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Lead time reduction methods in a lean manufacturing environment

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ABSTRACT:

This research follows a manufacturing project of six products in a lean manufacturing environment. The lead times of these products are attempted to be shortened. The lead times in previous projects have been long, and the demand for this product is increasing.

The literature review part of this thesis explores three different main theoretical frameworks for reducing lead time in a similar manufacturing environment: lean, the company's own model of continuous improvement, and process analysis and improvement subjects. Tools for reducing lead times are formed based on these subjects.

Based on the previously mentioned frameworks, a plan of action is formed for reducing lead times. First, an "as-is" value stream map is formed, and a "to-be" state visioned. A five-step improvement plan is formed to achieve the "to-be" state. The first step is to improve the flow of information. Second, mapping the workflow with a swimlane diagram. Third, miscellaneous improvements that arise over the course of manufacturing. These three steps directly affect this manufacturing project. The next two are more long-term improvements for future projects. The first of these is data collection and research, and the other is semi-structured interviews. The results of the interview are analyzed both numerically and thematically.

The "to-be" state is not achieved in all phases, but improvements on three out of four phases are, and the total lead time is achieved. Based on the results, a new "as-is" state and a "to-be" state are formed, and recommendations to achieve the new "to-be" state are given based on the research results and literature.

KEYWORDS: Lead time reduction, lean manufacturing, continuous improvement, value stream mapping, process analysis and improvement, swimlane diagram, theory of constraints

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Tiivistelmä:

Tässä tutkimuksessa seurataan kuuden tuotteen tuotantoprojektia lean-tuotantoympäristössä, joiden läpimenoaikaa yritetään parantaa. Tuotteiden läpimenoajat aiemmissa projekteissa ovat olleet pitkiä, ja niiden kysyntä on kasvussa.

Kirjallisuuskatsauksessa käydään läpi kolme eri teoreettista viitekehystä läpimenoaikojen parantamiseen vastaavassa toimintaympäristössä: leania, yrityksen omaa jatkuvan parantamisen mallia, sekä prossessianalyysi ja -parannus otsikoiden alta. Näistä kehitetään erilaiset työkalut läpimenoajan tehostamiseen.

Kirjallisuuskatsauksessa tutkittujen viitekehysten pohjalta kehitetään toimintasuunnitelma, jolla läpimenoaikoja lyhennetään. Ensin luodaan arvovirtakaavio tuotannon tämän hetkisestä tilasta, sekä tulevasta, tavoiteltavasta, tilasta. Tavoiteltavan tilan saavuttamiseksi kehitetään viisikohtainen parannussuunnitelma. Ensimmäisenä parannuskohtana toimii informaatiovirran tehostaminen. Toisena työjärjestyksen kartoittaminen uimaratakaaviolla. Kolmantena kohtana ovat sekalaiset parannuskohteet joita tuotannon aikana nousee esille. Nämä kolme kohtaa vaikuttavat suoraan tähän tuotantoprojektiin. Seuraavien kahden vaikutus kohdistuu enemmän tuleviin projekteihin. Ensimmäinen tällainen keino on datan kerääminen ja tutkiminen. Toisena puolirakenteisten haastatteluiden järjestäminen, joiden tuloksia analysoidaan sekä numeerisesti, että temaattisesti.

Tavoiteltavaa tilaa ei saavuteta kaikilla vaiheilla, mutta parannuksia kolmella vaiheella neljästä, sekä kokonaisläpimenoajassa saavutetaan. Tuloksista muodostetaan uudet tämän hetkisen ja tavoiteltavan tilan arvovirtakaaviot, sekä kirjallisuuskatsaukseen että tutkimustuloksiin pohjautuva parannussuunnitelma joilla uusi tavoiteltava tila on saavutettavissa.

Avainsanat: Läpimenoajan lyhentäminen, lean tuotanto, jatkuva parantaminen, arvovirtakartoitus, prosessianalyysi ja -parannus, uimaratakaavio, rajoitteiden teoria

Contents

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Abbreviations

AI	Artificial Intelligence
BPI	Business Process Improvement
BPR	Business Process Re-engineering
CM	Cellular Manufacturing
CMS	Cellular Manufacturing System
GT	Group Technology
JIT	Just-In-Time
RCA	Root Cause Analysis
SMED	Single-Minute Exchange of Dies
STH	Sustainable Technology Hub
TA	Thematic Analysis
TOC	Theory Of Constraints
TPM	Total Productive Maintenance
TQM	Total Quality Management
VSM	Value Stream Mapping
WCI	Wärtsilä Continuous Improvement
WIP	Work-in-progress

1 Introduction

The subject for this master's thesis was commissioned by Wärtsilä Finland Oy. It focuses on a certain product that has a growing demand in the Wärtsilä Vaasa factory, STH (Sustainable Technology Hub). Previous manufacturing projects have had long lead times. Because of the growing demand, Wärtsilä needs to have a structured and streamlined approach to the manufacturing of this product. The company has set a goal of 40% faster lead times than in the previous projects. In this study, a manufacturing project of six products will be observed and trialed with. The manufacturing project will entail an iterative, continuous improvement program to improve the results with every iteration. Literature will be reviewed to provide background to the manufacturing environment and to discover lean tools and methods for lead time reduction. Also, the company's WCI program (Wärtsilä Continuous Improvement) is explored. More about these subjects in the coming chapters.

1.1 Wärtsilä

Wärtsilä is a global company that is divided into two segments: the marine and energy segments. The marine sector offers lifecycle solutions, propulsion and navigation technologies, marine main engines, and services. The energy sector uses the engines for electricity generation. The STH factory produces and offers internal combustion engines for the needs of both segments. Their portfolio of engines varies from W14 to W50 engines, according to Wärtsilä's website (2025). W refers to Wärtsilä, and the number stands for the diameter of the cylinder bore in centimeters. A power plant typically consists of one to twelve engines, and a cruise ship has four to six engines. In addition, the energy sector offers energy storage solutions. Wärtsilä's (2025) websites describe the company as "a global leader in innovative technologies and lifecycle solutions for the marine and energy markets." They state that the Wärtsilä energy department helps their customers to accelerate their decarbonization journeys with their market-leading technologies and power system expertise. They continue that the marine department has a "broad portfolio of engines, propulsion systems, hybrid technology, exhaust treatment, shaft line solutions, and digital technologies, as well as integrated powertrain systems".

1.2 Structure of the study

The lead time reduction methods need to align with the company's manufacturing strategy, lean manufacturing. This paper aims to reduce lead time through lean-aligned tools, methods, and philosophy. First, a literature review on lean, the company's internal instructions, and other improvement practices is conducted. Next, the research methods are presented. Third, in the research results, revised practices are implemented, or an implementation plan is proposed. Finally, the results are discussed.

1.3 Scope of the study

The scope of this work is confined to the processes within the Wärtsilä Vaasa factory, STH. It will only handle subjects directly related to manufacturing. Not, for example, issues in design or purchasing. The processes covered in this work are related to the five phases determined later in this paper. The fourth phase is not included in this, other than for feedback to the other engines in the project. Below, in Figure 1, this is visualized further.

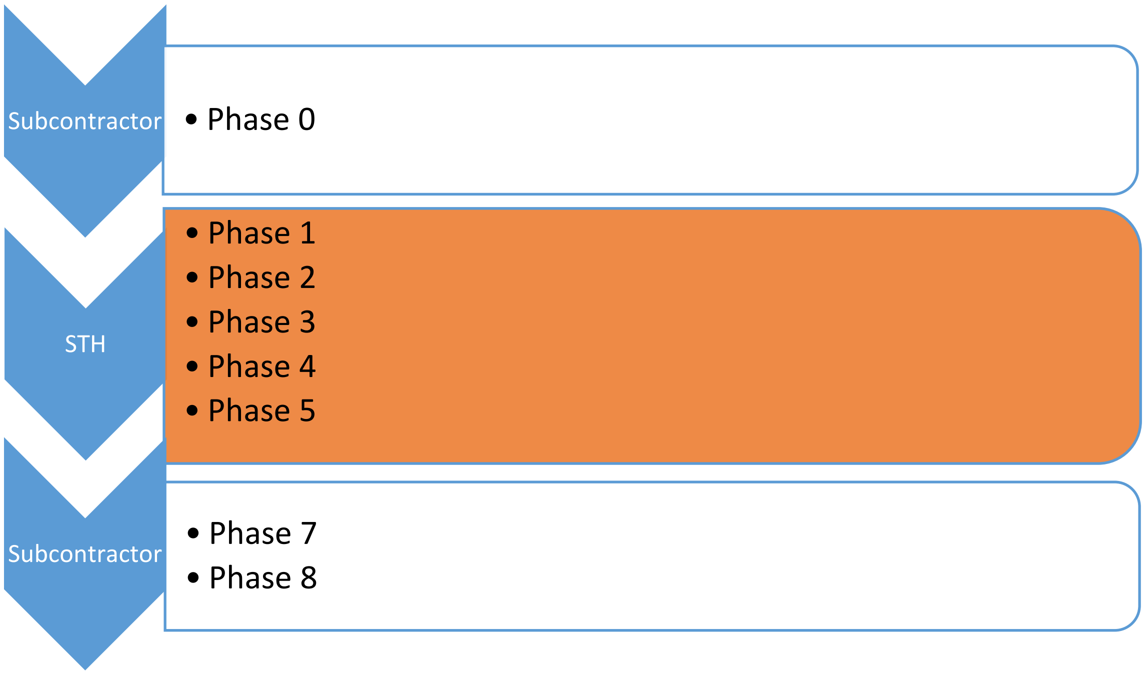


Figure 1. A process chart of actions inside and outside of STH.

1.4 Research questions, objectives, and deliverables

To achieve the lead time reductions, the research questions are as follows: what are the bottlenecks in the processes and how to identify them? How can the production methods be enhanced? What are the current lean tools to address lead time? The objectives of this thesis are to analyze the current lead time components, to structure the production processes into a more effective whole, and to identify areas of inefficiency and highlight support needs. All this will be gathered from the company's systems, Power BI reports, emails, personal notes, interviews, and observations from active manufacturing projects and previous projects. This work will aim to deliver the following deliverables: a value stream map of the processes and the information flow related to it, research and gathering of statistical data, identification of bottlenecks, workflow optimization, and implementation and recommendations of lead time reducing actions.

2 Literature review

This chapter will focus on exploring literature related to lean philosophies, methods and tools, process analysis and improvement practices, such as the Theory of Constraints (TOC), and the Wärtsilä Continuous Improvement (WCI) philosophy. The aim is to build a theoretical background for lead time reducing actions in a lean manufacturing environment, Wärtsilä STH factory. These actions will then be implemented in the manufacturing processes as much as possible. The coming chapters will elaborate on that further.

2.1 Origin of Lean

To understand the nature of lean, it is good to know the reasons behind its invention. Lean was (unofficially) invented in Japan by Kiichiro Toyoda, who founded the Toyota Motor Corporation and its production system, the Toyota Production System (TPS). After the Second World War, Japan was limited by resources and funds. Kiichiro Toyoda had to develop efficient operations as a result. Monden and Ohno (2011) write that TPS was born out of Toyota's efforts to catch up with the Western automotive industry, despite lacking the funds and fine facilities. Their most important mission was to increase productivity and reduce costs. They set out to achieve this by eliminating waste, meaning anything from materials to processes. Modig and Åhlström (2013) agree with this. They wrote that Japan was scarce in terms of land, technology, machines, raw materials, and financial resources. This scarcity forced Toyota to focus on efficiency. Flow efficiency, to be accurate. More about flow efficiency later in this chapter. They add that Kiichiro's father, Sakichi Toyoda, had already invented some basic processes for efficiency with his efforts with automated looms. According to them, this acted as a source of inspiration for the creation of TPS.

Even though lean was born from TPS, they are not synonymous concepts. Lean as a concept was recognized in 1988, when John Krafick wrote an article comparing production methods between car manufacturers. The article celebrated lean manufacturing as victorious. This led to other articles and other studies, as well as the adoption of lean into many different functions and areas. There is still no clear consensus for a definitive definition of lean (Modig & Åhlström, 2013). There is, however, consensus on what it entails. This is discussed below in the next subchapters.

2.2 Lean philosophy

As the heading suggests, lean is not only about tools, processes, or methods. It is a comprehensive philosophy that covers the whole organization. For a company to implement lean successfully, the idea needs to be adopted comprehensively to guide the whole organization. Gupta and Sanjiv (2013) write that in order to implement lean, all the stages of the organization need to be committed to the concept, from top management to workers. According to them, proper communication and training are needed. Modig and Åhlström (2013) describe the level of comprehensiveness differently. They describe a visit to the Toyota Motor Corporation office in their book, "This is Lean". The visit contains a meeting with a Toyota senior executive, who explains that lean is not just a collection of methods and tools. The executive continues to explain that everything they do at the Toyota Motor Corporation is guided by their values and principles. Values are at the top of the pyramid, principles are after that, and only after those two come methods, and finally, the tools. This is illustrated below, in Figure 2.

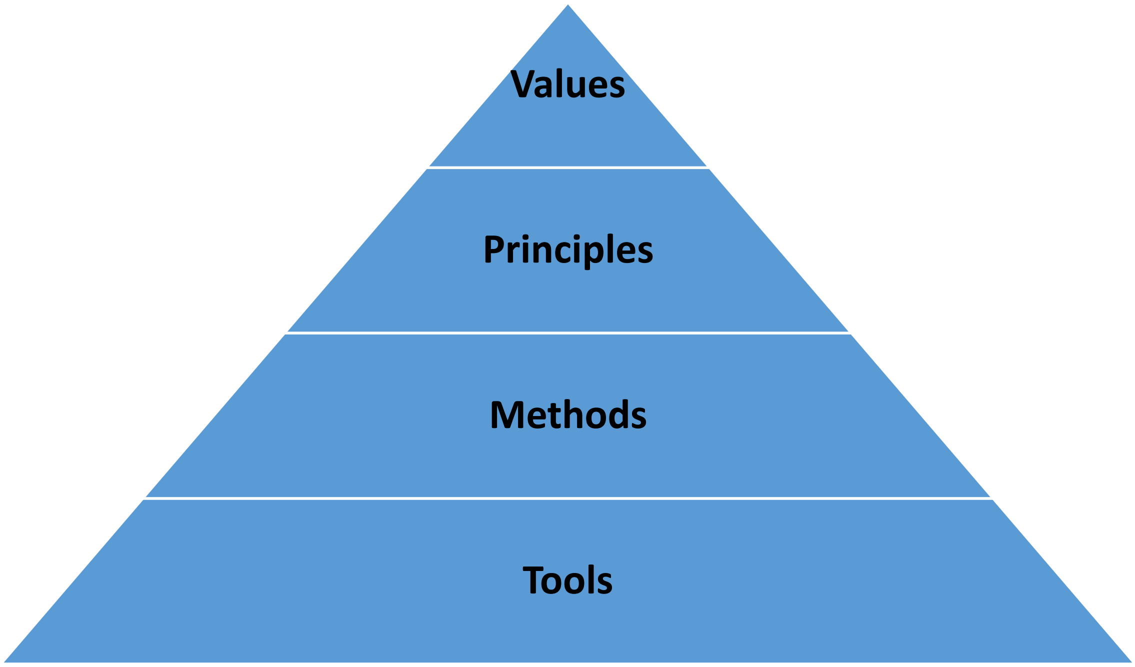


Figure 2. Different levels of abstraction of lean (Modig & Åhlström, 2013, pp. 138).

All of the previously mentioned levels of abstraction are needed for an organization to be comprehensively lean. Monden and Ohno (2011) contemplate that their just-in-time system might not be directly applicable to all circumstances, but that the desired end result is the same everywhere. Thus, they hope that their book, Toyota Production System, could be used for "another effective American production system".

2.3 Lean values and principles

The same senior executive from Modig and Åhlströms (2013) visit to the Toyota Motor Corporation office went on to explain their company values and principles further in the story. He elaborated that their values define how they must act in any situation. He believed that values were the foundation of everything. Principles would define how they make decisions and what they hold important. One of these principles was Just-In-Time, and the other was Jidoka. Just-In-Time (JIT) is a principle for creating flow. The end goal of JIT is to deliver to the customer what they want, on the right time, with the right amount. Jidoka is a principle for creating transparency. Its aim is to create transparency, so that everyone in the organization knows what is happening to be able to work towards the common goal. To summarize, values show how an organization should be, and principles define how an organization should think.

2.4 Lean methods

Methods define what an organization should do. They tell the organization and its workers on a tangible level how to perform different functions. The Toyota executive in Modigs and Åhlströms (2013) story describes lean methods through an example. According to him, they developed numerous methods to implement JIT, the principle previously mentioned. He continues that standardization is one of the most important methods to create an efficient flow so that everyone knows how something should be done. Visual planning is a method mentioned for implementing Jidoka. The tools that are about to be discussed in the next subchapter, in cooperation with functions, form methods. For example, a hammer and a nail are tools. Banging the hammer on the nail is a function. Together, they form a method to stick pieces together.

2.5 Lean tools

At the bottom of the pyramid are the tools and functions. Modig and Åhlström (2013) remark that the tools and methods developed at Toyota were right for Toyota in their operational environment. They might not work in other circumstances. They allow others to study their philosophy, so that they can develop a way of implementing lean in their own way. Bhamu and Singh (2014) reviewed tens of papers regarding lean manufacturing. They say that because so many organizations are aspiring to be lean, there are numerous tools, techniques, and methods. According to them, new ones are being proposed daily. Their literature review showed that the most referred ones were value stream mapping (VSM), kanban, JIT, 5S, total productive maintenance (TPM), cellular manufacturing, kaizen, total quality management (TQM), and single-minute exchange of dies (SMED). The ones linked to this work and production at Wärtsilä are explored in more detail in the subchapters below to demonstrate the working environment and build the framework for the research.

2.5.1 Value stream mapping

Value stream mapping is a tool that visualizes a process and identifies the parts of it that do not yield value for the process chain. It can be used to promote the material or information flow of the process. Sangwa and Sangwan (2023) define VSM as "a visual representation of a process for identifying non-value-adding activities and determining how to reduce or eliminate them." They performed a literature review on the subject in their case study paper. They found that it has been a very successful tool in reducing waste in processes and is widely adopted. However, for complex production environments, it is a challenging task to form a value stream map, which is what the authors wanted to solve, which suits the purpose of this paper well. Below, in Figure 3, is the VSM implementation process chart.

