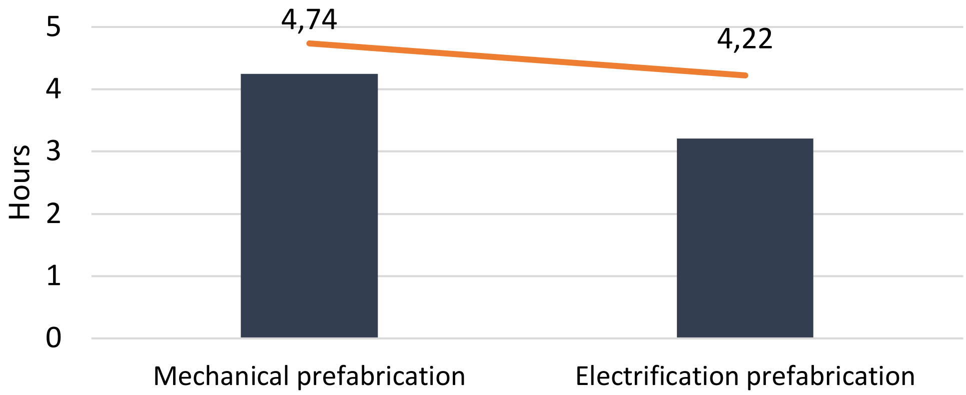

Figure 13. Future state production capability of each prefabrication phase compared to takt time.

Table 5 compares the time metrics values of the current state to the future state. If the future state can be implemented successfully lead time is reduced by 65,5 hours or by 35 %, NVA time is reduced by 39 hours or by 62 %, and VA time is reduced by 26,25 hours or by 22 %. Although 26,25 hours' worth of VA time is reduced from the total production lead time, this work does not entirely disappear. Some of the VA work is eliminated but most of this work is conducted in the mechanical and electrification prefabrication workstations. Therefore, work that is conducted in the mechanical and electrification prefabrication workstations are not calculated to the total production lead time.

Table 5. Current state values compared to future state values.

	Current state	**Future state**	**Time saved**
Value added time	120,75 h	94,5 h	26,25 h
Non-value added time	62,58 h	23,58 h	39 h
Necessary Non-Value Adding	5,67 h	5,42 h	0,25 h
Production lead time	189 h	123,5 h	65,5 h

The future state is achieved if the terms which were defined during the workshop event are fulfilled. 16 different terms were defined which are to be fulfilled to achieve the future state. These 16 terms are presented below.

1. Excess material away from the collection cart by delivering the materials indented for the packaging phase to the storage shelf of the packaging phase.
2. Queuing pick lists and work orders for the picking, mechanical prefabrication, and electrification prefabrication phases.
3. Queuing collection carts in prioritization order.
4. Prefabrication of compressors, heat exchangers, and pipes.
5. Ordering prefabricated pipes.
6. Collecting materials in a specific place on an order-by-order basis in mechanical prefabrication and electrification prefabrication phases.
7. Improvement in pictures and plans (mechanical and electrification phases).
8. Improving small supplies storage system (Etra).
9. Implementing vacuuming automation.
10. Acquiring four pumps for all vacuum carts.
11. Regular maintenance for vacuum pumps and hoses.
12. Prioritizing the new work correctly.
13. Prefabrication of cable trays, motor cables, and pressure switches.
14. Replenishment of tools and small supplies for lines 3 & 4 of the electrification phases.
15. Supplementing the work instructions.
16. Improving the programs used, IO-testing, refrigerant filling, and test bench technology.

The biggest issues of the current state were long process times, products will not go through the manufacturing process without additional work, a lot of physical movement of technicians, and issues concerning material retrieval, shortages, and storage. The future state has taken measures to develop these issues among other things. Extra work has been eliminated to decrease VA, NVA, and NNVA time. The prefabrication of mechanical and electrification phases again decreases VA, NVA, and NNVA time. This arrangement has a big effect on the total production lead time as the work has been optimized to achieve production efficiency. In addition, implementing vacuuming automation decreases the process time of the third manufacturing phase. Additional work has been decreased by for example improving plans and pictures, ordering and producing prefabricated material, implementing regular maintenance, and improving work methods and equipment. In general, all these measures improve the quality of the products produced. The physical movement of technicians is minimized by improving work order practice, optimizing workstations, and reorganizing work. Material retrieval and storage has been improved by reorganizing practices and optimizing material availability. Overall, development measures to most issues identified in the analysis of the current state were able to be generated.

