Increase Space utilization and production capacity through process flow analysis

- A case study of NIBE AB

Master thesis in Supply Chain Management and Quality and Operations Management

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Abstract

NIBE is a global provider of sustainable climate solutions. The strategy for the company is to increase the revenue by 20 % annually, both by acquisitions and organic growth. Their product range includes various energy efficient climate solution such as water heaters, elements, and stoves. This thesis is focused on one of their product families within the water heater segment, *Compact*, at one of their facilities in Markraryd.

Due to their philosophy to cover as large share of the market as possible, the company produces a vast variety of products and components leading to an increased complexity of the production. And their high expansion rate causes problems since they experience that they need to utilize the available factory space more efficiently. As of today the production system is characterized by a push-based approach, leading to inventory build ups that covers valuable factory space that could have been used to increase the current production capacity. This thesis therefore mainly focus on the enhancement of space utilization and increase in capacity by providing suggestions and recommendations regarding reduction of inventories and work in progress (WIP) for the production flow of the *Compact* product family. To gain an overview of the production flow, value stream mapping was used as a tool. In order to understand the processes and where potential problems arise, the conducted current state map was analyzed and several improvement suggestions such as CONstant work in process (CONWIP) loops and supermarkets have been recommended. With all improvement suggestions considered, a future state map was developed. This map visualized how the suggestions could lead to a reduction of inventories due to a more pull-based approach, hence increase the throughput according to Little's Law.

As can be seen in the future state map in section 7.3 the average waiting time is reduced, thereby both the space utilization and production capacity is believed to be increased. Although, it should be noted that it is needed to take a long-term strategic approach in order to evaluate which improvements that are feasible, and in which extent they are effecting the production flow. Crucial in order to achieve this is the communication between the different departments, as well as striving to continuously improve the flow further.

Keywords: Value stream mapping, inventory reduction, space utilization, capacity, CONWIP, push and pull production

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1
Introduction

The following master thesis is conducted on behalf of NIBE AB and in collaboration with AFRY AB. AFRY AB is a consultancy firm with many areas of expertise. In this project, the department of production and logistics has been involved and provided valuable insights and guidance. In the following section the background of the research is covered as well as the problem statement that initiated the research, the aim of the thesis, and delimitations.

1.1 Background

NIBE Industrier AB is a global group that operates within the energy and heating industry. The group is divided into three different business areas - Climate Solutions, Element and Stoves - and produces and develops a wide range of energy efficient climate solutions. From the beginning the company has been driven by a strong culture of entrepreneurship and responsible business operations with a strong focus on growth and the strive to grow has lead to investments in product development and acquisitions. Combined these factors have generated a turnover of over 25 billion SEK in 2019 and the goal is to reach 40 billion SEK by 2025 (NIBE, 2020). To reach this goal NIBE are planning to double their production capacity in Markaryd, both by increasing the efficiency of the current production but also through expansion.

NIBE's long-term strategy is to produce world-class energy solutions that contribute to a sustainable society. To reach this strategy they have four strategic focus areas; growth with profitability, innovation, market oriented expansion, and long-term approach (NIBE, 2020). These strategic focus areas lead to a production that constantly has to face an increased demand, as well as a need to be able to produce innovative new products. This creates a demand for both higher volumes and an increased variety of products. According to Lewis and Slack (2017) higher volumes and increased variety often result in increased production costs due to the increased need for flexibility.

To achieve profitable growth, NIBE has an average growth target of 20 percent annually. To achieve this, they strive to have a 10 percent organic growth and 10 percent growth through acquisition. The organic growth is done by continuous development of new products and regular product releases. To be able to develop and produce new products there is a continuous development of current operations and a high investment rate. Moreover, NIBE emphasizes an effective production and joint purchasing of material for all companies within the NIBE group (NIBE, 2020). According to NIBE, an effective production is built around the idea that everything can be improved and that operations that are not measured cannot be improved. Time-measurements is therefore a commonly used tool to create correct calculations and production plans as well as sound investment plans. The measurements also lay ground for NIBE's performance-based salary system, where employees get payed based on the amount of products they produce.

According to production managers at NIBE, the performance-based salary system leads to operators wanting to produce as much as possible, thereby creating a push flow where components are pushed to the next activity, creating buffers between activities. Another consequence caused by this salary system is that all the operators mainly look after their own personal benefits which ends up in that the production flow can be said to be divided into different silos. Within each silo each activity is planned in isolation without taking other activities into consideration, leading to either big buffers or shortage of material between activities. In the long run this leads to transpositions in the production plan, thereby they are producing products that are not demanded downstream the production flow. Further, the buffers between activities have increased the need for storage and has thereby taken valuable space in the factory that otherwise could have been used for production, harming the efficiency of the production.