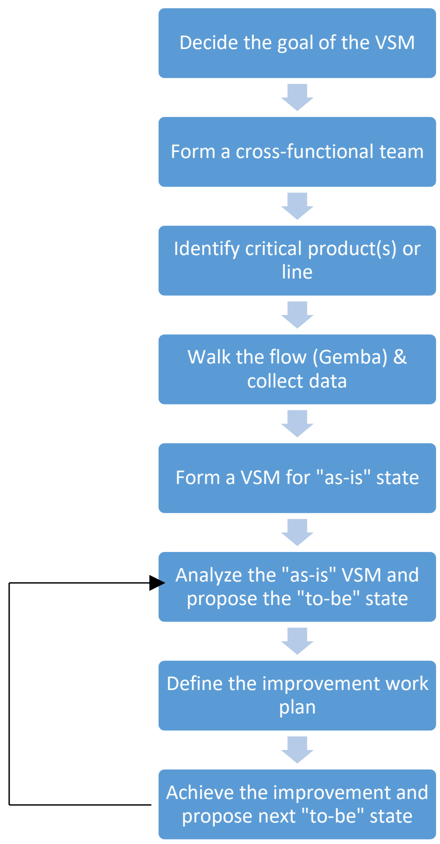


Figure 3. A VSM implementation process chart. (Sangwa & Sangwan, 2023, pp. 900).

As Figure 3 suggests, the first step of value stream mapping is deciding on what the goal is. Next is to form a cross-functional team. Cross-functionality brings different strengths and views to consideration. The target of mapping is then selected. The team is then recommended to take "Gemba" walks along the selected target line. Gemba is a term for going to the factory floor, where the actual processes happen. Romero et al. (2020) state that Gemba walks are a way for lean managers to go and see what is happening on the shop floor. According to them, the term Gemba walk is a sum of the following terms: gemba (the real thing), Genchi Genbutsu (go and see), and Genjitsu (real facts). Next, an "as-is" VSM is formed. The "as-is" state is analyzed, and a "to-be" state is proposed. A plan for the improvements is defined. And finally, when the improvement is achieved, a continuous improvement loop starts the "as-is" analysis again.

2.5.2 Kanban

Kanban is a pull method for controlling the production flow. It determines what, how much, and when parts are produced. According to Monden and Ohno (2011), a pull system works by people in a certain phase taking the necessary amount of parts from the previous process phase when needed. Then the previous process phase replaces those withdrawn parts with the same principle. They further explain that kanban is a card, which the needed amount of units is written. Ikonen et al. (2011) explain that kanban is a Japanese word for a signboard. This card is sent to the preceding process of the assembly line. The kanban system is an information system that triggers the production of a process. There are two types of kanban cards: a withdrawal kanban and a production-ordering kanban. A withdrawal card communicates how much the current phase should withdraw, and a production-ordering card communicates to the preceding one how much they should produce to maintain the same amount of buffer parts (Monden & Ohno, 2011).

Kanban has evolved from Monden and Ohno's (2011) definition. It is currently being used in other industries as well, most notably in information technology and software engineering. They use Kanban boards to control the amount of work and to visualize the flow and the details of a task, such as who is doing it and at what stage it is. It is beneficial in IT projects, as in others, that the whole team can see how the project is progressing. Ikonen et al. (2011) state that lean thinking has been successful in manufacturing, and it has recently been adopted in software engineering. The Kanban method is often implemented in IT and software projects, where the cards do not communicate the number of parts, but rather the tasks, and organize the workflow.

2.5.3 Just-In-Time

As stated before, JIT is a principle of lean. It is a principle for creating flow. The end goal of JIT is to deliver to the customer what they want, on the right time, with the right amount (Modig & Åhlström, 2013). The principle can be applied at a smaller level as well. Wärtsilä, for example, has a system where the parts of an activity are requested by an assembler when the activity is supposed to begin. It is not only about delivering to the customer their needs at the right time, but also for smaller-scale operations and processes as well. It can be used for supply chain management, warehouse management, and production management through tools and methods that are aligned with the principle. The Kanban system, previously discussed, is an example of a tool to implement JIT. In addition to the traditional reasons for JIT approach adoption, such as operational efficiency, waste reduction, or cost reduction, a recent driver for JIT practices is sustainability. Garcia-Cutrin and Rodriguez-Garcia (2024) define JIT from a different angle. They wrote that JIT "revolutionized manufacturing by emphasizing waste reduction and the seamless flow of goods.". According to them, JIT can be defined as a managerial philosophy or as a set of practices. They studied the effect of JIT principles on corporate sustainability. Even though they did not research environmental footprint directly, they determined that through waste minimization, resource efficiency, and reduced inventory levels, JIT practices align with sustainable business practices, boost operational efficiency, and promote environmental sustainability goals. Singhal et al. (2024) examined JIT more deeply from the environmental point of view. They introduce a concept of "green-JIT", as environmental sustainability has become a significant factor for companies. They did not directly find JIT environmentally friendly, because smaller inventories need more frequent deliveries of goods. However, they saw potential through the use of "green-JIT".

2.5.4 5S

5S is a method for keeping the workplace efficient and organized. By keeping the workplace in order, everything stays in the same place and can be found immediately. For example, tools should be set in the same places every time, and the station should be cleaned regularly. A standardised workplace is an efficient and safe workplace. According to Mazur et al. (2024), the name 5S comes from the Japanese language. Seiri (sorting), Seiton (organizing), Seiso (cleaning), Seiketsu (standardizing), and Shitsuke (maintaining). They have been translated into English as Sort, Set in order, Shine, Standardize, and Sustain to meet the name, 5S. According to the authors, the benefits of 5S are improved productivity, reduced employee absence rate, decreased errors, improved quality, and improved morale and safety.

Mazur et al. (2024) attempted to implement this method in a case study of a company in the automotive industry in Slovakia. Their methodology for the implementation was described step by step. First, Seiri (sort): the goal is to remove all unnecessary items from the production station by going through everything in the workspace, separating the necessary and unnecessary items, and moving, scrapping, or recycling the unnecessary items. Second, Seiton (set in order): the goal is to set the necessary items in order and easily accessible by choosing the best locations for all the items, and marking the locations and tools visually. Third, Seiso (shine): the goal is to uphold cleanliness in the work area by regular cleaning, upholding accountability of cleaning for everyone, and creating a regular schedule for cleaning and maintenance. Fourth, Seiketsu (standardize): the goal is to create standards for cleaning and organizing by establishing processes for sorting, organizing, and cleaning, instructions and checklists, and regular training for the employees. And lastly, Shitsuke (sustain): the goal is to better and uphold the 5S practices by performing audits, engaging with the employees, promoting continuous improvement, and implementing a rewarding system for good practices. The authors claim that by implementing the 5S practices in the case company, they were able to save over two hours from each worker's day.

5S has evolved from 5S to 6S in recent years. Jimenez et al. (2019) propose in their paper an extension to 5S to safety and security aspects, 6S. The authors note that under EU law, there are safety requirements. For this reason, a sixth S could be a way to meet the requirements. Supervising and promoting safety has other benefits as well. Fewer employee absences lead to better productivity and lower costs.

2.5.5 Cellular manufacturing

Cellular manufacturing (CM), sometimes referred to as cellular manufacturing system (CMS), refers to a layout design in which the product is assembled in an assembly cell instead of an assembly line, for example. The cell is used to manufacture similar products. This increases the employees' ownership of the product and, in some cases, the cell itself. YounesSinaki et al. (2023) preface CM with another term: group technology (GT). According to them, GT is "a method to manufacture parts by classifying them using similar manufacturing operations." They continue that CM is a manufacturing philosophy, where GT is implemented to group similar products together. They write that CM is aimed at reducing work-in-progress, shortening set-up time, lessening inventory, and increasing visibility of the product status and the speed of solving deficiencies. This is in line with lean objectives, reducing waste and increasing visibility (jidoka). CM involves two key definitions: product family and manufacturing cell. A product family is a group of similar products, and a manufacturing cell is a workstation specialized in producing some product families. The authors saw that the future of CM could be reconfigurable, artificial intelligence (AI) aided, self-configurable, and self-optimizable cells.

2.5.6 Kaizen

Kaizen is a Japanese term that has been translated to continuous improvement. It encourages everyone to take part in the continuing improvement process. According to

Berhe (2022), the term originates from the Japanese words Kai (change) and Zen (good), which together translate to change for the better. Its roots are in the Toyota production system. It is a widely accepted management philosophy, not limited to manufacturing, but also for other areas such as personal and social fronts. It can range from small to breakthrough improvements. Berhe writes that Kaizen can be seen as principles, values, and techniques. As principles and values, Kaizen focuses on processes, standards that are upheld and built on, Gemba improvements, and commitment from management, for example. As techniques or tools, the author mentions different types of quality control tools, 5S, iterative cycle tools such as plan-do-check-act (PDCA) and standardize-do-check-act (SDCA), client orientation, and a proposal system, among others.

2.5.7 Jidoka

As previously stated, Jidoka is a principle that creates transparency. It aims to create transparency, so that everyone in the organization knows what is happening to be able to work towards the common goal. The Toyota executive from Modigs and Åhlströms' book (2013) demonstrates Jidoka with an example: in order for the players to make goals, they first must see the pitch, the ball, and the goal. Secondly, they need to see their teammates and the opposing players. Thirdly, they must see what the score is and what is left of the game time. Fourth, they need to hear the whistle, and finally, to hear their teammates and the audience cheering. Every player sees and hears what is going on at all times. With this overall picture, they can make goals. He criticizes current organizations for having hundreds of tents on the pitch with multiple balls in play. Every tent thinks that they have scored after kicking the ball out of their own tent. He summarizes that jidoka creates a transparent and visual organization, where the constraints to the flow can be eliminated at once.

Monden (2011) defines Jidoka differently. He writes that Jidoka is also called autonomation. A term that is used for "improving machinery to reduce the number of workers.". Deuse et al. (2020) also support this definition. They write that it is a Japanese term for intelligent or autonomous automation. They continue that jidoka is a method that monitors the manufacturing process and stops the manufacturing when a defect is detected. Deuse et al. (2020) introduce a term called Jidoka 4.0, which is a version of Jidoka to predict product quality utilizing machine learning and data analytics.

The difference between the definitions depends on the abstraction level at which it is seen. Modig and Åhlström (2013) write about it at a principle level, while Monden (2011) and Deuse et al. (2020) describe Jidoka as a set of methods. Both definitions are correct and emphasize Jidoka's complicated nature. They do not exclude each other, but complement one another.

2.5.8 This is lean

Modig and Åhlströms book, this is lean: resolving the efficiency paradox (2013), defines two types of efficiencies: resource efficiency and flow efficiency. Resource efficiency refers to maximising the usage of every single resource, whereas flow efficiency focuses on the unit to be processed. According to them, resource efficiency is the traditional and usual form of efficiency. They illustrate the difference through two different stories of a woman seeking medical aid and the journey they take through the system to get a diagnosis. The first one seeks help from a traditional health center. She gets a doctor's appointment for the same day. The doctor orders them to undergo a mammography. The woman is submitted in a couple of weeks for the procedure. From there, she gets to a surgeon after ten days. The same continues between different experts and departments until she gets a diagnosis after six weeks. In this first scenario, all of the experts and equipment are in use all of the time, which means that every resource is being used efficiently. This leads to long waits between all of the different components between the start and the end of the journey, even if everything is used efficiently. This is resource efficiency. The second woman seeks medical aid from an experimental clinic that takes the patient through all of the procedures in one visit. She gets her diagnosis in two hours, 500 times faster than the first patient, even if the resources are not used as efficiently as with the first example.

The paradox that Modig and Åhlström are describing is the fact that concentrating too much on resource efficiency often leads to problems that require more work. Even if the resource is used efficiently, it might not be adding value to the unit under processing. They claim that it affects flow efficiency negatively. The solution they introduce for this paradox is to focus on flow efficiency and a strategy called lean. According to them, lean has proven itself efficient in removing waste and extra work. Their book is the foundation for the second chapter of this literature review, below, WCI.

2.6 Wärtsilä continuous improvement program

According to Michele Cafagna, vice president of Wärtsilä continuous improvement program, continuous improvement is a part of Wärtsilä's strategic framework, along with lean. It is called the Wärtsilä way. Wärtsilä has a relatively short history with lean. Cafagna says that it began in 2010 with lean thinking experiments. This leads to the conclusion that Wärtsilä shifted toward lean only 15 years ago (Wärtsilä, 2024).

To implement the Wärtsilä way, Wärtsilä launched an internal educational program at the end of 2024, called the Wärtsilä continuous improvement program (WCI), to educate its workers on lean methods, tools, and thinking. The goal of the program is to achieve better flow efficiency in their operations and deepen the workers' knowledge of lean. Additionally, the program requires all workers who took part in the program to either take part or initiate a WCI case and implement their learnings in a real setting. It was hosted by Niklas Modig, one of the authors of the book already referenced multiple times in this thesis, This is Lean (2013). The books' influence on the program is noticeable.

The education package consists of 18 different learning modules, starting with the WCI introduction, followed by case investigations. The first case follows the same formula as the previously discussed medical aid journey, but in a slightly different setting: ADHD investigation. The cases are reviewed and reflected on. This leads to introducing the WCI model, which can be seen below in Figure 4.

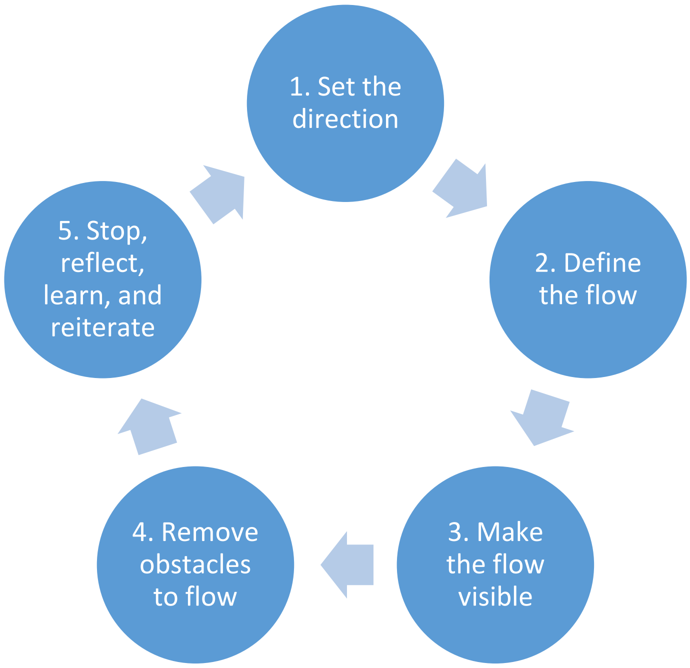


Figure 4. The WCI model. (Wärtsilä, 2024).

The WCI model represents lean values, principles, methods, and tools in the Wärtsilä way. It combines flow efficiency, jidoka, VSM, and continuous improvement. As previously discussed in this paper, JIT is a principle for creating flow, Jidoka is a principle for creating transparency, and Kaizen is a Japanese term for continuous improvement. It also follows roughly the VSM process that Sangwa and Sangwan (2023) proposed.

2.6.1 Set the direction

Setting the direction is the first step on the WCI model wheel. According to Modig (Wärtsilä, 2024), in the WCI training program, it is most important to define what the goal is. He elaborates that a sandcone theory is a good starting point to answer that question. According to Rezaei and Behnamian (2021), the sandcone theory suggests that improving performance has a sequence that should be followed, and the improvements should be cumulative. Below, in Figure 5, is a mockup of the sandcone model.

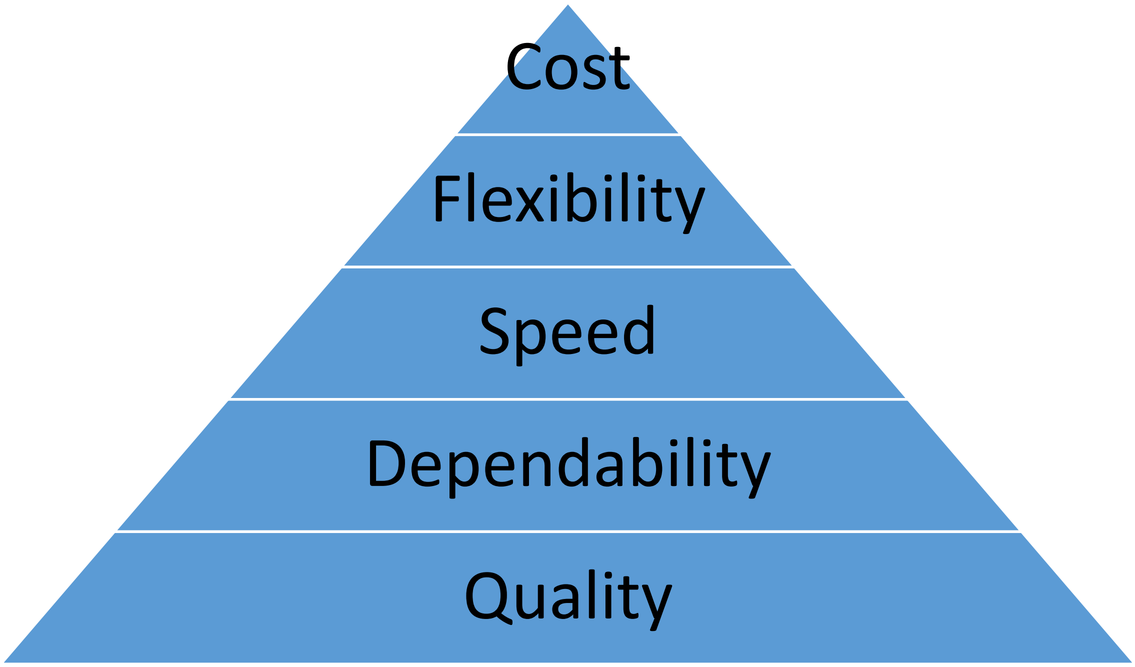


Figure 5. A mockup of the sandcone model (Rezaei & Behnamian, 2021).