4.4 Planning and implementation

The aim of the final phase of the VSM process was to define a working plan for fulfilling the terms defined in the future state workshop. After the working plan is defined the implementation process can begin. However, as stated in the scope the implementation process is excluded from this study. The workshop for defining the working plan was carried out with the plant manager, development manager, and foreman. Again, the author acted as a facilitator during the workshop event.

During the workshop event, the future state and all terms were reviewed. The aim was to arrange the terms to wholes. The wholes were prioritized based on discussion with the participants. Each development whole was assigned to a specific person or persons. A rough schedule for the implementation was conducted. The prioritization was based on how difficult the implementation is and how critical is the implementation. Table 6 presents the final working plan which was generated during the workshop event. A schedule for four development wholes was not defined. This was for various reasons: the need for implementation after production resources are increased, new resource had to be acquired for carrying out the implementation, implementation of another whole must be carried out before the next is able to be started, and an unspecified amount of data needed to be collected. The role of a successful implementation was understood by all participants of the VSM project team. It was understood that without appropriate implementation the future state cannot be succeeded. While the implementation process relies on the person in charge, the successful implementation relies on every employee at the manufacturing plant. This is the stage in which the most important part of the VSM project starts.

Table 6. Working plan.

Prio	Target of improvement	Person in charge	2022										2023				
			3	4	5	6	7	8	9	10	11	12	1	2	3	4	5
1	**Change of work policy (picking):** - A specific place for picklists - Work management queues picklists - Identify and mark the location of the four collection carts (order of priority) - Picking takes the materials needed in the packaging stage to the storage shelf in tha packaging area (extra material is removed from the collection cart)	Work Management & work phase technician	■														
1	**Commissioning of mechanical prefabrication:** - Prefabricating: 1.Compressors 2. Pipes and exchangers - Change in working methods and order (informing technicians) - Arrangements for technicians' shifts - A place for work orders - Work management queues work orders - Designated place where prefabricated materials are collected based on order	Plant Manager	■	■													
1	**Ordering of prefabricated pipes (BCF)**	Plant Manager			■												
1	**Improvement of plans (mechanical):** - Mapping problems from technicians - Making changes to plans	Designer	■	■	■	■	■	■	■	■	■	■					
1	**Improvement of Etra's storage system**	Work Management & work phase technician	■	■													
1	**Vacuuming automation**	Plant Manager	■	■	■	■	■										
1	**Four pumps for all vacuum carts**	Work Management & work phase technician	■	■													
1	**Improving test bench technology**	Development Manager	■	■	■	■											
1	**Improving programs**	Development Manager	■	■	■												
2	**Regular maintenance of vacuum pumps and hoses (creation of system)**	Work Management & work phase technician	■	■													
2	**Commissioning of electrification prefabrication:** - Prefabricating: cable trays, motor cables and pressure switches - Change in working methods and order (informing electricians) - Arrangements for electricians' shifts - A place for work orders - Work management queues work orders - Designated place where prefabricated materials are collected based on order	Plant Manager & work phase electrician	■	■													
2	**Improving electricity plans**	Development Manager	■	■	■	■											
3	**Replenishment of tools and materials (electrification):** - Tools and materials required for lines 3 and 4 - Possible tool cart	Work Management & work phase electrician	**Depending on the amount of resources (need only when resources are added)**														
3	**Replenishment of work instructions:** - Sublamenting the shortages of the work instructions such as: - Performing only the 1000 V test. 500 V test not performed (electrical test) - Air conditioning and flashing light installation (electrification) - No need for marking the pipelines (test run)	New resource															
3	**Improving the IO-testing**	Development Manager	**Can be performed after programs and refrigerant refill have improved**														
3	**Improved refrigerant filling**	R&D	**Continuous data collection**														