An additional reason to the build up of buffers is due to the many different products being produced since there are several different product families, each one containing a number of different product variants. This entails that a large number of different products are in the production flow at the same time, hence creating a rather complex production system. Currently NIBE has no complete overview over the production systems, e.g. how long the lead-times are, what the bottlenecks are and where these are located, or how big the different buffers are. This indicates that NIBE lacks a system perspective over the production which makes it complicated to see how different improvements affect the whole production flow. Further, it makes it hard to know where to focus when investigating how to improve the production to meet the increasing production rate. According to Bellgran and Säfsten (2010), a system perspective is a holistic perspective that takes all the different parts of a production system into consideration and emphasise the the interplay between the different parts. Further, the authors explain that a system perspective is applicable when an organization wants to increase the understanding of a complex production system.

When evaluating an existing production system, a system perspective is important since a comprehensive view of the system is only accomplished if the entire system is evaluated (Bellgran & Säfsten, 2010). According to the authors, a process flow analysis explains feasible improvements of a production system. As stated earlier, NIBE lacks a complete overview of thei production systems and it was mentioned by a manager from the logistics department that they suffer from sub-optimization due to their tradition of using a functional layout in the water heater factory. To counteract that improvements are of local character, and instead take the whole system into consideration, value stream mapping is a commonly used tool (Rother & Shook, 2003). A value stream map (VSM) is a type of self-assessment tool, and is a visual representation of all the activities in the process - from material to information flow. By visualizing the whole flow it is possible to see how value is added and see the different sources of waste (Rother & Shook, 2003). Therefore, this tool seems suitable to use in order to increase their understanding of the existing production process, identify sources of waste, and suggest measures to eliminate these.

1.2 Problem statement

As a result of NIBE's goal to annually have a 10 percent organic growth the production constantly has to be able to scale up and increase the capacity. And, as previously mentioned, NIBE is planning to double the production volumes in their factories in Markaryd, both by increasing the efficiency of the current production but also through expansion. This has made NIBE realize that they need to analyze how they produce their products. As stated in section 1.1, NIBE lacks a complete overview over their production process in the water heater factory. They are therefore interested in evaluating these areas in order to get an overview over the production and get potential ways of removing waste and improving the production. Also, a more effective production can lead to sustainable benefits since a reduction of overproduction and inventories lead to reduced use of resources and therefore a more sustainable development of industry, innovation and infrastructure. This to be able to meet their objectives and achieve a cost-efficient and sustainable production.

1.3 Aim

The aim of this thesis is to investigate the chosen production flow for the *Compact* family and provide NIBE with an overview of all activities and suggestions regarding how to increase the capacity of the production. The company and its products are further described in section 3. To guide the thesis and make sure the aim is fulfilled the following research questions will be answered:

- **What is the current state for *Compact* water heater production process regarding capacity, bottlenecks and variation?**
- **What improvements can be made to cope with the identified improvement potentials in the current production flow?**

1.4 Delimitations

This master thesis project shall be finished within a time frame of 20 weeks, hence the scope of the project will be limited. The study will only focus on one of NIBE's product families, the *Compact* water heater family, and the production flow related to these products in the water heater factory. The decision to solely study the flow of one product family has been taken in consultation with NIBE since it is considered that the chosen products' flow are representative for NIBE's other products. The analysis and conclusions can therefore in a larger extent be looked upon as relevant for other parts of their production facilities as well.

2
Methods

This section contains information and explanation about the used research method, as well as a short description regarding how the value stream map was developed and how it was analysed.

Holme and Solvang (1997) illustrate methodologies to describe and solve problems in order to generate new knowledge. The authors express that what methodology to use depends on what type of information that is going to be examined. According to Williams (2007) quantitative and qualitative research methods consider the different claims to knowledge and are designed to address a specific type of research question. The author states that quantitative methods are aimed at providing an objective measure of the current state, while qualitative methods on the other hand are characterized by explore and better understand the complexity of a situation.

2.1 Quantitative research methods

Quantitative research methods include collection of data in order to be able to quantify information and be subject to statistical treatment (Creswell, 2003). These research methods often involve collection of numeric data and require mathematical models and tools to analyse the data. According to Williams (2007) quantitative research begins with a problem statement and the research should include formation of a hypothesis or research questions, a literature study, and a quantitative analysis of the collected data.

Leedy and Ormrod (2001) classify quantitative research methods into different classifications; experimental, casual comparative, and descriptive. When applying an experimental research method Leedy and Ormrod (2001) bring up three different types of exploratory approaches; pre-experimental, true experimental, and quasi experimental. The true experimental approach contains a systematic procedure to quantitative data collection involving mathematical models in the analysis, whereas the pre-experimental and quasi-experimental designs include study participants that are non-random respectively randomly selected. Because of this the validity of the results may be lower for the quasi-experimental method due to the limited control.

In a casual comparative research, the aim is to examine how independent variables are affected by dependent variables and therefore contains of relationships regarding cause and affect among the variables (Williams, 2007). This method allows the opportunity to examine the interaction between independent variables and how they influence dependent variables.