According to the model, quality should be considered first, then dependability, third speed, fourth flexibility, and finally cost. The idea is that by building a solid foundation, reliable improvements can be achieved. Modig continues that after setting a clear goal, the current state should be measured, and a desired state set. The progress should be visualized by using a graph.

2.6.2 Define the flow

To define the flow, a whiteboard is recommended to be used, or an online version, where a timeline can be drawn. There are seven steps recommended to build the timeline, and the flow unit that is under scrutiny. To start with, a current state analysis should be done. For this, the first step is to pick one flow and one case, where you have historical data or an active case. The case should have several functions involved from start to end. The second step is to develop the timeline. In this step, the unit of analysis needs to be determined, along with the scope, then the lead time, and finally the timeline. Third, identify the functions. determine who and what are involved. Fourth, identify milestones and phases. Divide the flow into parts. Fifth, identify activities. determine what is happening within each phase. Sixth, identify the flow. Connect the activities into one line, one flow. After this, you have developed a current state analysis. The seventh step is to create the desired state. This includes removing, combining, and simplifying the activities. After this, you can determine how long the desired lead time should be. Modig's final recommendations are to simplify the flowchart and not to get stuck in details. He recommends to include about 7 functions and phases.

2.6.3 Make the flow visible

The purpose of this step is to visualize the flow and measure whether improvements are achieved. For this, Modig (Wärtsilä, 2024) recommends first identifying all the phases. Then, creating a table for measuring the lead time for each phase. In the table, list the current state lead time of each phase and the desired state lead time. Indicate in the table whether improvements have been made and if there are obstacles. This way, progress control can be established.

2.6.4 Remove obstacles to flow

Removing obstacles to flow starts with the identification of waste. It can be identified from different sources, such as historical cases, real-time observation, or data from real-time management of the progress control. When removing the obstacles, it is important to fix the root cause of the problem. Modig (Wärtsilä, 2024) suggests the five-why method. Barsalou and Starzyńska (2023) describe the five-why method as a "proximate cause strategy for RCA." RCA is short for "root cause analysis". They continue that the strategy begins with an evaluation of symptoms of the problem and identifies each underlying cause of the symptom, leading to the root cause. Modig's practical recommendations for removing obstacles to flow are first to identify and describe wastes and non-value-adding activities—both from the flow analysis and actual go-and-see observations. Next, list all the obstacles and perform RCAs. Summarize everything in a table and provide improvement suggestions. Finally, manage resources by identifying the needed resources, defining their current and desired states, and improving and iterating.

2.6.5 Stop, reflect, learn, and reiterate

For this phase, Modig recommends starting by developing a prioritization board. His example of the board is a matrix that consists of the amount of effort on one axis and the amount of effectiveness on the other. The second step is to prioritise improvement suggestions on the matrix, to determine which needs the least effort for maximum effectiveness. After that, start generating improvement activities. Fourth, develop an improvement board to control the workflow. A kanban board is suggested for this. As previously discussed, they are often used to control the amount of work and organise the workflow. Fifth, organise a recurring improvement meeting, and finally, reflect on how to make this a success. When this is done, the wheel can start again from the first phase of the WCI wheel: set the direction. Modig points out that it does not have to start from there, but where necessary to be effective. If the direction is clear, then proceed to the next phase. Neither does every task have to be taken, but these can be flexibly utilized for each need as best.

2.7 Process analysis and improvement

Process analysis and improvement practices can range from small improvements to complete redesigns. Businesses try to improve their processes to gain an advantage over the competition and keep up with technological advancements. Zellner (2011) studied different business process improvement approaches. He identified many terms that were related to improving processes. They ranged from radical business process re-engineering (BPR) to incremental business process improvement (BPI). His problem statement was that even though BPI is ranked as very important, there are no clear guidelines for implementing it, and it is poorly supported. He concluded that while there are BPI frameworks, it is left to the user to decide what to do.

This chapter will examine two other methodologies that are aligned with the previously discussed topics of lean and WCI frameworks. They were selected because they match the research questions and objectives, and the swimlane diagram has already been in use in Wärtsilä. These main topics (lean, WCI & BPI) form the theoretical frame for the practical part of the thesis.

2.7.1 Theory of constraints

Theory of constraints (TOC) is a theory that focuses on throughput and flow. It was introduced by Eliyahu Goldratt and Jeff Cox in their book "The Goal: A Process of ongoing improvement", from 1984. The book teaches its lessons through a story of a plant manager, whose plant is under the threat of discontinuation. The plant is losing money, delivering late, has excess inventory, and long lead times. The plant manager seeks help from an outside consultant, who helps the plant become a success story.

The plant is focused on efficiencies and cost reductions. Every workstation is attempted to be utilized as much as possible, and costs are minimized by fewer installations with bigger batches. The plants' efficiencies are boosted with new robot technologies. Everything is seemingly being done to make the plant work and be profitable. The problem is that the workstations themselves are efficient, but as a system, they are not. This is also what Modig tries to communicate in his book "This is Lean", as well as the WCI program. Uneven flow through the plant leads to an increase in work-in-progress (WIP) and inventory massed at different workstations, with longer lead times. The performance metrics for the plant in the book measure local efficiencies and unit costs instead of generated revenue, which, in part, is the flaw in the system.

After speaking with the consultant, the managers in the plant started looking for bottlenecks in their system. They began seeing the whole system as more intertwined and the bigger picture as a whole. Through trial and error, they created a system: The TOC principles. Below, in Figure 6, are the principles.

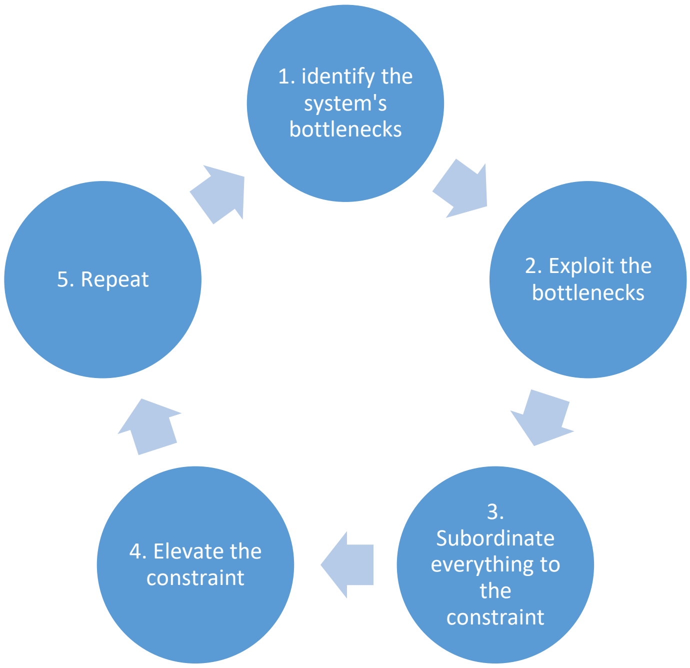


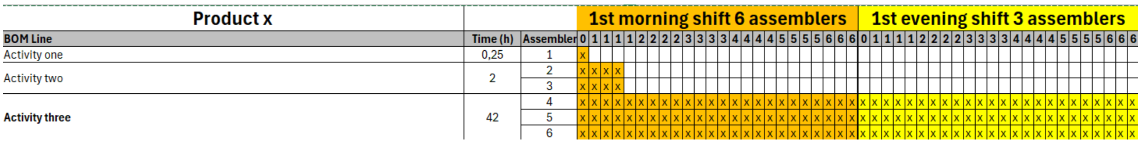
Figure 6. The TOC principles (Goldratt & Cox, 2012).

As the TOC principles dictate, the first step is to identify the bottlenecks in the system. The managers in the story identified them by discovering where inventory was piled. They found two bottlenecks in their system and moved to step two. They began running the bottleneck machines as continuously as possible. They then arranged the work orders in a manner to optimize throughput, moved all possible work to other machines to free up capacity, and implemented a quality system to ensure that no work at the bottlenecks goes to waste. The third step is to make sure that the constraints set the pace of the flow. The managers discovered this by mistake. They used the other, more efficient stations to work on other pieces in the meantime, when the bottlenecks constrained the flow. This led to inventory and WIP buildup throughout the plant. By subordinating everything to the constraints, flow is improved, and the system is synced. Step four, to elevate the constraint, means increasing capacity at that workstation. The managers did it by adding a third shift to run the second constraint, bringing old equipment back to add to the first constraint's capacity, and investigating the possibility of outsourcing those work phases. And finally, the fifth step, repeating the process for an ongoing loop of improvement. The book claimed that the bottleneck will eventually become market demand, instead of plant capacity. And that was one of the consequences of applying TOC in the factory of the story. They improved lead times, reduced inventory, reduced WIP, and became more dependable and profitable.

To summarize, TOC promotes flow efficiency, throughput, a systems thinking model, transparency in the organization, and continuous improvement. It is not limited to shop floor activities only, but relates to management, strategy, and sales, among others. The goal, as emphasized in the book's title, is for a company to make money. The TOC principles guide toward that goal.

2.7.2 Swimlane diagram

Swimlane diagrams are a visual tool and a flow chart to communicate business processes. The diagrams include a more detailed role assignment function compared to other diagram types. The swimlane diagram lists the responsible stakeholders on the y-axis and tasks horizontally to represent a task. They are often used in workflow analysis and improvement efforts. Waterhouse (2021) studied the workflow analysis process, which resulted in swimlane diagrams. She described swimlane diagrams as a technique that lists "tasks in a workflow sequentially as rows in a spreadsheet and then identify the person(s) or unit who performs that task by column.". Below, in Picture 1, is a short presentation of a swimlane diagram used in Wärtsilä. They are formed for each product type separately, since the activities vary from model to model. It does not follow the previously mentioned definitions entirely since the responsible persons are listed horizontally, likewise with the sequence of tasks. The duration of the tasks can be read vertically. However, it serves the same purpose. Each row represents one assembler, and each column is 15 minutes of active work. For example, activity two would theoretically consume 2 hours of work (1 hour per assembler). Two assemblers are recommended for that particular activity. All of the tasks seen in this diagram can be done simultaneously, since they are overlapping.



Picture 1. A swimlane diagram model from Wärtsilä.

According to Waterhouse (2021), process mapping can help workflow analysis by visual methods and by identifying obstacles to efficient workflow. She continues that "swim lane diagrams are particularly useful for identifying redundancies, problem areas or inefficiencies in a business process", and "Process diagrams are also useful to identify the problem areas related to task sequencing". The study concluded that other advantages of the diagram were its usefulness in determining tasks that can overlap and be executed at the same time, identifying bottlenecks, inefficiencies, and waste.

2.8 Literature summary and conclusions

This literature review addressed subjects ranging from overall lean values, principles, methods, and tools to guide the reader into the subject. This was followed by a more detailed overview of the tools and methods that reflect manufacturing in the Wärtsilä STH factory, or those that will be utilized in this research. Listed was value stream mapping, which was one of the agreed-upon deliverables of this thesis. Next, Kanban was explored to provide background to tasks from the WCI model. Third, JIT is a principle used in Wärtsilä, and was detailed because the research methods should reflect this principle. 6S gives more insight into the working culture of Wärtsilä. Cellular manufacturing is also used in the factory. Kaizen is a core principle that was repeated in WCI and process analysis and improvement parts. Jidoka was also a principle that will be used in this research. The book "This is lean" was explored more thoroughly, because it reflects Wärtsiläs strategy, and leads the reader to the next chapter, WCI. The WCI chapter deepens the chapter from lean into what it actually is in Wärtsilä. It explains what the Wärtsilä Way is and how the company attempts to implement its version of lean. The process analysis and improvement part supports and complements these Lean and WCI principles with literature aligned with the objectives of this thesis. The TOC principles can be used for the objective of identifying bottlenecks, upholding continuous improvement principles, and addressing lead time. The swimlane diagram can be used to identify the bottlenecks, structure the production process more effectively, and highlight support needs as the research questions and objectives demand. Below in Table 1 is an attempt to summarize the reasons for including each subject in this literature review.

Table 1. A review matrix.

	Provides insight	**A tool to be used**	**Leads to another subject**	**Core principle**
VSM	Yes	Yes		Yes
Kanban	Yes			
JIT	Yes	Yes		Yes
5S	Yes			
CM	Yes			
Kaizen	Yes	Yes		Yes
Jidoka	Yes	Yes		Yes
This is lean	Yes	Yes	Yes	Yes
WCI	Yes	Yes, partially		Yes
TOC		Yes		Yes
Swimlane diagram		Yes		

As Table 1 communicates, several tools from the literature review were utilized. The coming chapters will introduce value stream mapping, JIT principles, kaizen, jidoka, subjects from "this is lean", WCI principles, TOC principles, and a swimlane diagram. Many of these subjects are so similar that they cannot be differentiated as distinct from one another. For example, jidoka is always present when speaking of "making the flow visible" from the WCI model. Kaizen is always present when speaking of any of the continuous improvement models, which are a part of lean, VSM, WCI, and TOC. JIT is always present when speaking of flow.

The WCI model was not directly used, but it was partially utilized, for example, in deciding the goal "set the direction" and improving the flow of information "make the flow visible". The TOC principles were not used in the improvement plan, but as the results of the VSM become known, recommendations are given based on the TOC principles to create an even flow, "maximize throughput" through the factory. The next chapters will elaborate further on the use of these tools.

3 Research methods

Research methods of this thesis will combine different tools that were discussed in the previous chapter. In addition to those, this paper includes qualitative research and data analysis. These will be discussed in more detail below in this chapter.

3.1 Value stream map

The first step of this research is forming an "as-is" state for the production of the product and establishing the current benchmark for the lead time of these products. As Sangwa and Sangwan (2023) guide, the goal of the VSM is already established, along with the people involved, which product to concentrate on, and the data is available. Data for this purpose will be gathered from different sources, ranging from personal notes, emails, and discussions to company Power BI reports. The data will be gathered from a previous comparable project from last year. After this, the "to-be" state is formed, and the improvement plan is formed.

3.2 Information flow

The improvement plan is fivefold. The first part is to improve the information flow of the project. Such as the principles of Lean and WCI dictate. At the principal level, the goal of jidoka is to make the organisation so transparent that everyone can work towards the common goal. To work towards this goal, a Microsoft Teams channel is created. This channel includes everyone related to the project, such as the project manager, project engineers, development engineers, team leads, and coordinator assemblers. Through this channel, general information is relayed, targets set, and feedback communicated. In addition, a go-and-see meeting is set up twice a week on the factory floor, and a daily, continuous dialogue is upheld. The go-and-see meeting is also used to communicate and track the overall goal of the manufacturing lead time. Ways to improve information flow through other means are also explored.

3.3 Swimlane diagram

The second part is to map the workflow with a swimlane diagram. The diagram is aligned with multiple subjects from the literature review. It is used for removing obstacles to flow (WCI) and finding the constraints (TOC). Continuous improvement practices (kaizen) can be improved by analyzing the results. At the shop floor level, this tool can be used to discover the natural workflow, identify bottlenecks, remove obstacles, highlight support needs, and communicate daily targets. The diagram is already formed by the development team, and as such, will be used in this thesis. The diagram lists manufacturing activities phase by phase. The manufacturing of this product is divided into phases. Each phase includes certain activities. The swimlane diagram has all of the activities listed with a recommendation of how many assemblers that activity would require, and for how long. The diagram is a Microsoft Excel file, with each phase on its tab, with the activities sequenced as they have been planned. Workflow is observed daily and marked in the file. Targets are communicated with the swimlane recommendations through the Teams channel.

3.4 Other

The third approach is "other" improvement initiatives that are not listed in this chapter. Improvement subjects will come to our attention during the manufacturing of these products, and they will be taken into consideration and possibly into action immediately. A WCI initiative was also launched from another department to reduce the lead time of this product type. This will be considered as a part of the "other" improvement efforts.

3.5 Data

The fourth approach of the improvement plan is to collect data. The data will include activity and phase lead times, deviations, quality notifications, and the effect of worker numbers on lead time. The numbers might not be accurate, since that would require clocking. They are, however, accurate on a day-to-day variation range. Clocking is not in the scope of this thesis. The data will be used for the standardization of activity times, to improve the company's Power BI performance reports, and to establish a new baseline for further improvements. As previously stated, standardization is one of the most important methods to create an efficient flow so that everyone knows how something should be done.

3.6 Interviews

The fifth and final approach is to arrange semi-structured interviews. This will be done near the end of the project, so that input can be given on how the project went. The interviews will include the operational people involved: the coordinator assemblers, optionally with their team members. The interview will support the findings of the swimlane diagram, clarify missing information, and gather feedback. The interview questions will be listed in the next chapter. Grading and thematic analysis will be conducted to review the interview results.

3.7 Fulfilment review

This thesis included three research questions, three research objectives, and five preagreed deliverables. A short review of whether they will be fulfilled is conducted next. The first research question is "what are the bottlenecks in the process and how to identify them?" The VSM and the swimlane diagram will identify the bottlenecks. The second question, "How can the production methods be enhanced?", is a sum of all of these improvement practices. They will be listed in more detail in the next chapter. "What are the current lean tools to address lead time?" The answer is a combination of the subjects listed in the literature review. Even if the tools are not recently discovered, they are still relevant and can be applied in a modern way. The standardisation through Power BI reports and information flow through Microsoft Teams are examples of this. The first objective, to "analyze the current lead time components", will be met with the VSM process and historical data. The second objective, "to structure the production processes into a more effective whole", will be delivered as a result of the VSM and the results of the swimlane diagram. The third objective, "to identify areas of inefficiency and highlight support needs", is also a direct result of the swimlane diagram and VSM. The deliverables (VSM, research and gathering of statistical data, identification of bottlenecks, workflow optimization, and implementation and recommendations of lead time reducing actions) will all be delivered.

4 Research results

This chapter will present the detailed results of the improvement plan in action. As discussed in the previous chapter, the first step of the research was to form an "as-is" state. After that, a "to-be" state is introduced, and an improvement plan is created to achieve that. Lastly, the results of the improvements are discussed.