4.5 Comments about the VSM project

In general, the project was successful in the opinion of both the author and the case company. This is certainly largely due to thorough planning work as well as preparation work conducted before the workshop events were conducted. The support from the case company and the commitment of the staff played a big role in the success of the project. The most challenging issue during the project was to be able to adapt the VSM framework to the MTO environment and the complex product. Defining the time metrics to suit the scope of products was challenging. But when understanding that the state maps are estimations, the results are credibly sufficient.

5 Summary and conclusions

This chapter of the thesis summarizes the findings of the research empirical study. Additionally, it includes discussion and conclusions between the theory and results of the study. Finally, it proposes possible future research opportunities that can be conducted to continue the development of processes.

5.1 Summary of the research

The thesis began by defining the purpose and goals of the research. Hereafter the scope was defined and Oilon Oy was introduced which acted as the case company for the research. The theory of lean and VSM was reviewed in a profoundly way from both the traditional and MTO aspect. Following the review of the theory, the methodology of the study was presented. Finally, the empirical study of the actual VSM analysis for the case company was carried out.

Although a traditional VSM analysis has been used successfully in a MTS environment it was proven, during the making of the research, to be flexible and effective also in a MTO environment if used in a correct manner (Mudgal et al., 2020, pp. 826-830). Applying VSM to a MTO environment requires more reviewing and defining. The results of the VSM analysis are not as precise as in a MTS environment rather than a descriptive of the average and in some cases estimates. In addition, often the VSM analysis for MTO environments concentrates on a specific path and not the entire manufacturing process. However, this accuracy of results is sufficient enough to achieve good results from a VSM analysis.

The purpose of this thesis was to review and re-evaluate the current manufacturing process of the case company through a VSM project. The aim was to optimize and redesign the manufacturing process. The literature review of lean and VSM offered a framework and guidelines for conducting the research. The research was conducted through nonstructure interviews, observation of work, workshop events and reports collected from the case company's ERP system.

The research question of the study was: *How can Oilon Oy's manufacturing processes be developed by value stream mapping?*

In order an answer to the research question was able to be achieved four objectives were set to be defined: (1) define the value stream mapping process, (2) define how the product flows in the current manufacturing process, (3) define the future state of the manufacturing process, and (4) define the improvements and requirements to achieve the future state. By defining the objectives, the research question was answered during the implementation of the VSM analysis.

Four phases for the VSM analysis were identified: (1) preparation, (2) mapping the current state, (3) mapping the future state, and (4) planning and implementation. The preparation phase included six steps: define scope, define the process, path, and procedures, define project team, prepare project team, summarize to SIPOC, and select process metrics. The second phase of mapping the current state followed a six-step process: identifying the needs of the customer, identifying the main process, reviewing the value stream phase by phase and filling in data boxes, establishing how work is prioritized, calculating summary metrics, and generating ideas throughout the mapping process. The third phase of mapping the future state followed a three-step process: analysis of the current state, review of the issues and problems and creation of development ideas, and mapping the future state. The final phase of planning and implementation included the process of generating the working plan and implementing it.

The flow of the product in the current manufacturing process was identified during the first workshop event. 16 different wastes and several additional issues were identified to be disturbing the flow of the product. The future state of the manufacturing process was redesigned and defined in the second workshop. During the second workshop development ideas and 16 different terms of the future state were also defined. The working plan was defined during the third and final workshop of the VSM project. Below are figures that are accomplished when the future state is implemented successfully.