The authors describe descriptive research method as a basic method that examines the current situation and describe the as-is situation based on an observational basis, or the investigation of correlation between two or more appearances. And since the aim of this project is to examine one of NIBE's product flows one could argue that this is a suitable method to use when describing the as-is situation.

2.2 Qualitative research methods

Qualitative research methods build their premises on inductive reasoning rather than deductive reasoning (Williams, 2007). What initiates qualitative research involves determined use for explaining, describing, and interpreting the data that have been collected. According to Creswell (2003) qualitative research enables the researcher to develop a high level of detail due to the possibility to be highly involved in the actual experiences. This is one distinct difference compared to quantitative research where the researcher is outside of the situation investigated.

There are five different classifications of qualitative research; case studies, ethnography studies, phenomenological studies, grounded theory studies, and content analysis (Williams, 2007). Creswell (2003) describes how these methods meet different needs, and in what situations they are more appropriate to use.

A case study is defined by Creswell (2003) as "researcher explores in depth a program, an event, an activity, a process, or one or more individuals", and Leedy and Ormord (2001) state that case studies are used to increase the knowledge about a quite unknown or poorly understood situation. According to Yin (1999), case studies are used to explain, describe, or explore causes in an everyday context in which they occur. Further Crowe et al. (2011) explain that case studies create a good understanding around the questions how, why, and what. Hence, one could argue that this is a suitable research methodology since the aim of the research topic is to increase the understanding of a product flow in order to evaluate its effectiveness and possibly suggest some improvements on how to improve the flow. It is also stated in literature that case study is a suitable method when applying a descriptive research method as stated in section 2.1

2.3 Data gathering

The data collection for a case study is broad, hence Crowe et al. (2011) stress the importance of applying multiple sources of evidence, such as observations, on site visits, and interviews, in order to develop a deep understanding about the situation.

2.3.1 Literature review

In order to gain relevant knowledge about the subjects that were investigated and to prepare for further data gathering a literature study was conducted. Related literature were collected primarily through Google Scholar, Chalmers Library, University of Gothenburg's library, and information from NIBE. Key words that were used during this process are value stream mapping, lean production, and production planning.

By conducting a literature study not only will the researchers be better prepared for any future interviews and site visits, but it will also increase the thesis' validity since the deeper understandings will lead to more thorough discussions and by that better conclusions could be drawn.

2.3.2 Interviews

In the early stages of the research unstructured interviews were held with people within NIBE's supply division to gain understandings about the organisation and the challenges that NIBE are facing within the research topic. Unstructured interviews are characterized by being more of a discussion rather than being carried out by prepared questions (Creswell, 2009). This leads to more flexibility since the interviewers does not have the control over the discussion and is preferable in early stages of projects when the researchers does not have enough knowledge and expertise within the research topic. Later on in the project semi-structured interviews were applied to enable larger data collection (Creswell, 2009). Semi-structured interviews are chosen since they allow the interviewers to direct the interviews to ensure that relevant aspects to the research topic are brought up, but it will also allow the interviewees to explain their meanings, and by that increase the crucial in-depth understanding (Yin, 1999). The questionnaire can be seen in Appendix A. Interviews were carried out with six persons with relevant knowledge regarding the product flow that was investigated. The interviews were held with production planning, managers and foremen from the different production departments, i.e. welding, metal sheet and painting shop, and final assembly.

The focus during the interviews with the responsible personnel was on how well the production line is performing and what they experience as the strengths and weaknesses of the current production. For the interviews with the production planning the focus was on the organisation's planning processes and forecasting, and how it is related to the studied production flow. Lastly, when all the collected data from the interviews were compiled and analyzed it was discussed with experts to collaborate possible hypothesis and conclusions.

All interviews except one was held face-to-face. When interviews are one of the main sources of information physical interviews are preferred over telephone interviews since it provides better quality data (Knox & Burkard, 2009). All interviews were recorded upon permission since it enabled the interviewers to listen multiple times and therefore enable better analysis. This also reduced the risk of distorting the interviewees answer to question which can happen when the interviewer themselves writes down the answers to questions (Bell, Bryman, & Harley, 2019).

Besides the interviews a number of meetings were held with some of the persons that previously were interviewed and with employees with knowledge of production data. These meetings were held to clarify things and to get an insight on how the data for the production is gathered and measured.

2.3.3 Site visits and observations

Site visits at NIBE's facilities in Markaryd was conducted in connection with the scheduled interviews, and allowed the researchers to observe the current product flow that was investigated in order to get a deeper understanding and a more comprehensive view of the situation. During the site visit a guided tour was given by a person with extensive experience from the different departments. This tour gave the researcher further understanding of the production flow. Site visits also offers the possibility to interact with people close to the production line to better understand the activities in the flow and how they are performed.