4.1 Value stream mapping

According to Sanga and Sangwan (2023), in the VSM implementation process chart, the first step is to define the goal of the VSM. The WCI program suggested that the sandcone theory was a good place to start. The sandcone theory dictates that improvements should be cumulative, and in the order of first quality, second dependability, third speed, fourth flexibility, and fifth cost. The assumption is that previous projects have made progress on the quality aspect of manufacturing. To validate this assumption, quality notifications and deviation trends are analysed next. Notifications are created if a deviation needs further action or other changes are necessary. There are different types of notifications: Internal notifications, vendor notifications, design notifications, and late change notifications, to name the common ones for manufacturing. Deviations are created by assemblers if they face challenges in their work. They might be resolved immediately or dismissed in some cases. They also might lead to notifications. In picture 2, below, is a chart comparing the last two projects' quality notifications from the company's ERP systems.

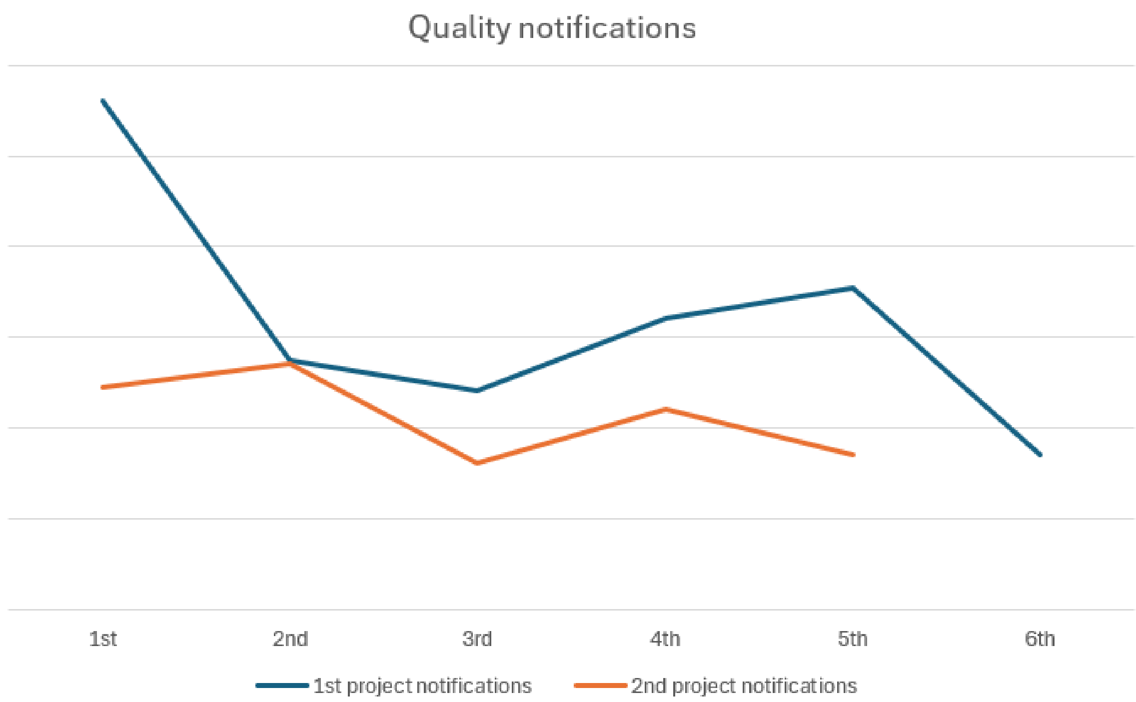


Figure 7. Comparison of notification amounts.

The amounts of the notifications remain undisclosed, but the graph communicates the trends clearly. The first project can be seen to make progress towards the final product. The curve is downward. The first product has the highest amount, and the last one least. The second project stabilises at a similar level to the last product of the first project. Below, in picture 3, are quality deviations from a different ERP system.

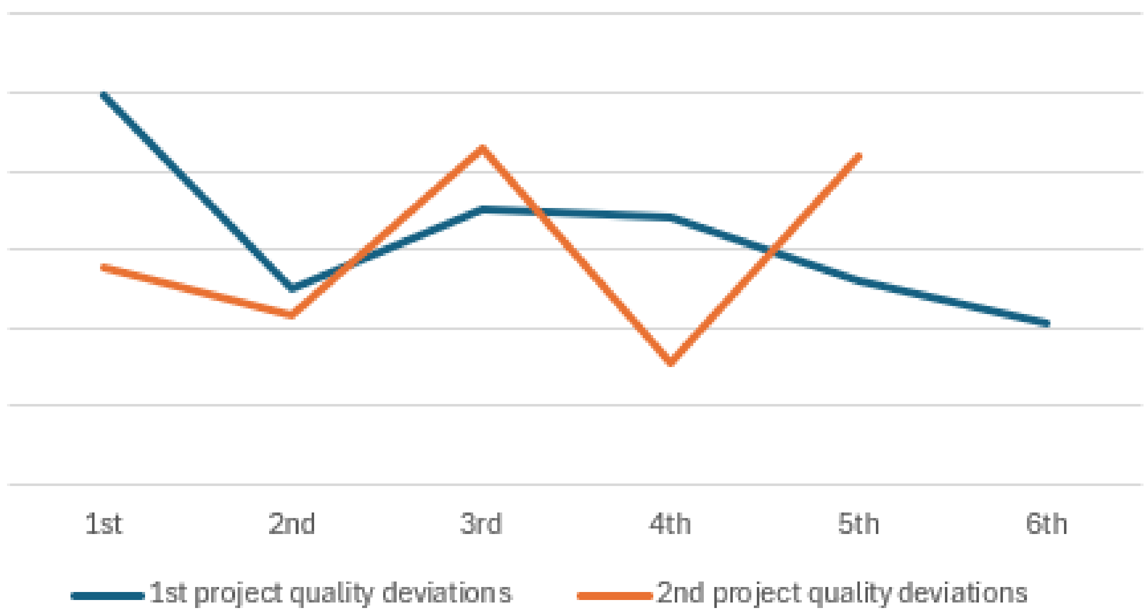


Figure 8. Comparison of quality deviations.

The trends on this chart are not as clear as the previous one, but it can be interpreted that the majority of the second project's products are below the level of the first project. The two products, the third and fifth, of the second project do not support the view that quality has stabilized. Despite this, the majority of the data from both pictures, 2 and 3, suggests that better quality has been achieved. Thus, the goal of this thesis will be to achieve dependability. The overall lead time through the factory was targeted to be reduced by 40%. Phase 2 lead time was targeted to be reduced by 22,87% and stabilized there.

The second step was to form a cross-functional team. This was not formed separately for this VSM. Rather, a cross-functional team is already in place for the improvement of this product and its manufacturing. This will be elaborated in the coming information flow chapter. The third step, to identify critical product(s) or line, is also not relevant, since this thesis already focuses on a certain product family.

The fourth step is to walk the flow and collect data. Data was gathered from six different main sources. The first one was a shared file, which was filled by production planning in collaboration with the subcontractor who delivers the first subassembly to the factory.

It lists times when this subassembly is supposed to be delivered. The second source was a file shared among the project team members that lists all projects of that team with some details, such as the start of assembly dates. The fourth source was email. The fifth source is a diary written by a project team member. It lists actions on a daily basis. The sixth source was a communications channel used by a certain department. Other data sources include company ERP systems, and personal notes and observations. By combining and comparing the data, the lead times of the second project's different phases could be determined. Walking the flow, the gemba walk, was a daily routine on the factory floor. At least once a day, a gemba walk was conducted during this project.

Forming the "as-is" state was approached by first identifying the different phases of the flow. Next, the information flow was recognized, and different parties were identified. Then, the lead times of the different phases were retrieved from the previously mentioned data sources. Some data points could not be obtained from the previous project, but almost all the information was recovered, and the missing data points could be inferred from other available data. This was set as the baseline for the VSM. For the purpose of this paper, the data is not disclosed, but the "as-is" point is set to 100%. Below, in Figure 9, is the formed "as-is" VSM.

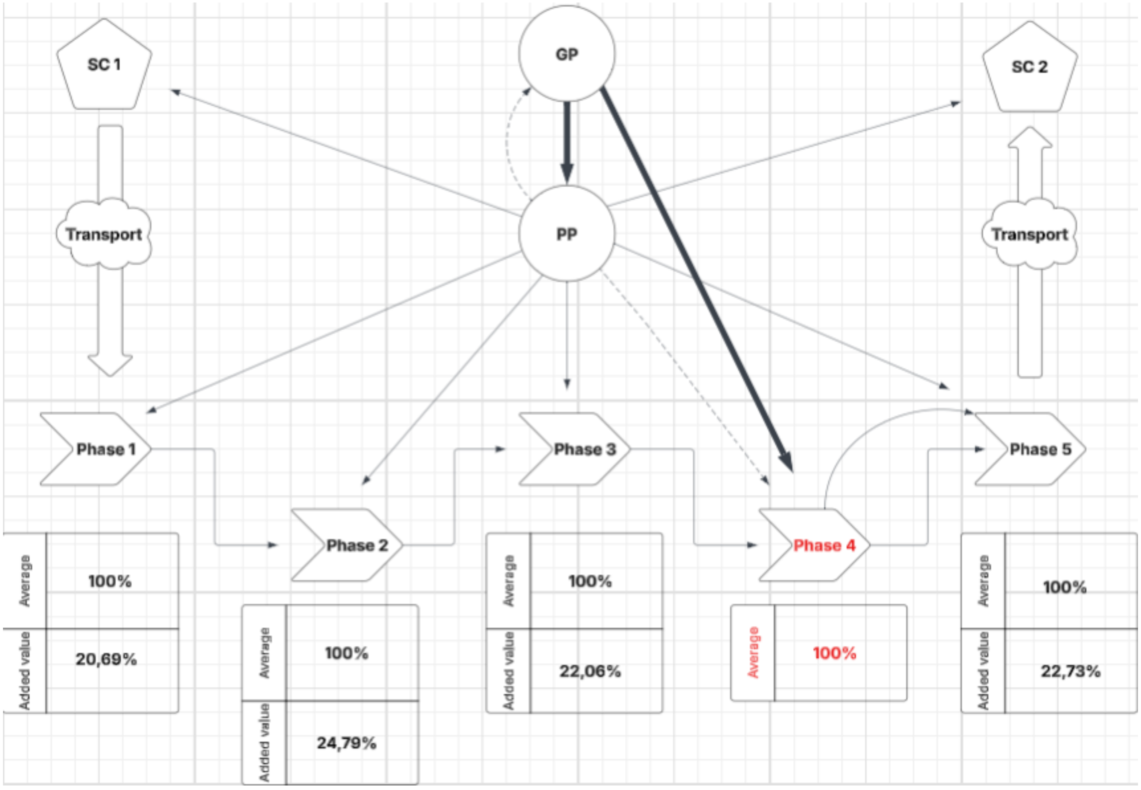


Figure 9. An "as-is" value stream map of the manufacturing processes.

As shown on the map, the process can be divided into 5 different phases. Phase number four, highlighted in red, was outside of the scope of this thesis. As are the two subcontractors, SC 1 and SC 2, at the ends of the process. Two key departments, PP and GP, are listed for their central effect on the information flow and management between these phases and different parties. Those departments communicate with one another, managing the flow through the plant. GP dictates the order of new starts to PP and manages the phase 4 workflow. PP manages all other phases and subcontractors according to the communicated order. PP also communicates to phase 4, but on a more general level. Phase 4 shares information to phase 5, as well as PP (E. Tuovinen, personal conversation, 25.7.2025). The amount of value added in each phase is determined by swimlane findings, interviews, and observations. These will be elaborated further in the coming subchapters.

The sixth step of the Sanga and Sangwan (2023) VSM model is to analyze the "as-is" VSM and to propose a "to-be" state. The value added columns of each phase are at 20,69%

the lowest, and 24,79% at the highest. There is potential for improvement across all the phases. The most that can be directly affected by this research is phase 2. Achieving the goal of reducing and stabilizing the lead time of this phase will allow for other phases to be more easily forecasted in the future, thus reducing their lead times. The assumption that quality has improved will lead to a reduction in the lead times of phases 1, 2, and 5. Phase 1 is dependent on the actions of PP and can be reduced to zero in the best-case scenario, but reducing the lead time to a certain point is also desirable, as long as value can be added to it. Phase 3 cannot be affected directly, as it is dependent on phase 4, which is controlled by GP. This leads to the conclusion below of the proposed "to-be" state in picture 5.

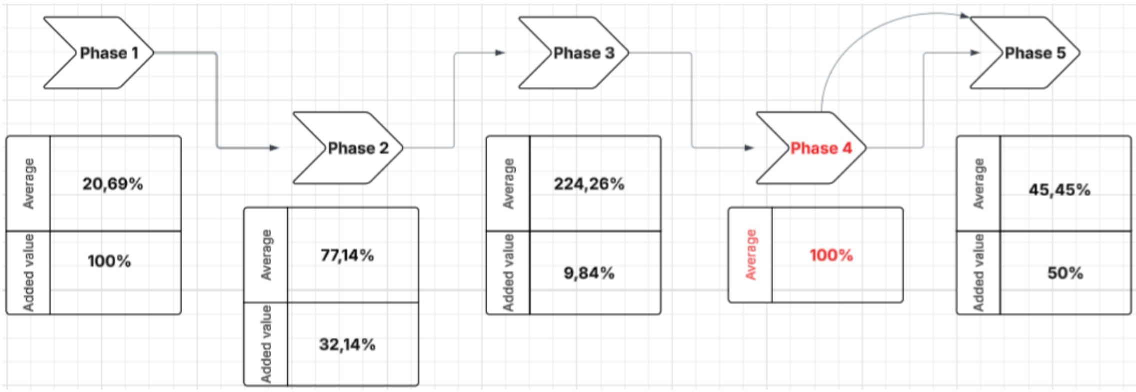


Figure 10. A "to-be" state of the manufacturing process.

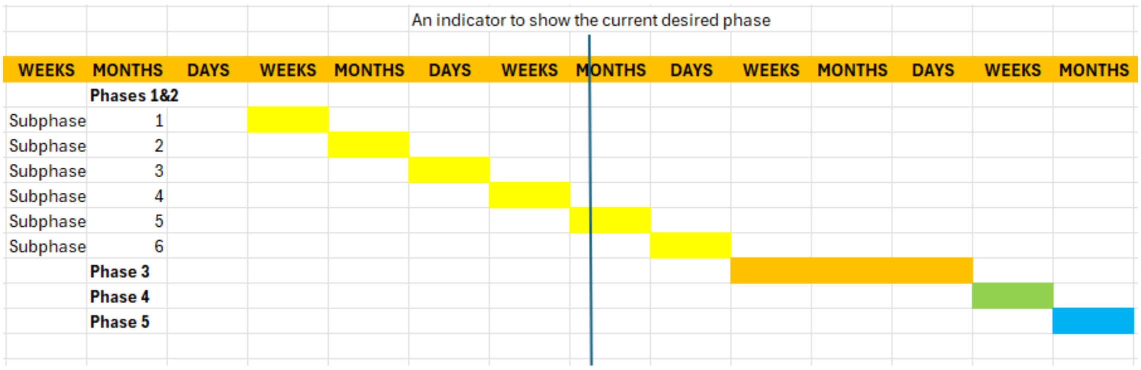
As stated before, phase 1 can be ideally removed from the process entirely, or reduced to 20,69% of the benchmark lead time. Both will lead to a 100% added value. This is achievable by planning the flow of products coming into the factory from SC1 to match the amount of products moving from phase 2 to phase 3. Phase 2 reflects the target of reducing the lead time by 22,86% and stabilizing it there. Phase 2 can, and is being attempted to be streamlined into a more efficient and dependable process in this research. However, this will lead to a large increase in phase 3 lead time, as it is dependent on phase 4, which can not be controlled directly. By consistently delivering the reduced phase 2 times, phase 4 can be planned accordingly by GP, and the total lead time reduced. Phase 5 could be attempted to be reduced to 45,45% of the previous benchmark, leading to 50% added value. This is a lead time that has already been achieved previously. The process of phase 5 should also be streamlined to a more dependable phase. These improvements would amount to 82,42% of the benchmark project's lead time. A 17,58% reduction, instead of the original 40% target. The only way to reduce lead time further is for GP to plan phase 4 sooner, so that phase 3 would be reduced as well. This is achievable through the dependability of delivery from phase 2, which is a target of this thesis.

The seventh penultimate step, defining an improvement plan to meet the "to-be" state, consists of five different main approaches to improve the process, as discussed in the previous chapter. Three of them are directly for this project, and two are for upcoming projects, to achieve continuous improvement. They are introduced in detail below.

4.2 Improving the flow of information

The first approach to improving the process is to enhance the flow of information. This aligns with multiple subjects from the literature review of this thesis. Jidoka is a principle for creating as transparent an organisation as possible, so that everyone knows what the goal is and how they can work towards it. It is a core part of lean values and principles, as Modig and Åhlström (2013) wrote. In addition, the WCI model's third step is to make the flow visible. Tracking whether improvements are made leads to progress control.