1. Production lead time is reduced by 35 %
2. NVA time is reduced by 62 %
3. The share of VA time of the production lead time is increased by 13 percentage points to 77 %
4. The value of First Pass Yield is increased by 40 percentage points

5.2 Conclusions and future research

The VSM analysis gives an effective framework to redefine and redesign manufacturing processes in a systematic way. It delivers a very comprehensive and realistic description of the current state. By following the steps of the VSM analysis a critical and systematic review of the current state can be made and the future state can be designed based on the issues and development needs identified. The VSM analysis can be fitted to suit a more complex environment. As the study presents, a VSM analysis for a MTO environment can utilize the traditional framework of four or five phases. However, to be more suitable for a more complex environment the phases need to include more steps. The traditional framework has the benefit of being a clear framework. But in addition, it is flexible to be fitted to suit different environments.

Conducting a thorough preparation phase has a big effect on the outcome of the analysis. All necessary factors should be defined as far as possible to avoid any issues or obscurity during the later phases of the analysis. Also, every participant of the project needs to have sufficient understanding and knowledge to be able to be a part of a VSM analysis. The development and success of the analysis lie with the project participants and their ability to think critically and in the right manner to identify issues and generate development ideas for the future state. In addition, the motivation of the project participants is crucial. In this case, the plant manager, development manager, and the foreman led by example and made efforts to motivate the participants of the project. In consequence of this most project participants were very committed to the project and good results were accomplished.

In a complex and dynamic environment, the design for the future state is to be made flexible. For example, process times and demand changes thus the design for the future state must have the ability to adapt to the changing environment. In this case, the design for the future state was based on averages of the production times. In addition, the possibility of relocating resources is taken into account to ensure the flexibility of the future state. Critical review needs to be included in the implementation phase of the VMS project. In case the design of the future state plan has been planned to be too stiff measures are to be taken to overcome these issues and ensure the flexibility of the manufacturing process.

Takt time is a critical part of the VSM analysis and the creditability of the future state. As the manufacturing processes are based on the takt time the functionality of the processes is more credible and realistic. In a complex manufacturing environment, the lean guidelines on which the manufacturing system should be based are harder to achieve. For instance, if the demand constantly changes or is not known the takt time of the production cannot be calculated. However, the takt time can be based on the average demand. Therefore, in a complex environment, the fact that the analysis is based on averages and estimates must be accepted. Nevertheless, implementing VSM and critically reviewing the current state is one of the biggest objectives of the analysis.

This VSM project for the case company is a good continuum for their lean development projects. However, continuous improvement must be executed at all levels and not be content to remain in place. New methods and opportunities for process development must be searched for to ensure competitiveness. As the VSM analysis reviews the whole manufacturing system and does not go deep into the work conducted in the manufacturing phases future research can study the work conducted in these manufacturing phases by applying process mapping. Thus, working methods can be developed. Future research can also include conducting a VSM analysis with an environmental aspect. The research could study for example energy waste, material waste, as well as garbage waste and how the manufacturing system can be developed to minimize all environmental wastes.

As this VSM project excluded some products from the scope, future research can consecrate on identifying the shared processes and functions of all manufactured products in the case company's plant. As the shared processes and functions are identified they can be critically reviewed and improved.