2.3.4 Quantitative data gathering

To create a complete overview of a certain situation both quantitative and qualitative data can prove to be useful (Davidson, 2019). According to the author, relying on assumptions or precedence can lead to mistakes. Therefore, data-driven decision making is important if the organization strives to cut costs by understanding how processes work and how they perform.

Quantitative data can come from a various amount of sources such as experiments, surveys, or observations (Davidson, 2019). During the project the researchers need to have access to NIBE's production plans and follow-up systems to be able to calculate cycle times etc. Due to the performance-based salary system used at NIBE the researchers will ensure that the given data is accurate by comparing the data with fresh data measured by people at the line to ensure verifiable and testable results.

2.4 Quality criteria

According to Bell, Bryman, and Harley (2019) quality criteria in business research makes it possible to evaluate if the results from the study are valid, reliable and replicable.

Validity is related to whether the conclusions from the study are trustworthy and how well the study studies what it is supposed to study (Bell et al., 2019). According to Yin (2003) validity relates to the integrity of the results generated from the study. He describes validity as how well a measuring measures the concept it should be measuring. Bell et al. (2019) explain that it exist four types of validity; measurement, internal, external and ecological. Measurement validity is related to whether a measurement entails what it is supposed to entail. Internal validity is related to results about cause and effect from the study. External validity is connected to whether results can be applicable to other contexts. Lastly, ecological validity is related to whether the results of the study are applicable in real life (Bell et al., 2019).

In NIBE's factories the production system is rather complex, meaning that the process times for different models within the product family varies widely and this may effect the measurement validity of the research. In order to ensure the validity of the research, time-measurements that NIBE performs for the different processes will be used. These measurements are performed by specially trained personnel, are continually updated and lays ground for the performance-based salary system. Thereby, the risk of bias from NIBE when performing the measurements is minimized. To secure the internal validity of the research, continuous dialogue and discussion with the factory management will be held. Since the study is conducted at NIBE, the analysis and conclusions are related to improving the current situation at NIBE. This might imply that the provided suggestions might not be useful and applicable in other contexts. There are however some theoretical and general areas like value stream mapping that can be used in other contexts and thereby ensuring the external validity. Since the aim of the research is to provide NIBE with an evaluation and improvement plan the study is applicable in a real life context. To further make sure the ecological validity is assured, interviews and discussions are performed in social and natural settings for the managers and operators, e.g. conference and meeting rooms within the factory.

Reliability is connected to whether the findings from the study are repeatable, meaning that the next time the study is performed the outcome and the results will be the same (Bell et al., 2019). The reason for achieving reliability in a study is to make sure that errors and biases are minimized (Yin, 2003). According to Bell et al. (2019) the reliability of a study can be increased by using triangulation, which they describe as a process of using multiple sources of data when searching for information and thereafter comparing and analyzing the different sources. For the following thesis the reliability was of specific focus during the creation of the value stream map. To ensure that it was reliable, the researchers started by performing observations and mapping their own process map, these were thereafter compared and any deviations was broken down in order to reach a consensus regarding the maps. Thereafter, a value stream map was jointly developed, and to be validated it was shown and discussed together with managers and operators ensuring that it was reliable. Further, the literature review also consisted of triangulation by using multiple sources of information.

To make sure the interviews were reliable a standardized interview guide was developed. The chosen participants were managers and foremen, and foremens were chosen together with the managers. To get at wider perspective, but also a more detailed overview of the current situation, interviews were held with participants from all the different departments. Discussions were also held with less experienced employees, but which were considered to be able to give additional and valuable insights. All interviews were recorded so the researchers had the possibility to add valuable insights and facts to the notes that were taken during the interviews. Thereafter, the transcript and notes were analyzed and compared in order to reach consensus and form conclusions from the data.

2.5 Ethics

When performing research there is always an aspect of ethics when involving people. According to Bell et al. (2019) there is four main areas of ethics in business research:

- *Harm to participants* - Assuring that the participant is not harmed in any way by being involved in the research, e.g. physical harm and stress.
- *Lack of informed consent* - Making sure the participants are given the correct information in order for them to evaluate if they want to participate or not.
- *Invasion of privacy* - Assuring that the privacy of the participants are secured.
- *Deception* - Making sure that the study is characterized in the correct way, e.g. not misleading participants.

The data collection methods involving people in this research were related to observations and interviews. To assure that the ethical aspects regarding the observations were fulfilled, the people working at the chosen production line were informed by their manager about the observations beforehand and the specific purpose for the observations. When a specific activity were observed the operator performing the activity were asked if they had any objections regarding the observations. Another aspect that had to be taken into consideration was the performance based salary system. To not restrict the integrity of the operators, no time measurements from the researchers were conducted during the project due to that this is very sensible for the operators since they are evaluated depending on how well they perform.

For the interviews the ethical aspects were fulfilled by giving the interviewees correct information about the purpose of the research. They were further asked if they were okay with the interview being recorded and told that their answers would be anonymized in order to assure their privacy, allowing the participants to speak freely.