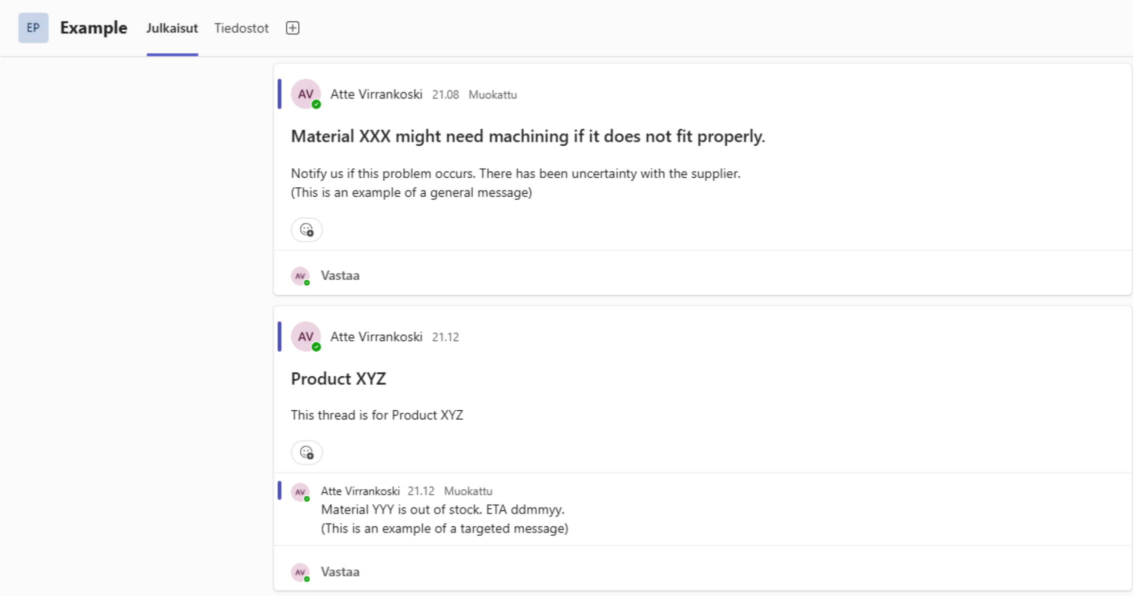
The first method for this was to set up a twice-a-week meeting on the factory floor, on Tuesday and Thursday mornings. To the meeting were invited the following key stakeholders: coordinator assemblers, and their team leads, members of the logistics department, members of the development department, the project team, and research and development members. Together, this group formed the cross-functional team called for in the VSM process. The meeting was set up on the factory floor to lower the threshold to attend the meeting and encourage go-and-see practices. The agenda for the meeting was to communicate the targets of phases one and two and whether they were being met, communicate and provide general information, determine whether there were obstacles to flow, facilitate peer-to-peer advice between assembly teams, and enable easy access to experts from different departments to help with challenges. A Gantt chart, which reflected the target lead times, was projected on a television screen at the meetings. The chart displayed the current desired phase, which was compared to the actual progress to achieve progress control and communicate targets on a general level. Below, in picture 2, is a mockup of the Gantt chart.



Picture 2. A mockup of the Gantt chart.

With the support of the Gantt chart in picture 2, it was discussed whether the actual progress matched the targets and if actions were needed.

The second method for improving the flow of information was to form a Microsoft Teams channel for all the members mentioned previously. This channel was used in cooperation with the go and see meetings. It was used on a daily level, rather than bi-daily, to communicate challenges, general information, and the targets according to the swimlane—more about the swimlane in the next chapters. The information shared through this channel could be more targeted to a single product in the project or a certain person. The channel contained general information for all, as well as targeted information. For example, if a problem arose during the first engine's assembly and would impact the other engines in the project, it would be posted on the channel for everyone to see and reminded in the bi-weekly meetings. Below, in Picture 3, is a mockup of the channel.



Picture 3. A mockup of the Microsoft Teams project channel.

As seen in the picture above, an example of a targeted message would be on the "Product XYZ" thread if a product-specific material was missing. It was visualised and posted on this specific product's discussion thread with an estimated time of arrival. The first thread, "Material XXX might need machining if it does not fit properly.", is an example of a general message targeted for everyone. This was to ease workflow planning and reduce unnecessary work. Other information included transfer dates and locations, reminders, and suggestions.

Other methods included daily discussions on the factory floor, direct phone calls, messages, and added notes to the company ERP tool that the assemblers use to manage activities, create deviations, call materials, and search for assembly pictures. These methods are elaborated on next. As previously mentioned, daily gemba walks were conducted during this project. They included discussions with the assemblers to share information and plan the material flow, in addition to collecting data. If visiting the factory floor was not possible and important or urgent information was to be shared, the assemblers could be reached by phone calls or messages. Lastly, the ERP tool messages were trialed. The tool lists all the activities required to build the product. If any specific activity required attention, it could be added in conjunction with the activity. The second approach to improve the manufacturing process is demonstrated next.

4.3 Workflow mapping

The second approach of the improvement plan was to implement swimlane workflow mapping. It aligned with the research question and objectives, the reviewed literature, and lean manufacturing. As Waterhouse (2021) stated, process mapping with swimlanes can help with workflow analysis, identify obstacles, redundancies, problem areas, and inefficiencies. It answers the research question "what are the bottlenecks in the processes and how to identify them?", and helps to understand "how can the production methods be enhanced?". In cooperation with the VSM, it meets the objectives of analyzing the current lead time components, structuring the production processes into a more effective whole, and identifying areas of inefficiency and highlighting support needs. It supports JIT practices, aligns with the TOC process, and upholds kaizen.

As previously mentioned, the swimlane was formed by the development team from Wärtsilä. It listed all of the activities of phases 1 and 2 from the VSM. The swimlane worked under the assumption that each day would consist of two shifts. Each shift would contain six hours of active work. The morning shift would have six assemblers, and the evening shift three. Activities were sequenced and listed with an estimated time needed to complete the activity, with an ideal number of workers to do it. Each day, targets were set for the day according to the swimlane estimates in the Teams channel. The results were reviewed at the end of the morning shift and along the gemba walks. The idea of the swimlane was to support work planning and ease the assignment of tasks for each individual assembler. If problems, support needs, or obstacles to the flow arose, they would be marked in the swimlane. The direct results of the swimlane will not be disclosed in this thesis. Three of the products in this project were subject to swimlane target setting. Two were not applicable because they were different types of products, and one was of low priority. It was low priority firstly because of the high workload on the assembly team, secondly because the product would have met constraints during the flow otherwise, and thirdly because this would have led to a long waiting period on phase 3.

The swimlane results revealed three main obstacles to flow. An estimate of fixing those issues has the potential to reduce the phase 1 and 2 lead time by a further 8% from the original benchmark. It also highlighted support needs for various activities, including the need for further education in some cases, unclear instructions for others, and issues with workflow sequencing. For this research, it successfully helped identify the areas that were desired for the result. For target setting, it was not successful. The swimlane is not flexible and requires a lot of attention to uphold. Some problems with the swimlane included the inability to uphold an accurate workflow map with multiple products simultaneously, the fact that assembler amounts would change from day to day, which caused issues with the target setting and modifying the swimlane file, and weekend work would give no insight into what was achieved in a day, and what the sequence of activities was. For more accurate results, continuous presence and clocking of the assembly activities would be required—more about the swimlane issues and findings in the coming subchapter, interviews.

According to the swimlane, the best theoretical lead time of phases 1 and 2 was 21,81% of the benchmark project. Another way to interpret this estimate could be that the benchmark project added value to these phases only 21,81% of the time. Later estimates from interviews and swimlane tracking suggested that this was slightly too optimistic. Revised theoretical lead time was concluded to be 24,11 % of the benchmark—more about this conclusion in the interview chapter. The swimlane findings varied from product to product and from team to team. Next, the lead times of the swimlane tracking subjects are examined.

4.3.1 Swimlane tracking lead times

As Table 2 below displays, the actual lead time of phase 1 was increased by 3,45% from the benchmark project's average lead time. It had a long waiting period, with a maximum potential of 20% added value during that phase. A "revised" row, however, is added because a force majeure event took place during that time. The revised row shows a major improvement, reducing almost half of the lead time compared to the benchmark "as-is" state, leading to 37,5% added value for the phase.

Table 2. The first product's lead times for phases 1 and 2.

	Phase 1		**Phase 2**	
	Lead time	**Added value**	**Lead time**	**Added value**
Benchmark (as-is)	100%	20,69%	100%	24,79%
Target (to-be)	20,69%	100%	77,14%	37,5%
Actual	103,45%	20%	50,96%	48,86%
Revised	55,17%	37,5%	-	-

It is not an ideal result compared to the target "to-be" state, but an improvement. Phase 2 lead time saw a major improvement. The lead time was almost halved, and the added value column increased by over 10%, nearing 50%, exceeding expectations, and surpassing the target of 22,87% reduction.

The second subject to swimlane mapping reached the following results:

Table 3. The second product's lead times for phases 1 and 2.

	Phase 1		**Phase 2**	
	Lead time	**Added value**	**Lead time**	**Added value**
Benchmark (as-is)	100%	20,69%	100%	24,79%
Target (to-be)	20,69%	100%	77,14%	37,5%
Actual	55,17%	37,5%	50,96%	48,86%

The results in Table 3 above consolidate the results from the previous product. The same lead times were repeated. This table does not include a "revised row" because there were no distortions in the data. Major improvements were achieved, but phase 1 should be reduced further to meet the desired "to-be" state. Phase 2 is improved, exceeding the target.

Finally, the third subject to swimlane mapping reached the following results:

Table 4. The third product's lead times for phases 1 and 2.

	Phase 1		**Phase 2**	
	Lead time	**Added value**	**Lead time**	**Added value**
Benchmark (as-is)	100%	20,69%	100%	24,79%
Target (to-be)	20,69%	100%	77,14%	37,5%
Actual	20,69%	100%	60,61%	40,91%

The third product reached the best results out of the three. As Table 4 shows, both phases met the goals. Phase 1 was eliminated altogether and merged into phase 2. For comparison purposes, they are represented as separate phases. As a consequence of the merger, zero waiting time between the phases occurred, improving flow. This led to an improved added value amount of 100% for phase 1, and 40,91% for phase 2, meeting and exceeding the targets of 100% and 37,5%. Lead times were reduced to 20,69% and 60,61% of the benchmark project. This product, however, was 9,65% slower in phase 2 compared to the two previous products' lead times. The rest of the actual lead times, including all the phases and other products in the project, will be detailed in the coming chapter "Data".

4.3.2 Swimlane findings

Listed in Table 5 below, swimlane findings from all three engines included the following: 26 activities that required more time than the original swimlane suggested, one sequencing error, two resource allocation mistakes, 13 activities that needed to be reassigned to different phases, two unclear activity instructions, and one activity with a possible need for more education. Also, as previously mentioned, it identified 3 main activities that were bottlenecks, and one whole area, electrical work, that obstructed the flow.

Table 5. Swimlane findings.

Activities with insufficient time	26
Sequencing errors	1
Resource allocation errors	2
Activities reassigned to different phases	13
Unclear instructions	2
Activities with a need for further education	1

These findings will form the base for the new recommended swimlane. Activities with insufficient time will be allocated more time, and sequencing and resource allocation mistakes will be rectified. Activities that were reassigned to different phases will be submitted for evaluation at the department that is responsible for workflow planning, unclear instructions were reported to the department responsible for instructions, and activities that need further education will be proposed to the department respo. The three bottlenecks are reported to management, production planning, and the development department. Management can make decisions regarding the capacity for two activities, production planning can plan two activities to begin sooner, and the development team can further the implementation of a subassembly for one activity. Electrical work will be recommended in the new swimlane to be made earlier, and a swimlane for electrical work is underway.

4.4 Other improvement methods

The third approach of the improvement plan, which directly affected this project, is miscellaneous subjects that arose during the manufacturing of these products. Improvements were implemented immediately where possible. This chapter will also act as a bridge between the short-term (this project) and the long-term (future projects) improvements, as it includes both. These improvements are in line with WCI and kaizen practices.

4.4.1 Short-term improvements

The first action taken to advance this project was to communicate the need and the priority of it to the department responsible for resource allocation. This was to ensure the least possible waiting time and to improve flow. Secondly, lessons learned from the benchmark project were utilized. Some parts were monitored in case they would remain defective. This resulted in two sets of parts to be sent for modifications as soon as they could be flagged. Quality notifications were followed through with, and the department responsible for design was alerted after these incidents. Thirdly, lessons learned from earlier products in the project were applied to later products. Two activities were modified for the later products because of the findings with earlier ones. Fourth, other mistakes were reported to the responsible departments. For example, an error was discovered in two technical drawings, which were sent for fixing, and intermediate solutions were implemented. Fifth, and final, was the immediate improvement of piloting and implementing a subassembly installation, which was found to be successful. This subassembly was previously assembled partly by the assembly team, rather than the module assemblers.

4.4.2 Long-term improvements

Long-term miscellaneous improvements included more intangible improvements. First, the innovation of new ways of working arose from another project's product, which required rework. This rework could have been avoided with earlier pressure tests, which were suggested to the responsible departments. Another improvement initiative was the automatic creation and distribution of 3D models of the products. The models were sought after for most of the products in this project, as they ease planning by visualizing the parts and activities in a more detailed manner. The need for these was communicated to the development department and management. Third, a critical path for the activities could be established. This would reduce the amount of unnecessary work. This was presented to the development team and management. It could be a subject for another thesis and further research. The fourth subject was also presented to avoid unnecessary work that occurred in this project: a swimlane diagram for electrical work. The diagram was started as a thesis work (A. Järvikangas, personal conversation, 31.3.2025). Fifth, a summary of tools that need to be separately called from outside warehouses was created because of perceived confusion during this project (R. Boxberg, personal conversation, 14.8.2025). Informing the assemblers of the whereabouts of these tools and when they would need them should improve the flow of work. Sixth, the urgent need for certain subassembly jigs was communicated to the development department and plant asset management. One jig was needed to ensure the flow of certain subassemblies, and another to ease the installation of a certain part, which will reduce unnecessary work. The seventh and final improvement was attendance at a WCI improvement initiative, which also aims to reduce the lead time of these products.

4.4.3 A summary of the miscellaneous improvements

A summary of the aforementioned miscellaneous improvements is listed in Table 6 below, with insight into their status.

Table 6. A summary of the miscellaneous improvements

Improvement	**Timescope**	**Status**
Ensuring resources	Short	Done
Lessons learned from the benchmark project	Short	Done
Lessons learned from the early products in the project	Short	Done
Technical drawing errors	Short/Long	Done/Ongoing

Piloting a subassembly installation	Short	Done
Introducing new quality checks	Long	Ongoing
Providing 3D models	Long	Ongoing
Defining the critical path of assembly	Long	Under review
Electrical work swimlane	Long	Ongoing
A tool summary from outside warehouses	Long	Done
Assembly jigs	Long	Ongoing
WCI initiative	Long	Ongoing

There are 12 different improvements listed in the table above. Five of them are short-term improvements, and seven are long-term ones. All of the short-term ones were executed during the manufacturing of these products. Only the "technical drawing errors" row remains ongoing for the long-term implications. For the long-term ones, five out of seven are still ongoing. One has remained a suggestion and is under review. One of the improvements could be finished by the time this thesis was written.

The following chapters will detail the other two remaining long-term improvements that are intended to be utilized for future projects from interviews and data collection. Even if the three approaches with immediate impact (improving the flow of information, swimlane target setting, and others) have long-term implications too, they were the ones with the most influence over this project. The following chapters focus more on the future. As the TOC-, WCI-, and VSM principles all dictate: analyze the results and repeat the process.

4.5 Data

The fourth approach of the improvement plan was research and gathering of statistical data. Data were gathered throughout the phases 1-5 from all six products in the project. One of the deliverables promised from this thesis was research and gathering of statistical data. This chapter will exhibit data first as an overview of the project, and secondly, from each product separately. That data is compared to identify patterns and differences, and measured against the targets set out to achieve in this thesis. First, total lead times are interpreted. These include phases 1-5, with phase 4 excluded (instead of only the phases 1-2 as the "workflow mapping" chapter did). Secondly, quality notifications and deviations are researched. Third, deviations overall are displayed. Fourth, individual products' lead times and flow are studied.

4.5.1 Total lead times

Total lead times through phases 1-5 are displayed in Figure 11 below. Phase 4 was not in the scope of this research and is excluded. The target "to-be" state is on the top row for easier comparison between the actual and the target values. The actual row is located on the bottom row. The actual row is color-coded to highlight whether targets were met, improvements made, or worsened from the benchmark project. Green highlighting means that targets were either met or exceeded. Yellow means that improvements were made, but targets were not achieved. Red means that the values were worse than the benchmark project.

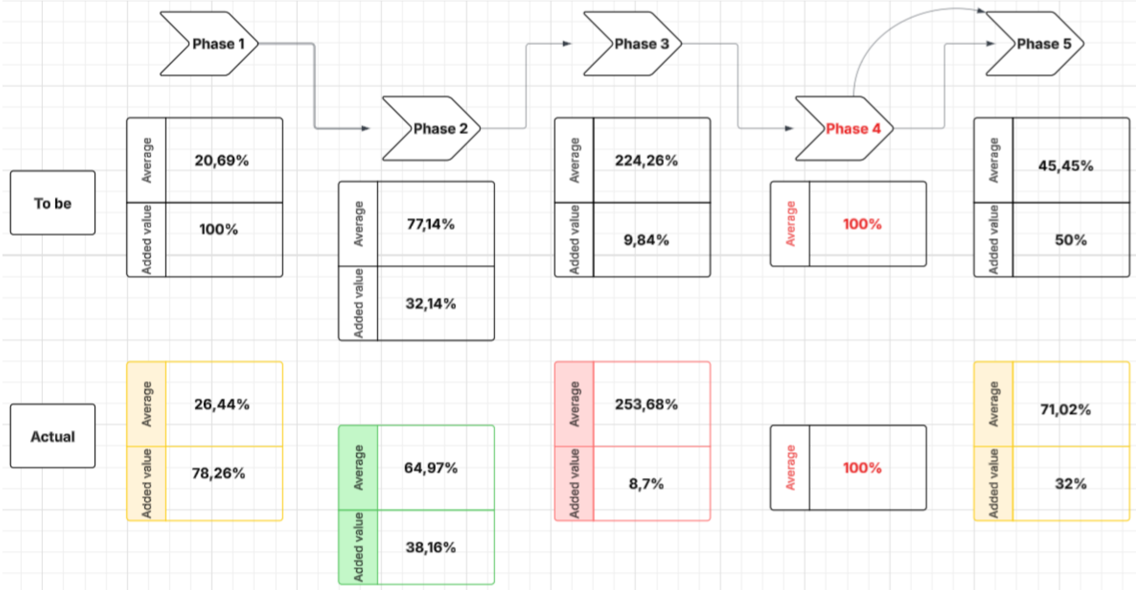


Figure 11. Total lead times of the project.