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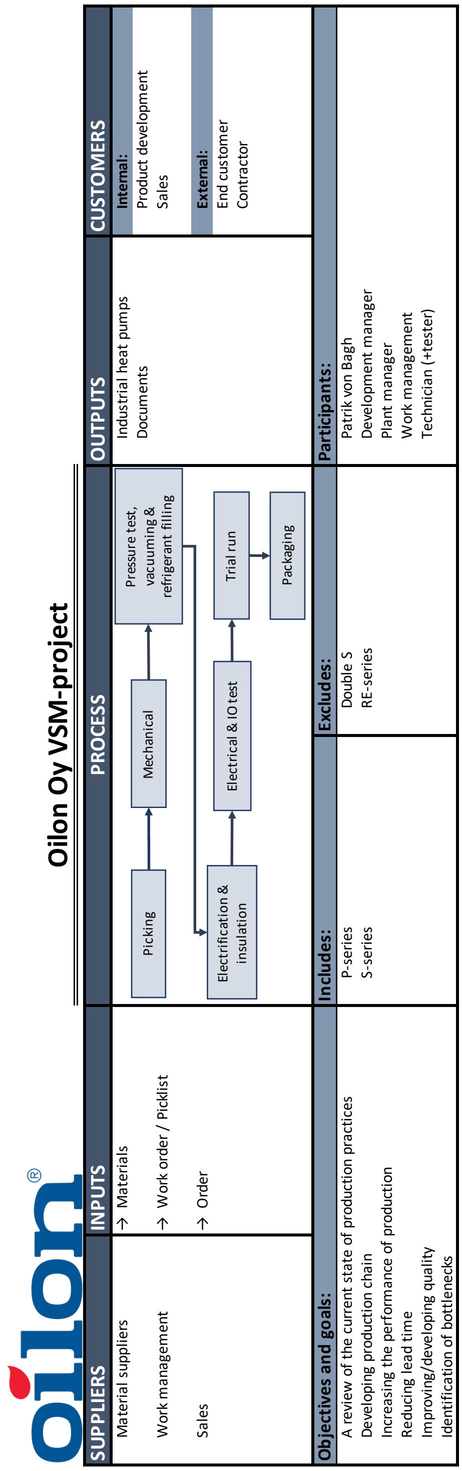
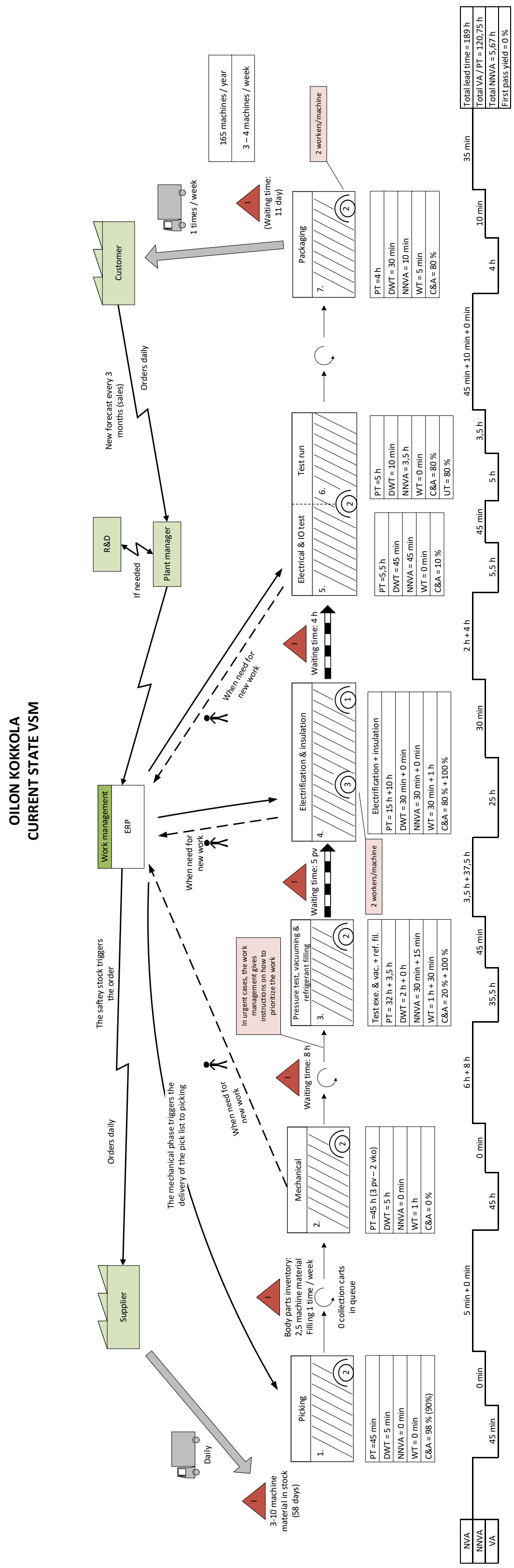
Appendices

Appendix 1. SIPOC-diagram



Appendix 2. Current state value stream map



Appendix 3. Future state value stream map