2.6 Current state map

Through the gathered data and information, a value stream map for the *Compact* was conducted. The authors used VSM as a tool to visualize the as-is situation for the production flow, but also to generate a improvement plan through a to-be situation with proposed improvements.

The current state map was drawn with support from the collected data from interviews, observations, and data from the ERP system. The data collection for the current state map was collected from the final assembly to the starting point of the production flow. During the data collection phase, current state maps were drawn by hand while walking along the flow. After this phase when all the empirical data was collected, the map was validated by people with great knowledge about the production flow. Thereafter, with the feedback from the validation, the map was further analyzed for improvements and the above mention procedure was repeated before the final current state map was completed.

To gain further understanding of the production flow, and to induce more parameters that could be analyzed and evaluated for the future state map a software called *Flow Planner* was used. *Flow Planner* is a tool for creating material flow charts within AutoCAD, and calculate material handling costs, distances, and time for different factory layouts. This provided the researchers with valuable insights about the current situation, and also gave an opportunity to evaluate future layouts.

2.7 Future state map

The future state is mapped with the purpose of eliminating waste and to produce according to the customer requirements, as stated in section 4.13.2. The map was drawn after analysing the finalized current state map, together with the data collected through the literature study. The analysis of the current state map was conducted with the intention of increase the available floor space in the factory by reducing the inventory levels, and identify potential bottlenecks.

To come up with potential improvements for the future state map, the map was drawn by consulting with people within NIBE that holds great knowledge about the current production flow and with great knowledge within the subject. Further, the questions presented in section 4.13.2 were answered. The finalized future state map is presented in section 7.

2.8 Analysis tool

In order to find suitable improvement suggestions an analysis over the current state map was performed. The analysis was aimed at identifying problems within the current production facility. The problem identification was mainly done through interviews and observations. When the problem identification phase was done and a number of problems were identified, the researchers focused on how to cope with these identified problems. The search was done by analyzing literature and thereby finding potential ways to solve the problems. This resulted in potential solutions for the different problems and thereafter these solutions were discussed with employees within NIBE. This enabled the researchers to see if the solutions would be applicable and gave further insight on how the solution would affect the production system. Once appropriate solutions were chosen for the different problems, a future state map was conducted as well as recommendations on how to approach the problems.

3
Company description

NIBE AB is a part of the NIBE group, which provides energy solutions for both private and commercial use. Accordning to NIBE (2020) their vision is to create world class sustainable energy solutions. NIBE AB is divided into three different business areas; NIBE Climate Solutions, NIBE Element, and NIBE Stoves (NIBE, 2020). In the following the chapter a more detailed description of the company will be presented.

3.1 NIBE Industrier AB

NIBE Industrier AB acts as parent company within the NIBE group, a global group that consists of 135 different brands worldwide with 17.000 employees. In 2019 the group had a total turn over of 25 billion SEK (NIBE, 2020). To be able to handle all these brands the group is, as explained above, divided into three different business areas. The group has four financial objectives. These are for each year to reach a operating margin of 10 %, a growth rate of 20 % where the aim is that half of this growth should be organic and half through acquisitions. The two last objectives is to have a return on equity of 20 % and that the solidity not goes below 30 % (NIBE, 2020). These goals are the same for all the different brands within the group, including the company that are subject for this case study NIBE AB.

3.2 NIBE AB

NIBE AB, from now on refereed to as just NIBE, is located in Markaryd in Sweden. The company operates three factories where they manufacture water heaters, heat pumps, and stoves. The product family that has been chosen is NIBE Compact, a water heater that belongs to NIBE Climate solutions.

The organizational structure of the water heater factory is presented in Figure 3.1. It is the factory manager that has the overall responsibility that the production plan is followed. To support the factory manager, there are three department managers that have responsibility for sheet metal, welding, and assembly respectively. Below these department managers there are foremen that have the responsibility for the operators at each activity in the flow. The factory also has support by production technicians and quality technicians that belong to other departments within the organization.