As Figure 11 displays, phase 1 is marked in yellow. A substantial improvement was made from the benchmark project, as the lead time of this phase, on average, was reduced to 26,44% of the benchmark lead time. Added value increased to 78,26% from 20,69%. The target "to-be" state could not be reached, as two out of six products had some waiting time in this phase. Phase 2 was an even larger improvement, as the green color communicates. Targets were met, and the lead time target exceeded by over 10%. The phase lead time was reduced to 64,97% of the benchmark project, increasing the added value percentage to 38,16% from 24,79%. Only one of the products in the project could not improve in this phase. As earlier stated in the "workflow mapping" chapter, one of the products was on low priority and with few resources. This product did not improve. The success in phases 1 and 2 led to an increase in the phase 3 lead time, as predicted. Phase 3 is dependent on phase 4, which cannot be directly affected. Because the improvements were bigger in phases 1 and 2 than the "to be" state anticipated, phase 3 was increased further, highlighting this phase in red. Lead time was increased by over 2,5 times over the benchmark project, to 253,68%, decreasing the potential value added number from 22,06% to 8,7%. Phase 5 saw an improvement compared to the benchmark project, but did not reach the "to be" state, highlighting the phase in yellow. Lead time was improved and decreased to 71,02%, and added value increased to 32% from 22,73%.

Below, in Figure 12, are the lead times of each product in this project (in blue), compared to the benchmark average (in orange dots). It also includes the lead time average achieved in this project (in green dots). Phase 4 is excluded. The total lead times were improved with every product, despite the long waiting times in phase 3. The first and sixth products were slower than the average in the project, but below the benchmark. The 5th product was nearly at par with the benchmark average, but slightly better. The second product was average, and the third and fourth products were faster than average, with the best overall lead times.

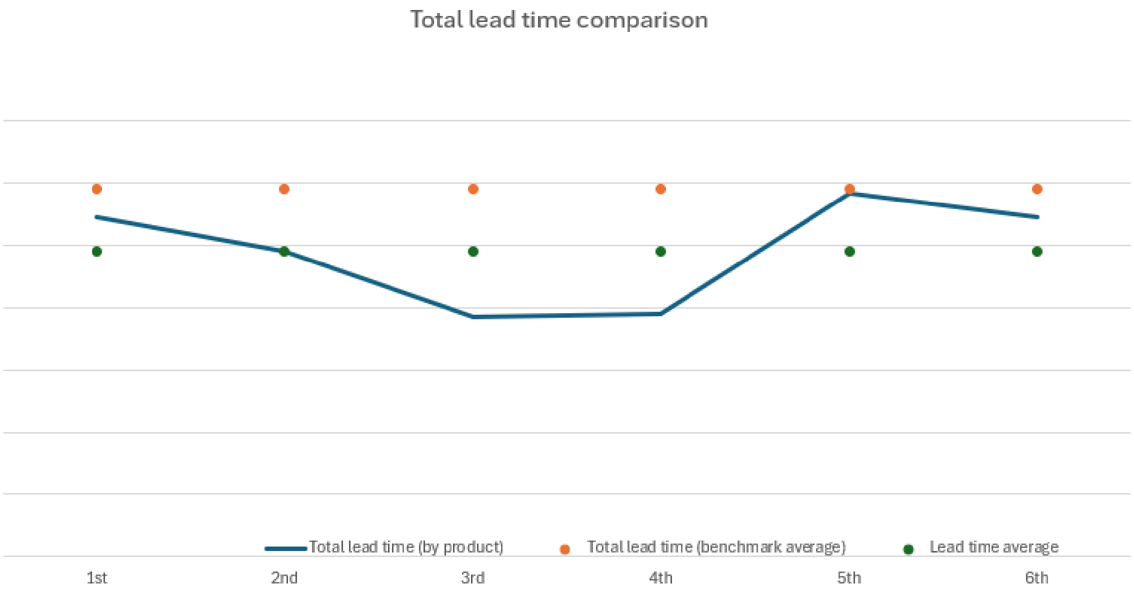


Figure 12. Total lead times by product (phase 4 excluded).

The targets of this thesis were firstly to stabilize phase 2 lead times to 77,14%, and secondly to reduce the total lead time by 17,58%. The VSM later revealed that there were other phases with potential for improvement. The first goal was achieved, and the lead times were stabilized at about 51-63% when the outlier, product six, is unaccounted for. Dependability has been achieved. As previously mentioned, dependability allows for GP to plan phase 4 sooner, which will reduce phase 3 lead times as a consequence. This will result in an improved flow, reducing total lead time further. The second goal of reducing the total lead time by 17,58% was nearly achieved, with an average of 17,16% overall reduction.

4.5.2 Quality comparison

The underlying assumption of the improvement plan was that quality had been stabilized, so that dependability could be pursued next, according to the sandcone model (Rezaei & Behnamian, 2021). This subchapter compares quality performance indicators from this project to those of the two previous ones to determine whether this remains the case. Below, in Figure 13, is the comparison of notification amounts.

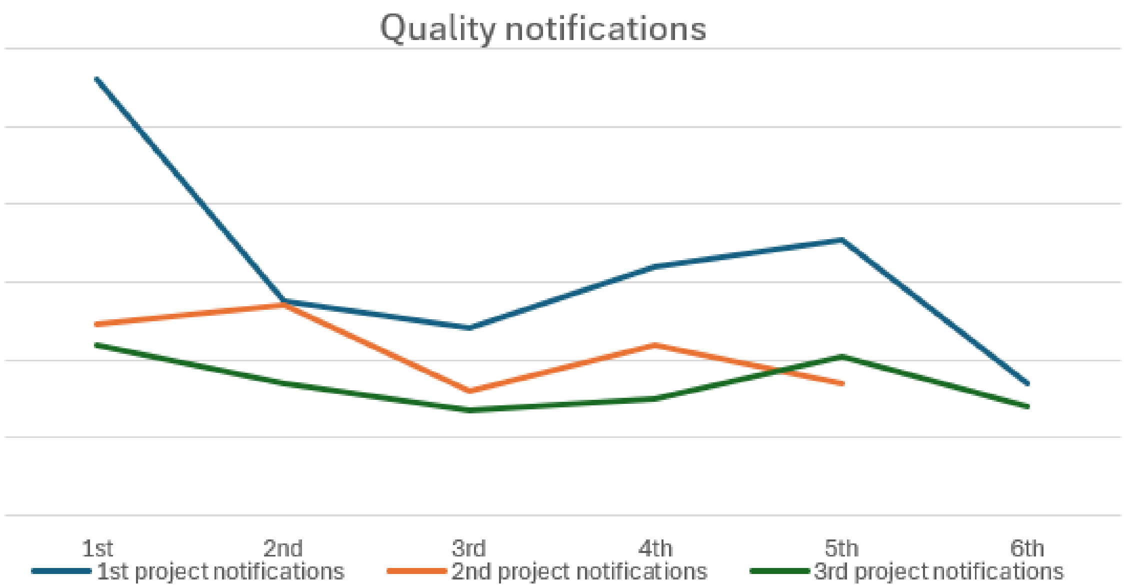


Figure 13. Comparison of quality notifications.

In Figure 13, the third project with a green trendline is the project researched in this thesis. The second project, in orange, is the benchmark project, against which lead times were compared, and the first one, in blue, is the one preceding it. Figure 13 supports the claim that quality was stabilized in the second project. The third project is slightly better still, but not significantly. Both have almost flat trendlines. The trends in each project are downward, with early products in the project having higher amounts than the later ones. Below, in Figure 14, is the comparison of quality deviations.

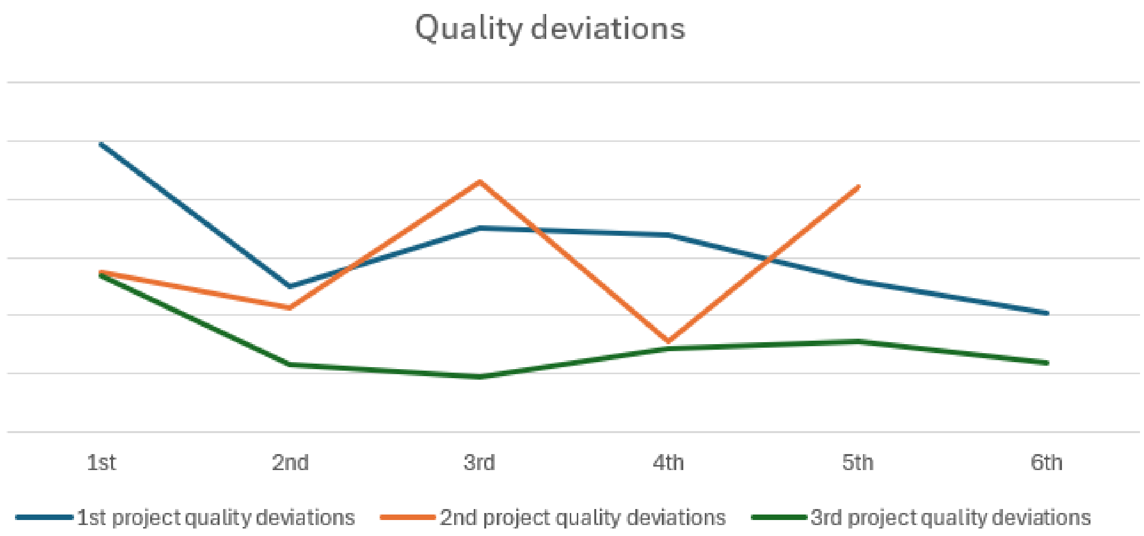


Figure 14. Comparison of quality deviations.

Figure 14 further strengthens the claims made in this thesis. Previously, this trend chart was not unambiguous, because the second project's third and fifth products had higher amounts of deviations than the first project. The third project decreases to an even lower level, evening out the trendline, confirming the assumptions made previously. Both projects 1 and 3 show similar trends compared to the notification amounts in Figure 13, suggesting that the second project's quality deviation amounts in its third and fifth products were an anomaly in the data.

Both performance indicators in Figures 13 and 14 show decreasing amounts of quality issues. Both are at lower levels than previous projects, with little variance. Other assumptions made in this research were that better quality would result in better lead times in phases 1, 2, and 5. All of the lead times of those phases were improved, further validating claims made. Phase 2 improved even further than targeted. Overall deviations, part responsible for the results so far, are explored in the next subchapter below.

4.5.3 Deviations

This subchapter exhibits deviations by project, deviations by product in this project, and the distribution of deviations by type. These numbers are expected to follow similar trends to the quality indicators. Quality deviations were already explored above. The assumption is that deviation numbers should affect lead times, as each deviation marks an obstacle to flow. Below, in Figure 15, are the deviation numbers by project.

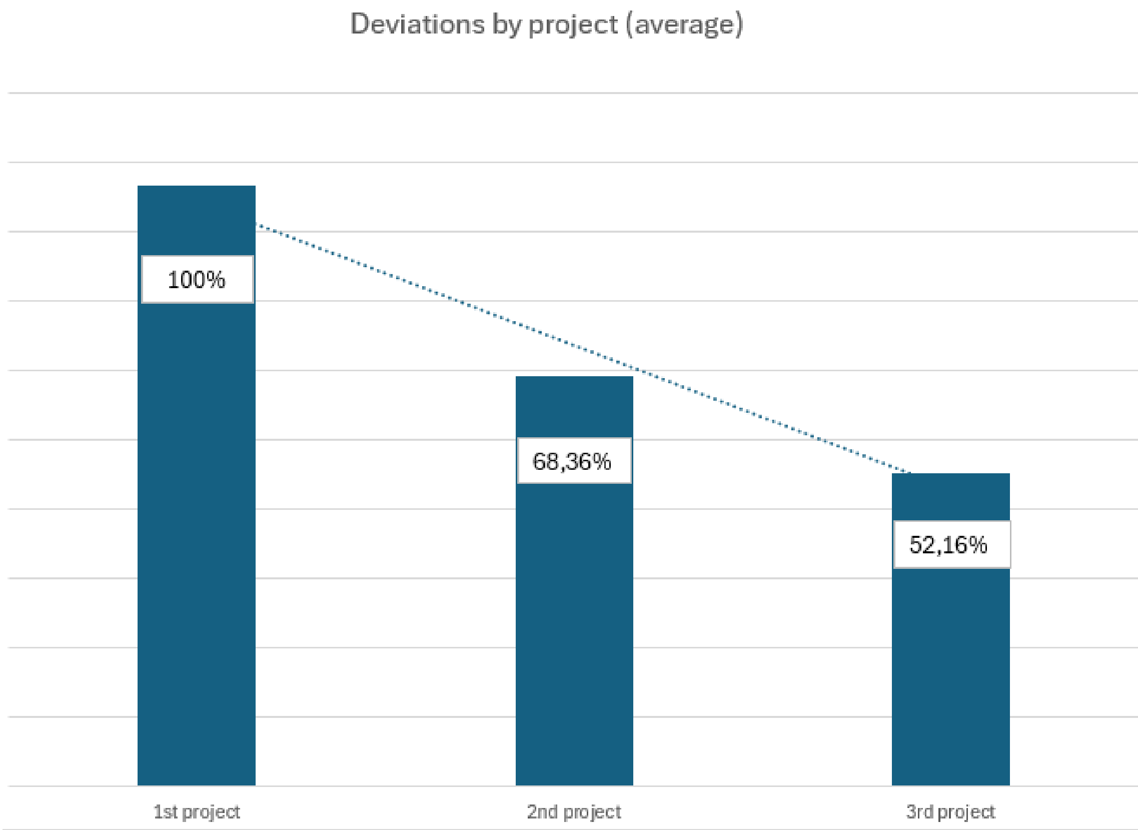


Figure 15. Deviation column chart with trend by project.

Figure 15 lists the deviation amounts in columns and includes a trendline for project-by-project comparison, in the same order as previously established with the quality indicators. The first project is the oldest, third is the main subject to research in this thesis. As expected, deviation numbers are in decline, similar to the quality indicators. The second project saw a decrease of 31,64% in deviation numbers, and the third project decreased to 47,84% from the first project. That translates to a 16,20% decrease from the second project. This, in part, contributes to the decrease in lead times as fewer and fewer obstacles to flow arise. Below, in Figure 16, is the deviation distribution by product in the current project.

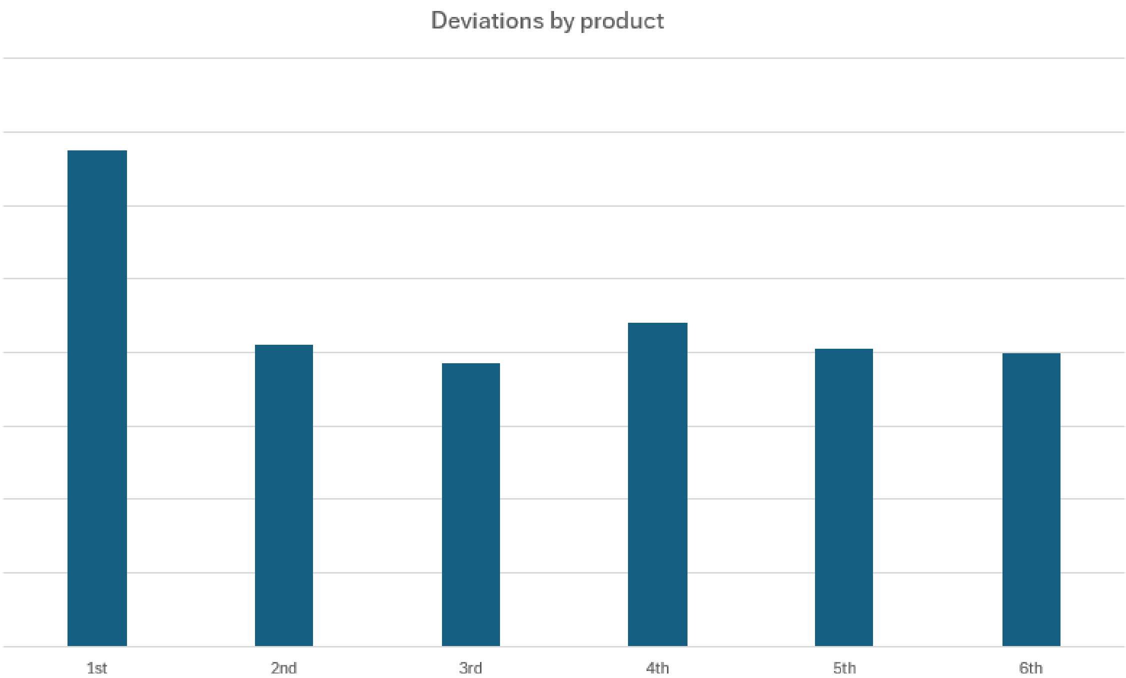


Figure 16. Deviation distribution by product.

Figure 16 above showcases a relatively even distribution of deviations in this project, with one exception in the first product. The first products tend to have more obstacles, as the quality indicators also imply. They, in most cases, have higher amounts of quality notifications, quality deviations, and deviations overall. This could be because they face challenges that can be removed or fixed for the later products in the project. Whether it correlates with the lead times directly can be seen in the coming subchapters that explore lead times in a more detailed manner per product. The project's deviation type distributions are explored first in Figure 17 below, however.

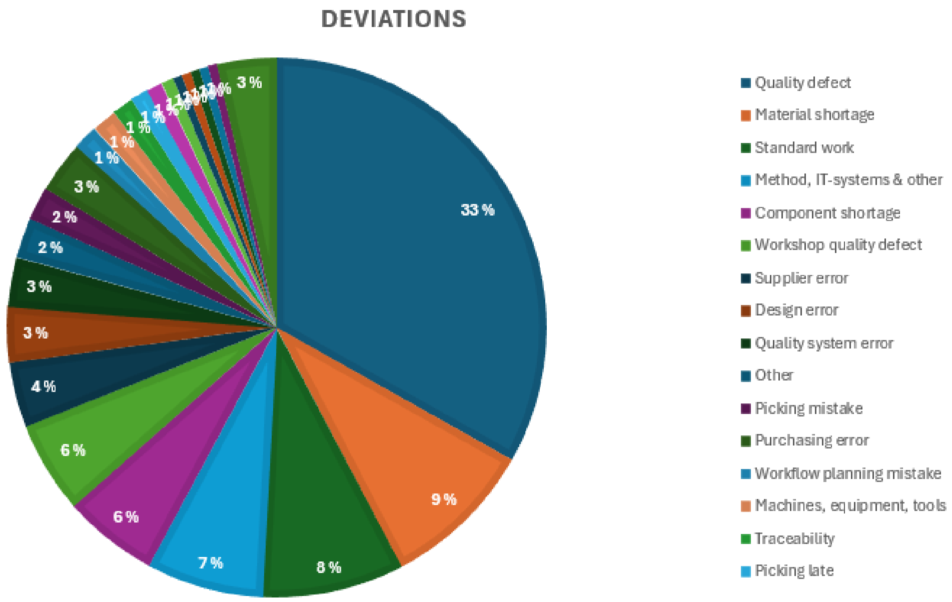


Figure 17. Deviation type distribution.

Figure 17 above showcases different deviation types and their share of the overall amount in this project. The biggest share of deviations is caused by quality defects, 33%. Even as their numbers have reduced, they still cause the most disturbances. This would suggest that quality overall should improve further with the coming projects. It also implies that there were few other deviations. They are much more evenly spread across different types. Material shortage is the second largest type, but with a much smaller share of 9%. Standard work with 8% means that the deviation was redundant. Method deviations, with a 7% share, range from instructions to ways of working. Component shortage with 6% could be calculated in the same category as material shortage, as it means that material is missing. Material in this category is more insignificant, for example, screws and washers. Together they form a 15% share, forming the second largest block.

4.5.4 First product

The first product's lead times are listed in Figure 18 below. As previously found, this product had the most notifications and deviations in this project. The "workflow mapping" chapter already showed the first and second phases. Phase 1 has potential for better results if PP can manage the flow into the factory more in line with JIT practices. Phase 2 was the best result of the project (with the second product). It could have been a better result, but the product was left unattended for 4,12% of the time. Those results in phase 2 came partly because this product had approximately 10-12 assemblers working. Phase 3 was increased to over 360%, together with phase 4 forming a major bottleneck. Phase 5 reached the targets set in the "to be" state. The expectation that notification and deviation amounts (within this project) would affect lead times did not happen. The amounts did not directly affect lead times in this case. On a larger scale, it does seem to correlate, however. The assumption that better quality (between projects) would affect phases 1, 2, and 5 does correlate with this product. If PP had planned the transportation later, all phases 1, 2, and 5 would have met the targets. Despite the improvements and the best phase 2 lead time, this product was over the average lead time overall, as Figure 12 visualized.

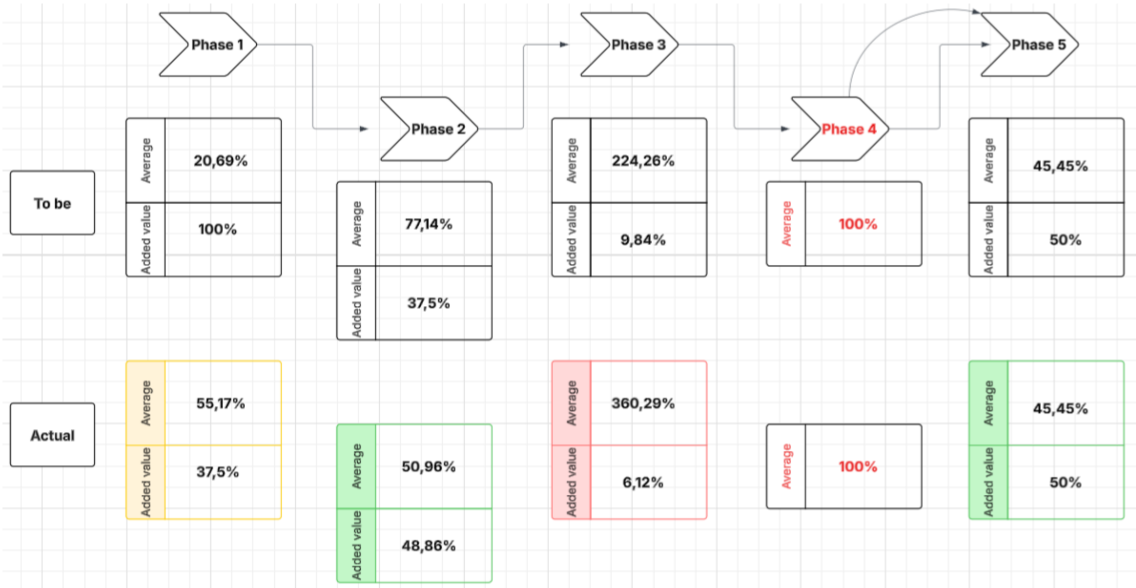


Figure 18. The first product's lead times (revised).

4.5.5 Second product

The second product's lead times are listed in Figure 19 below. The lead times of phases 1 and 2 are identical to the first product. PP should plan phase 1 in line with JIT practices to improve the flow. Phase 2 was achieved with approximately 4-6 assemblers on average. Either better deviation and notification numbers sped up this phase to the same level as the first one, or fewer assemblers per product are required to achieve these results. Many other variables cannot be taken into consideration here, such as assembly team competencies or individual performances. The swimlane recommends 6+3 assemblers for optimal flow. Phases 3 and 4 again form a major bottleneck with the lead time increased to 338,24%. Phase 5 exceeded the target and reached the best result of the project with 39,77% lead time. This product resulted in an average overall lead time, visualized in Figure 12.

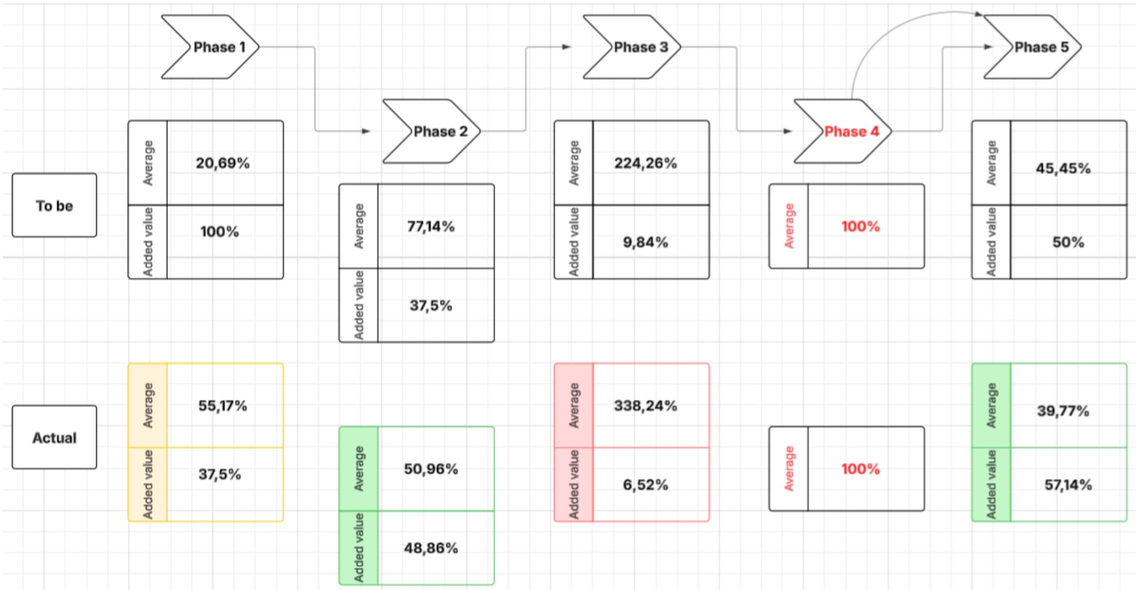


Figure 19. The second product's lead times.

4.5.6 Third product

Below in Figure 20 are the lead times of the third product. This product reached the target of phase 1. The phase was eliminated and merged with phase 2. They are listed as separate phases for easier comparison. The Phase 2 target was also met. However, it was almost 10% slower than the two previous products. Some reasons as to why that is include the inexperience of the assembly team with this product type, as well as piloting the assembly in a new assembly area, which resulted in obstacles. This product had approximately 10-12 assemblers allocated to it, as the first product. Phase 3 was considerably faster than the previous ones, with a lead time of 161,76%. It was still a major bottleneck. Phase 5 was improved to 62,50%, but did not reach the target of 45,45%. These lead times resulted in the best overall lead time, visualized in Figure 12.

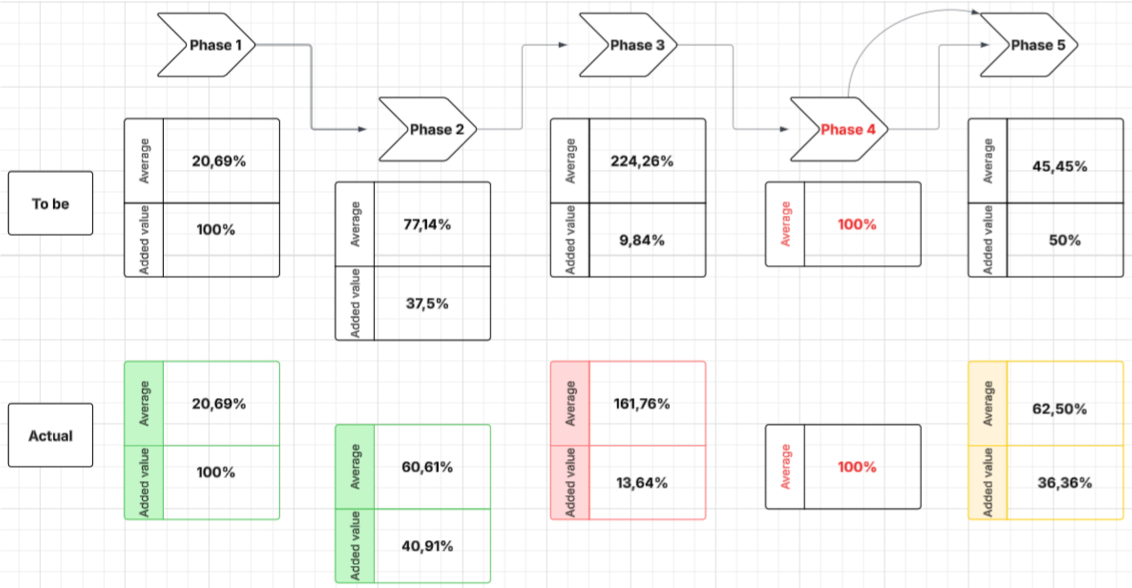


Figure 20. The third product's lead times.

4.5.7 Fourth product

Figure 21 below shows the fourth product's lead times. This product was the only one in the project that could improve the phase 3 lead time from the benchmark average. Phase 1 was merged with phase 2, and both resulted in successes. Targets were achieved with all of the first three phases. This was manufactured by an assembly team with no previous experience with these product types. Approximately 4-6 assemblers were allocated for this product. Phase 2 was slightly higher than the fifth product, which is directly comparable. The fifth product's result was 59,23% compared to this one's 63,36%. Deviating from the rest of the project, the fifth phase was not an improvement, with a result of 147,73%. This was due to quality issues and the subcontractor's inability to receive the product. This product achieved faster-than-average overall lead time, along with the third product. This is visualised in Figure 12.

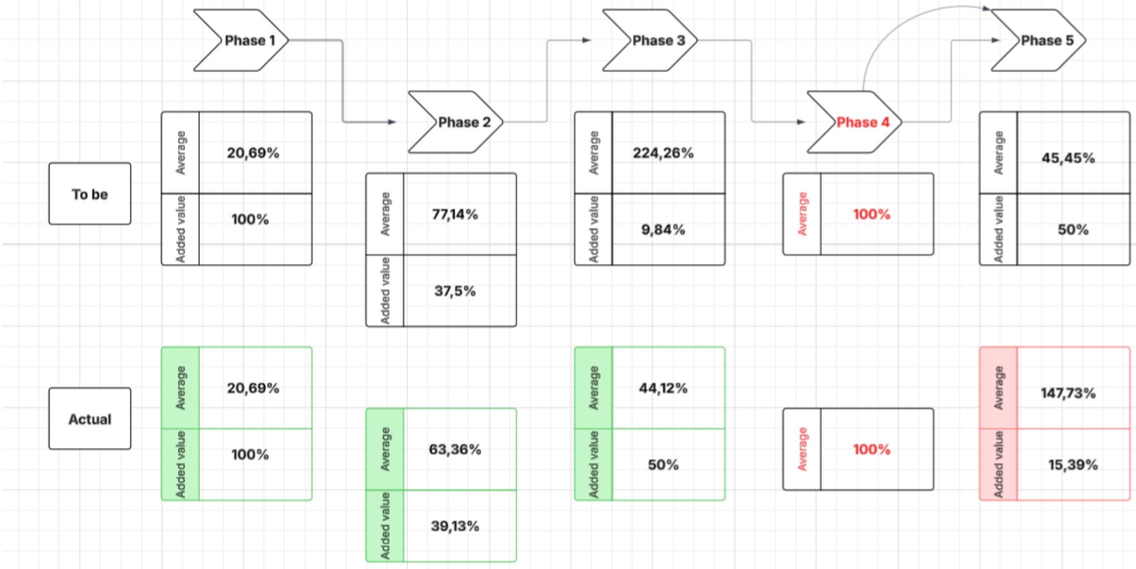


Figure 21. The fourth product's lead times.

4.5.8 Fifth product

Figure 22, below, shows the lead times of the fifth product. This product's phase lead times follow the same pattern as most others. Phases 1, 2, and 5 were improved while phases 3 and 4 formed a bottleneck. As with the previous products, phase 1 was merged with phase 2, achieving the targets. Phase 2 was improved further, to 59,23%. There were approximately 4-6 assemblers allocated to this product. Phase 3 was the worst result of the project, with a result of 463,24%. Phase 5 suffered from quality issues, resulting in an improved result of 62,5%, but missing the target of 45,45%. These lead times resulted in the worst overall lead time of the project, visualized in Figure 12.

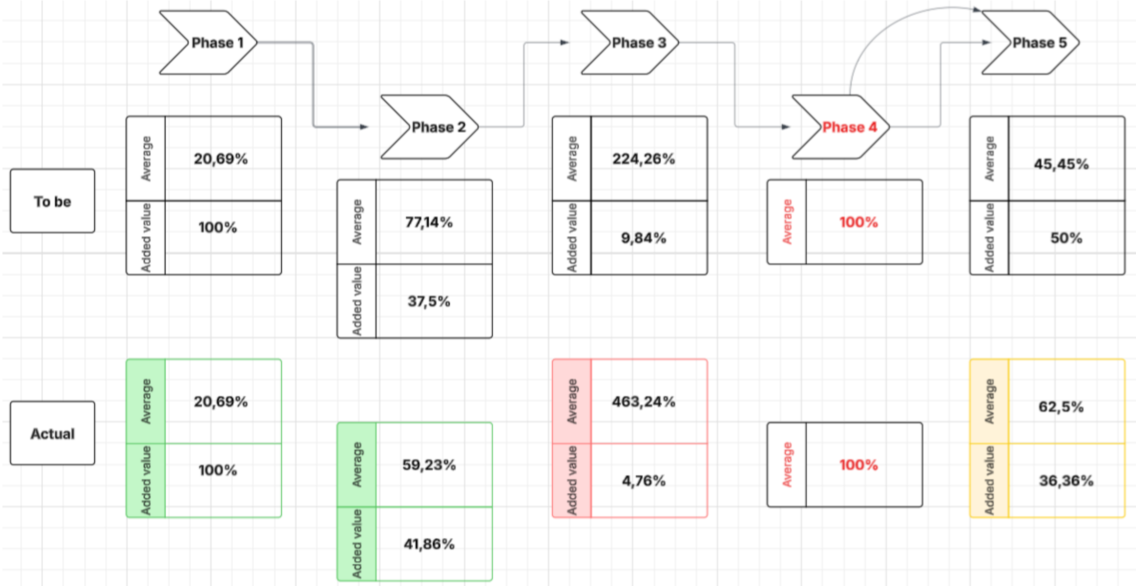


Figure 22. The fifth product's lead times.

4.5.9 Sixth product

The sixth product's lead times are displayed in Figure 23 below. This product is an outlier in the project, as it was set on low priority. Phase 1 was merged into phase 2, as with the previous ones, resulting in achieving the set target. Differing from the other products, phase 2 was increased from the benchmark project average by 4,68% as the only product in the project. The product was allocated to approximately 1-3 assemblers, which explains this result. Phase 3 was a bottleneck, as with the other products in the project. Phase 5 was improved to 68,18%, but was disturbed by quality issues. These lead times resulted in worse-than-average overall lead time, visualized in Figure 12. Even with the low resources and priority circumstances, this product was not the slowest overall, but the third slowest or fastest. This highlights the importance of the planning phase 4.

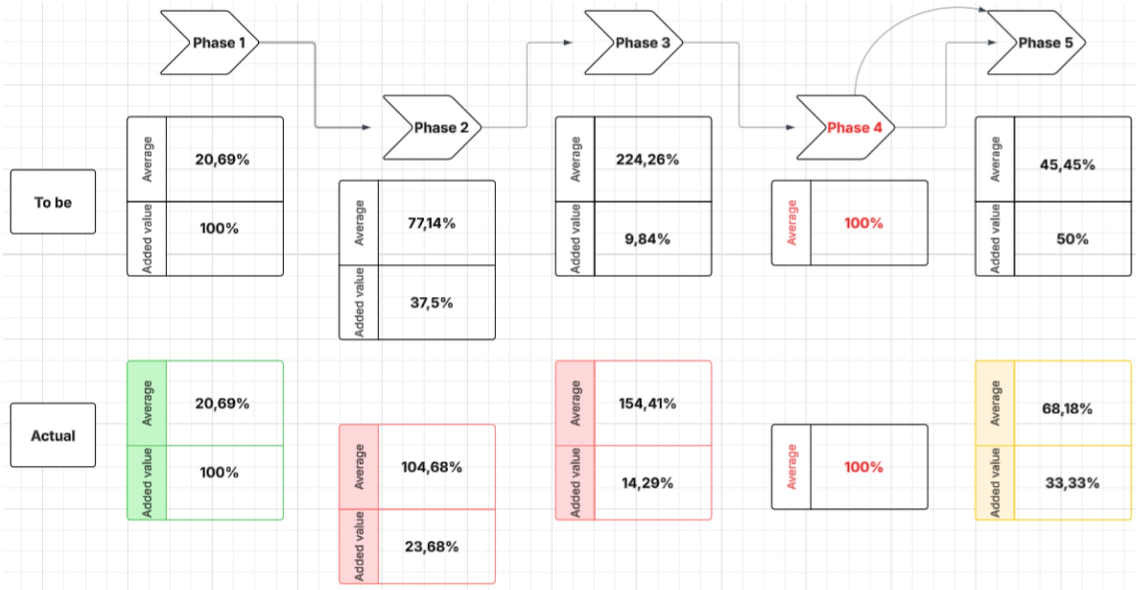


Figure 23. The sixth product's lead times.