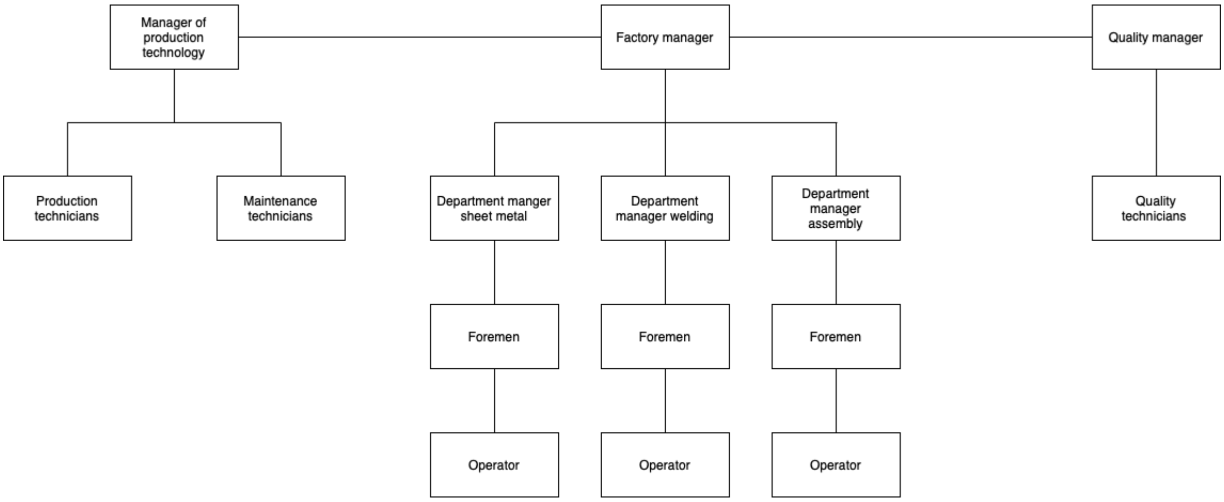

Figure 3.1: Organizational structure water heater factory.

3.2.1 Product description

The chosen product family *Compact* is a group of water heaters aimed for household consumers and can be ordered in three different materials; stainless steel, copper, and enamelled. Each of these three variants occurs in different sizes. The copper heater can be chosen in the sizes 100, 200, or 300 litres. The stainless steel heater occurs in 150, 200, and 300 litres, and the enamelled heater in 200 or 300 litres. The copper and stainless steel models are all manufactured in-house while the enamelled models are purchased from a supplier. All models consist of a cabinet with the vessel inside, which consists of two gables, and one mantle. An illustration of a water heater is presented in Figure 3.2.

Figure 3.2: Compact water heaters (NIBE, 2020).

3.2.2 Production system

The production at NIBE is planned by the company's sales department and their retailers. The company use a push-based production system where the majority of the orders are pushed out in the system without any customer order. It was stated by a manager at NIBE that "We always sell everything we produce". The company therefore use a make-to-stock (MTO) approach, and to plan the production NIBE use a Material requirements planning-system (MRP). NIBE provide the system with sales forecasts, then the MRP-system estimates when the production shall be initiated and when material need to be ordered. The production plan is said to be locked three weeks before the production starts, but since NIBE see themselves as very flexible and always want high customer satisfaction changes could appear even after the set release time fence.

As stated in section 1, NIBE use performance based salaries. According to the company, this system allow the company to have full control over how the operators' working hours are disposed, as well as it give the operators an incentive to develop existing and current methods and be as efficient as possible. But, as stated by NIBE, this approach also contributes to a lot of minor buffers between processes since every activity work independently and the operators want to produce as much as possible. The independecy further implies that they lack a holistic perspective over the production flow which cause a mismatch between the different departments, hence build ups of larger inventories between the departments is the major result.

3.2.3 Quality and maintenance

The quality department at NIBE use three variables when measuring quality; quality deficiency costs, the number of products that passes without any remarks, and the number of products that have defects that need to be remedied. The production quality is documented by on-site observations and controls at each production station. When defect products are observed they are moved to a control/repair station where the products are checked and repaired if possible, otherwise they are discarded.

To ensure high quality, quality observations are conducted at several occasions throughout the production flow. It is stated "Quality checks are performed at those stations that if the problem is not identified and solved at this point, we won't be able detect it and fix it later on" (Personal communication, 2020). The overall quality objectives that the company work towards is set by a business council and are the same for the whole NIBE group. These objectives are then decomposed to supplier quality, production quality, and customer quality. All quality areas are thereafter decomposed further down to the different department within each factory.

The maintenance work at NIBE is performed by the maintenance department and takes place on an ongoing basis. The planning is governed by the manger at the department, and the work is then performed by maintenance technicians. The operators have personal responsibility to keep order at the work station, in agreement with 5 Nibevanor (5NV), and to report wear and occurred errors.

5NV are five principles that says that everyone has a responsibility over their work place so that it is clean, efficient, and safe. According to NIBE this create discipline and prevent that errors occur. The 5NV are listed below:

- Sort out and recycle what is not needed.
- Organize the workplace so it is easy to use.
- Clean the workplace regularly.
- Create and visualize routines.
- Document and follow-up.

3.3 Factory description

The water heater factory is divided into three main departments: metal sheet and painting shop, welding shop, and the final assembly. An illustration of the factory is presented in Figure 3.3. The metal sheet shop is illustrated in red, the paint shop in orange, the welding shop in blue, and the final assembly in green.

Figure 3.3: An overview of the water heater factory (NIBE, 2020).

At the metal sheet and painting shops, parts are manufactured and painted for the majority of NIBE's facilities in Markaryd, it thereby produces parts for NIBE's whole product portfolio. At the welding shop, the vessels for the water heaters are manufactured and welded together, and at the final assembly parts from the above mentioned departments are sourced and assembled together into the finished products. For a more detailed description of the current production flow, see section 5.

4
Theoretical framework

This chapter presents the theoretical background for this thesis, and describes a number of theories and models that have been used in order to execute a successful project. The chapter also aims to give a deeper understanding of the subject of the thesis, as well as creating a framework for the analysis and conclusions.

4.1 Order Planning

Order planning is the planning level that relates to material supply to ensure that raw materials, purchased products, and semi-finished goods are purchased and manufactured in time and right quantities so that the production schedule can be held and carried out, and the result is material plans for manufacturing and purchasing in order to ensure the demand (Jonsson & Mattsson, 2009). According to the authors order planning executes plans established at a strategic and operational level within a company, and somewhat simplified one could say that the main purpose with order planning is to establish the quantities needed at the right time to ensure flow of material as efficiently as possible when considering tied up capital, delivery service, and resource utilization. Jonsson and Mattsson (2009) explain that considerations regarding current requirements of material and capacity must be taken into account in relation to supplies of material and capacity. Therefore, order planning must be executed from the perspective of both material and capacity.

4.1.1 Material Planning

Material planning aims at balancing supply and demand of material as cost-efficient as possible (Jonsson & Mattsson, 2009). One commonly used method for material planning is Material Requirements Planning (MRP). A MRP system is a composition of techniques that uses product structures, inventory data and a production schedule to calculate future requirements and ensure resource supply (Ptak et al., 2013). The fundamental principle of this method is to not schedule new orders before a net requirement arise. When designing a MRP system Jonsson and Mattsson (2009) state that different parameters needs to be defined and established, i.e. planning horizon, planning frequency, and types of orders.

Graves (2011) discusses the consequences of changes in the material planning, and states that a change in order priority leads to additional costs since changing priorities certainly lead to inefficiencies in any production flow, as material gets put aside in order to facilitate the higher priority orders. To cope with the challenges that come with re-planning and the induced uncertainty, Graves (2011) suggests using time fences. Time fences are defined as the time intervals which specify the types of changes in the planning that are allowed. And as stated by Graves (2011), these time fences provide some stability, since short-term changes in the demand forecast get accumulated and then postponed beyond the the frozen time period.

4.1.2 Capacity Planning

In order for a producing company to perform value adding activities different types of production resources are needed (Jonsson & Mattsson, 2016). The authors mentions that capacity is a indication as to what extent the production resources are capable of performing value adding activities. Having a certain amount of production capacity is related to a cost, too much capacity leads to resources being underutilized and a higher cost (Lewis & Slack, 2017). Too little capacity leads to limit as to which extent the customer demand can be meet and therefore the revenue is affected (Lewis & Slack, 2017). As a result of this there is a need to balance the company's access to capacity against the demand for capacity (Jonsson & Mattsson, 2016). The function in a company that involves balancing the access to capacity against the demand for capacity is called capacity planning (Jonsson & Mattsson, 2016). The authors further mentions that the capacity to produce is calculated or estimated for every specific group of production processes and represents a measure of how much each group can produce. The maximal capacity of a production group is the capacity that would be achieved if the production was producing non-stop, every day, the whole year (Jonsson & Mattsson, 2016). Since this is very uncommon the maximal capacity is often of less interest, instead the nominal capacity is often used when measuring the capacity (Jonsson & Mattsson, 2016). The authors mentions that the nominal capacity often is measured in four different variables:

- Number of machines or production units within the group.
- Number of shifts per day.
- Number of hours per shift.
- Number of working days per planing period.

By using these variables the nominal capacity of the production can be calculated. The nominal capacity usually cannot be fully utilized since it almost always exist some type of lapse of capacity, e.g. breakdown of machinery, maintenance and absence of personnel (Jonsson & Mattsson, 2016). By removing the lapse capacity the remaining capacity is called gross capacity. Included in the gross capacity is also different types of indirect times when production cannot be performed, e.g. waiting-time for material, time for meetings with management, etc. The remaining capacity after removing all these types activities is called net capacity and represents the amount of capacity that will be able to use for value-adding activities in the planned production (Jonsson & Mattsson, 2016). The net capacity than has to be matched with the demanded capacity in order to be able to produce the right amount of products (Jonsson & Mattsson, 2016).

4.2 Theory of constraints

Planning always involves a balance between what needs to be delivered and what is possible to be produced and taken from stock (Jonsson & Mattsson, 2009). This balance imply that resource limitations that exist within the production system need to be taken into consideration. According to the authors, the primary limitation that has to be considered is the manufacturing capacity, but other limitations such as storage areas, transportation handling equipment, and supplier capacity are important to consider as well.

A well-known approach that considers capacity limitations when planning material flows is the the Theory of Constraints (TOC) approach. It originates from a method called optimized production technology (OPT) developed by Dr. Eli Goldratt (1984). This method is characterized by identifying and fully utilizing bottlenecks and subordinating the production system to these. This method was later developed into a more constraint-based method rather than just focusing on bottlenecks.