4.5.10 Overview

Phase 1 lead times were improved to optimal states with four out of six products. In the future, PP ought to uphold this practice for all products to reach the best flow efficiency. Phase 2 achieved dependability, one of the targets of this thesis. The results exceeded expectations and the target "to be" state. Best lead times in this phase were a result of approximately 4-6 mechanical assemblers on the second product, and 10-12 assemblers on the first product. This suggests that 4-6 assemblers are as efficient as 10-12, but further research needs to be conducted to verify this claim. Resource allocation remains inconclusive, as there are a multitude of other factors to consider. The worst result came with 1-3 mechanical assemblers. Deviation and notification amounts were found to correlate with lead times on a larger scale (project by project), but not in every case (product by product). The first product achieved one of the best lead times on phase 2, even with a larger number of deviations and notifications. On average, the lead times of phases 1 and 2 were fast, but overall lead times were not improved as much because phase 3 formed a significant bottleneck. Phase 4 needs to be planned by GP earlier to result in further lead time reductions. The best overall lead times in this project resulted from the third and fourth products, which had the third fastest and the fastest lead times in phase 3. The sixth product, which was slow in the first phases, resulted in a tied third place on overall lead time. These instances highlight the importance of phase 3 and 4 planning for more optimal flow. Now that dependability has been achieved, that can be done. Phase 5 was affected by quality issues for three out of six products. Improvements were made, but better results are achievable. This phase has potential for further improvements and will directly affect the overall lead time.

4.6 Interviews

The fifth approach, semi-structured interviews, a qualitative method, was set up near the end of the project. These results would not affect the lead time of this particular project directly, but would yield results for further improvements for the next projects. The purpose of the interviews was to gather feedback, map out obstacles, and receive improvement suggestions. Other informal conversations are included in this chapter as well.

4.6.1 Background and interview questions

The interviews were arranged in a meeting room in person. First, results were displayed, deviations skimmed over, and personal observations discussed to ease the recall of events and establish a baseline. The questions covered four different subject areas: information flow, the project itself, swimlane, and workflow management. Each subject area included three to eight questions. Some questions could be answered with a grade from 1-5. 1 representing "very bad", 2 "bad", 3 "OK", 4 "good", and 5 "very good". Other questions were less formal, with a chance to answer freely. The answers were summarized in an interview file. The results were analyzed by looking at the average scores, and thematic analysis was carried out for the free-form questions. Below, in Table 7, are the interview questions:

Table 7. Interview subjects and questions.

Subject:	**Information flow**

Question 1:	How would you rate MS Teams as a channel for communication? 1-5
Question 2:	Should communications via MS Teams be continued? Yes/No
Question 3:	How many team members use MS Teams?
Question 4:	How would you rate the twice-a-week meeting on the factory floor? 1-5
Question 5:	How many times a week should the meeting take place? 1x-5x
Question 6:	Should it contain more or less of some specific content?
Question 7:	Were communications successful in this project? 1-5
Question 8:	How can the flow of information be improved?
Subject:	**Project**
Question 9:	How well did the project succeed? 1-5
Question 10:	What were the biggest obstacles during phases 1 & 2?
Question 11:	How about phases 3, 4, and 5?
Question 12:	How can these be improved?
Subject:	**Swimlane**
Question 13:	How well did the tool help the team in workflow planning? 1-5
Question 14:	Were the targets realistic?
Question 15:	Was the resource allocation sensible per activity?
Question 16:	Other comments about the swimlane?
Subject:	**Workflow management**

Question 17:	Should something be reorganized in the workflow?
Question 18:	Should something be added or removed from the workflow?

4.6.2 Interview results

The first interview was set up on 8.7.2025 with the team coordinator of the third product. The second interview, with the team coordinator of the fourth product, was set up on 22.7.2025. The third interview was arranged on 29.7.2025 with the team coordinator of the second and fifth products. The fourth interview was arranged on 5.8.2025 with the team coordinator of the first product. The fifth and final interview was set up on 21.8.2025 with the electrical team coordinator. Below, in Table 8, are the grades received from them.

Table 8. Interview grades.

Subject:	**Information flow**	**Answer:**
Question 1:	How would you rate MS Teams as a channel for communication? 1-5	3,60 (3-4-4-3-4)
Question 2:	Should communications via MS Teams be continued? Yes/No	Yes (Yes-Yes-Yes-Yes-Yes)
Question 3:	How many team members use MS Teams?	40,42% (35,71%-60%-18,18%-18,18%-70%)
Question 4:	How would you rate the twice-a-week meeting on the factory floor? 1-5	3,60 (5-4-1-4-4)

Question 5:	How many times a week should the meeting take place? 1x-5x	2,10 times (2,5-2-2-2-2)
Question 7:	Were communications successful in this project? 1-5	4,00 (4-3-5-4-4)
Subject:	**Project**	
Question 9:	How well did the project succeed? 1-5	4,40 (4-4-5-5-4)
Subject:	**Swimlane**	
Question 13:	How well did the tool help the team in workflow planning? 1-5	2,33 (1-2-4)

Microsoft Teams was rated at 3,60. Two respondents rated it as "OK", and three as "good". The respondents unanimously wanted it to remain a tool for communications. Furthermore, 40,42% of team members on average were estimated to use the software. This result varied from 18,18% to 70% across teams, which is a high range of variation. All teams had members who used the software. The twice-a-week meeting on the factory floor received a grade of 3,60. Same as the Teams channel. While most respondents rated this practice from "good" to "very good", one deemed it to be "very bad". However, all respondents agreed that two times a week is a good frequency, with an average score of 2,10 times a week. One respondent suggested that it could be arranged 2-3 times a week, which is listed as 2,5 in this score system. Communication in this project was rated better than the previously mentioned tools, as "good" with a grade of 4,00. One rated it as "OK", while others as "good" or "very good". The project as a whole was rated a success, with a grade of 4,40. Swimlane, however, was not very highly appreciated. It received an average score of 2,33, which is nearing a "bad" grade. Only one respondent thought positively about it with a score of 4. These results are analyzed further below.

Thematic analysis (TA) conducted for the free-form questions is based on Braun and Clarke's (2022) book "Thematic analysis: a practical guide". According to them, TA is a qualitative research method to develop, analyze, and interpret patterns in a dataset. Their process is divided into six phases. First step is to familiarize oneself with the data, second is to "code" the data, third is theme generation, fourth is theme development and review, fifth is refining those themes, and sixth is writing up. They emphasize that there are different ways to approach TA, and it requires the researcher to take an active role in making choices about the method and theory. Below are the results.

The analysis began by composing, reading, and re-reading the answers to familiarize with the data. It was then coded into segments, and those segments were compiled under similar themes. The fourth and fifth steps of the above guide were somewhat similar. The created themes were tested against the questions of "what do these themes say?", and "how do these communicate answers to the interview questions, and the research?". They were then compiled into Figure 24 below.

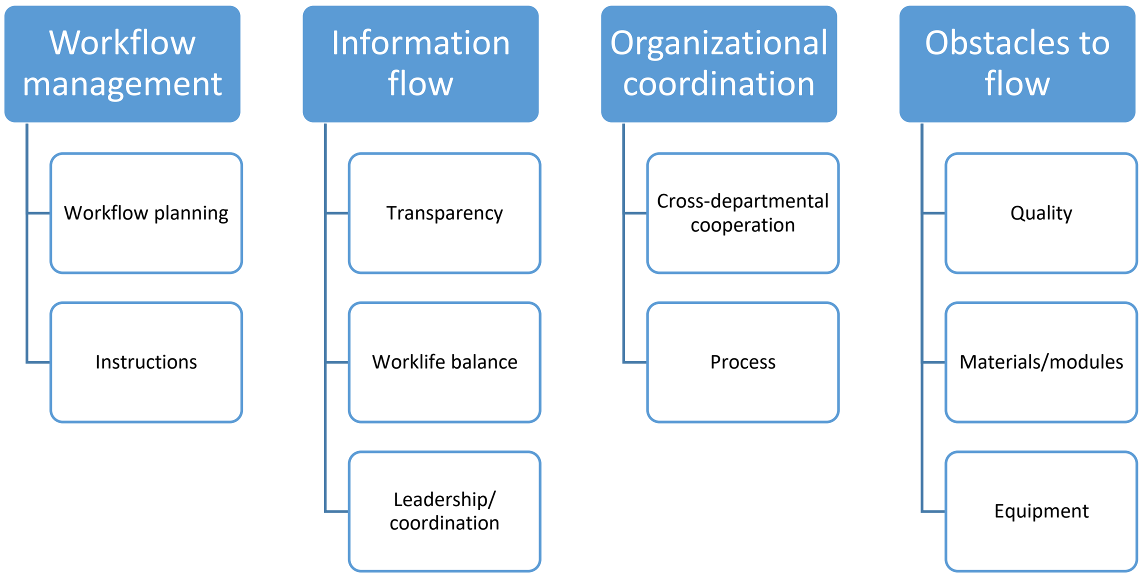


Figure 24. Themes and codes identified from the interviews.

Figure 24 illustrates the themes and codes identified from the interview data. The top rows in blue represent the themes, and below them are the segments or "codes". The themes follow similar areas to the subjects and the questions in the interview. They represent headlines for the received answers. The codes, or segments, are the parts of the answers that answer the interview and research questions.

The workflow management theme contains the segments of workflow planning and instructions. In workflow planning, the need for taking electrical work better into consideration was highlighted repeatedly. It was also seen as something that obstructed the flow in phases 1 and 2. Simplifying instructions would further support the smoother workflow, with less time spent on planning.

The information flow theme contains the segments of transparency, leadership/coordination, and worklife balance. Communications were deemed good (rated 4,00) during this project, even though the tools (MS Teams/factory floor meetings) were rated slightly worse (both rated 3,60). The other means were appreciated too, and presence on the factory floor was separately mentioned as a good way of improving communications. The twice-a-week meeting on the factory floor was criticized for upsetting worklife balance. It was suggested to be moved earlier to prevent it from overlapping with breaks. Leadership and coordination were requested by assigning tasks, upholding progress control, and ensuring resources at the meeting. Other means of improving transparency were suggested through repeating information in all channels, and informing more about potential obstacles.

The organizational coordination theme includes cross-departmental cooperation and process segments. Cross-departmental cooperation was named as the phases 3, 4, and 5 biggest obstacles and improvement areas repeatedly. The product is handed from one department to another twice during these phases. The work, however, often spills back to the previous or upcoming departments. Clear roles and responsibilities should be upheld, as should the possibility for flexible cooperation. Upholding processes was suggested, which could help with clear handovers.

The final theme, obstacles to flow, relates to the segments of quality, materials/modules, and equipment. Even though quality possessed the largest share of deviations (33%), missing materials and modules were seen as a more limiting factor to phase 1 and 2 flow. One answer added that equipment was a limiting factor in those phases. Quality was deemed limiting in the later phases of 3, 4, and 5.

4.6.3 Other personal communications

One interview resulted in a sequel to be arranged. The sequel included the majority of an assembly team to assess the swimlane files' activity durations and resource allocations. The file was estimated activity by activity, and the team gave their opinions on whether the estimates were realistic. It was then reviewed by another assembly team, who agreed with minor changes. A consensus was reached for the estimates. The consensus, along with personal observations, was the foundation for the "added value" columns in the VSM for phases 1, 2, and 3. The Phase 5 estimate was based on a personal conversation with the supervisor of the phase department, as well as personal observations. The times were used to build a new swimlane file with more accurate estimates. It can also be used for attempting to standardize the assembly work and to produce more accurate performance indicators for the company's Power BI reports.

5 Conclusions and recommendations

This research set out to find methods to address lead time in a lean manufacturing environment. The research questions were formed as: "what are the bottlenecks in the process and how to identify them?", "How can the production methods be enhanced?", and "what are the lean tools to address lead time?". The objectives aimed to reflect this ambition by "analyzing the current lead time components", "by structuring the production processes into a more effective whole", and "by identifying areas of inefficiency and highlighting support needs". The research began by conducting a literature review on lean, its principles, values, methods, and tools, Wärtsilä's continuous improvement model, and process analysis and improvement frameworks.

A manufacturing project of six products was the subject of research and implementation of improvement methods identified from the literature. The research methods were formed to align with the research questions, objectives, and the manufacturing environment. A value stream map was formed, and an improvement plan was developed to achieve the targets set in the "to be" state. The improvement plan determined five main subjects to improve the manufacturing process. The first one was to improve the flow of information. The second one was to implement swimlane workflow mapping and target setting. The third one was "other methods" that upheld continuous improvement throughout the project. The fourth one was to gather and research data from the project. The fifth was to set up interviews.

The results achieved in this thesis were many. Overall lead time was reduced by 17,16% from the benchmark project, nearing the target of 17,58%. Phase 2 lead times were stabilized below the target of 77,14%, to an average of 64,97% of the benchmark lead time. Information flow was improved, workflow mapping revealed multiple improvement areas, data was gathered and researched, and the interviews identified four improvement themes and many suggestions.

The literature reviewed provided valuable insights and aligned with the research results and project observations. The lean part primed the work well, leading to a deeper understanding of the concept, manufacturing environment, and provided essential tools, such as the value stream map framework. It also led to the "this is lean" and WCI chapters, where other key observations were provided, such as the concept of flow efficiency and the sandcone theory. Process analysis and improvement methods further strengthened the research with lean-aligned tools, the TOC, and the swimlane diagram. The swimlane diagram proved useful as a process improvement tool, and the TOC theory was validated with the findings from the research. Even with fast lead times in other phases, the overall lead time was dictated by the constraint, phase 4.

Research questions were answered, objectives fulfilled, and tangible results delivered. The recommendations for future projects are to align the flow through the factory with JIT principles, flow efficiency, and maximizing throughput. Phase 1 lead times can be either entirely removed or limited to a period where value can be added 100% of the time. According to the sandcone theory, speed can be pursued next, now that dependability has been achieved in phase 2. Phase 2 lead times have potential for further reduction. This is achievable by upholding the ways of working that were perceived as beneficial in this research, developing them further on the basis of the research findings, removing the main obstacles to flow, and continuing to seek ways to improve. According to the TOC principles, the flow should be planned according to the bottlenecks' capacity. Phase 4 was identified as the main bottleneck in this study. According to the principle, phase 4 capacity should be exploited to the maximum, the flow subordinated to it, and its capacity elevated. By doing this, phase 3 lead times will also be improved as a consequence. Phase 5 lead times have further potential for improvement, as the phase lead time of the second product proved. According to WCI principles and the VSM process chart, repeating the improvement process is required next. The new "as is" state is the one attained in this research, and the new "to be" state can be achieved by abiding by the recommendations listed above. Below, in Figure 25, are the new "as is" and "to be" states.

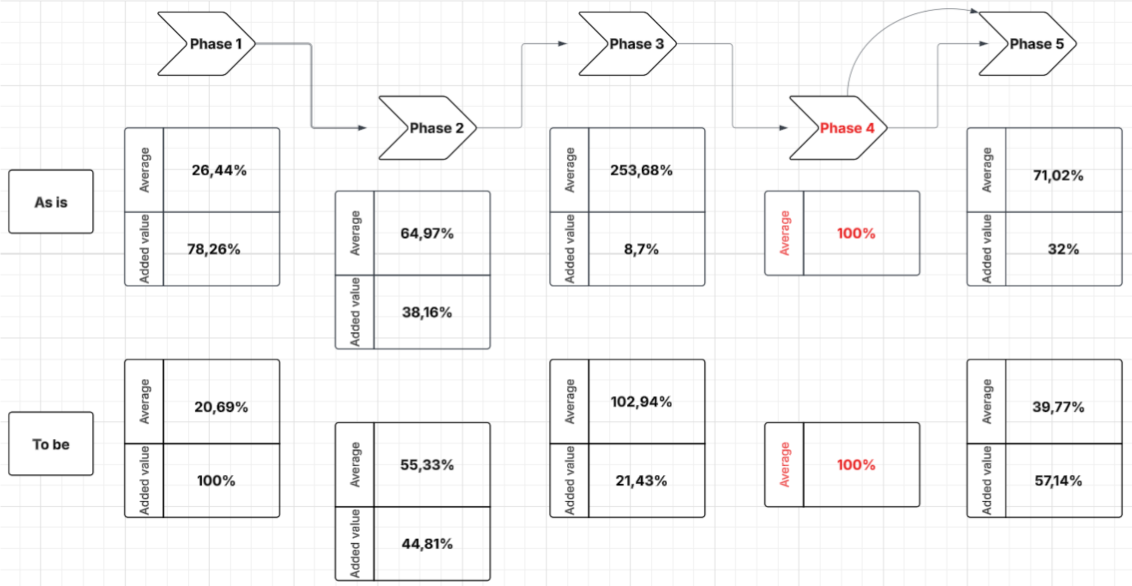


Figure 25. The new "as is" and "to be" states.

Figure 25 represents the recommendations outlined above. The new "as is" state on the top row is the one achieved in this project, and the "to be" state on the bottom row is the new target. The lead times are compared against the same "benchmark project". The Phase 1 target has not changed from the original one. It can be maximized to 100% added value. Phase 2 is reduced to 55,33% of the benchmark project. This would increase the added value to 44,81%. These phase 1 and 2 lead times would represent the 8% potential improvements identified in the workflow mapping chapter. By planning phase 4 to align with the attained "as is" state (as there are no guarantees that lead times can be further reduced), the average lead time can return to a similar level as the benchmark project, with an average lead time of 102,94%, restoring added value to 21,43%. Phase 5 can be attempted to match the new benchmark set by the second product in this project, reducing the phase lead time to 39,77%, increasing added value to 57,14%. All phases have a security buffer built in so that there is room for variability. As seen in this project, the phase lead times can vary significantly from each other. By delivering these results, the total overall lead time can be reduced by 45,76% from the original benchmark project. This would exceed the original target of reducing overall lead time by 40%, and exceed the result of 17,16% reached in this project.

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