According to Jonsson and Mattsson (2009), a constraint is defined as anything that harm and limits the performance of a system. Generally, a constraint take one of the following forms; physical, market, or policy. Physical constraints exists if the manufacturing capacity is lower than the demand. Market constraints occur when the demand is lower than manufacturing capacity, hence the system cannot be fully utilized. A policy constraint means, for example, that applied policies within the organization limit the capacity of the production system.

The essence of TOC is that all systems have constraints. The existence of constraints opens up the possibility of continuous improvements since, as stated above, a system always will contain at least one constraint. When a constraint has been identified one wants to synchronize the production and material flow with customer requirements (Jonsson & Mattsson, 2009). To be able to achieve this synchronization the following five steps presented by Goldratt and Cox (2004) are the core of the TOC approach:

1. Identify the constraint.
2. Exploit the constraint.
3. Subordinate everything else.
4. Evaluate the constraint.
5. Go back to the first step.

To find the limiting resource in the flow it is important to first only consider the flow of material and understand what is demanded on the market disregarding the available capacity (Jonsson & Mattsson, 2009). According to the authors this is the only way to find out if any throughput-limiting resources exist and where they are located. The next step is then to focus on the capacity in order to maximize the utilization of the capacity at the bottleneck and adjust the flow of material to the extent capacity is available. According to Rahman (1998) the TOC approach can be controlled by the Drum-Buffer-Rope (DBR) methodology. This method coordinates the utilization of materials with the system's resources. This is done by the pace of the constrain, the drum, which sets the pace for the whole flow. Then buffers are placed out strategically to prevent that the constraint never lack materials and create variations in the output of the system. Lastly the rope, e.g. a CONWIP card, handles the communication and makes sure that the products are pulled into the constraint at the right pace (Rahman, 1998).

4.3 Variation and capacity utilization

Bottlenecks arise for two reasons: that the theoretical capacity is not sufficient, or that the actual capacity is not sufficient. One of the main causes why capacity is not always sufficient has to do with variation. According to Holweg et al. (2018) variation constrain any process, and they define variation as a measured deviation from an expected outcome. The ability to detect and reduce variation allowing companies to produce better products to their customers, hence give them a competitive advantage (Loose, Zhou & Ceglarek, 2008). Variation can appear in three different configurations: quality, quantity, and time.

4.3.1 Variation in quantity and time

Variation in quantity and time influence both the supply and demand sides of the operation (Holweg et al., 2018). Seasonal customer demands can entail that quantities can vary substantially between periods with order releases or delivery dates that can be erratic. Moreover, the process itself can agonize variation in quantity and time since the output of the process may not be stable and produce expected quantities (Holweg et al., 2018). Variation in supply and availability of materials, and the work times for performing certain activities are further sources of variation explained by the authors.

4.3.2 Variation in quality

Traditional quality control within manufacturing focuses on statistical process control when detecting deviations based on product and process management (Loose, Zhou & Ceglarek, 2008). A drawback with thos method is that is that it not provides guidelines to identify the source of the variation. Holweg et al. (2018) highlight the importance of being able to distinguish random variation in the production from an transferable cause for a quality problem. They present a bunch of key quality tools that can be adopted by manufacturing processes, these are: Pareto diagram, Check sheet histogram, and Fish bone diagram. They have been useful when analyzing and controlling quality in many different settings.

4.3.3 Variation and capacity

Holweg et al. (2018) state that it is essential to understand what variation does to a process' output. Variation harms the capacity of any process, e.g. quality problems need time and resources to be fixed. Variation in quantities and time may starve or block stages within the process, and to cope with such variations the authors explain that more space, inventories, and labour may be needed. The search for capacity is fundamental in operations management, since capacity is a mean to fulfill customers needs (Holweg et al., 2018). But the exact capacity needed is seldom known exactly, and the same applies to the capacity available since many aspects influence the calculation (e.g. bottlenecks, product mix, variability in quantity and time). The capacity of a process often varies between the different stages, and every stage's capacity runs the risk of being the constraint of the entire process (Holweg et al., 2018). Further it is stated that not only is the capacity of the individual stages that can harm the total capacity, but also how the interaction between the stages works due to the variations that each stage is subject to.

4.4 The bull-whip effect

The bull-whip effect is a phenomenon that is one of the most common problems in companies supply chains. Singh (2018) defines the bull-whip effect as a concept to describe fluctuations and inefficient asset allocation due to demand changes in the supply chain. Companies try to forecast demand by collecting a significant amount of raw materials and resources in order to satisfy the customer requirements (Sales-academy, 2018). However, while going up the supply chain variations tend to be amplified, causing issues regarding time, costs, and inventory (Sales-academy, 2018). According to Jonsson and Mattsson (2009) variations in demand tend to double for every step in the supply chain. The effects of the bull-whip effect are illustrated in Figure 4.1.

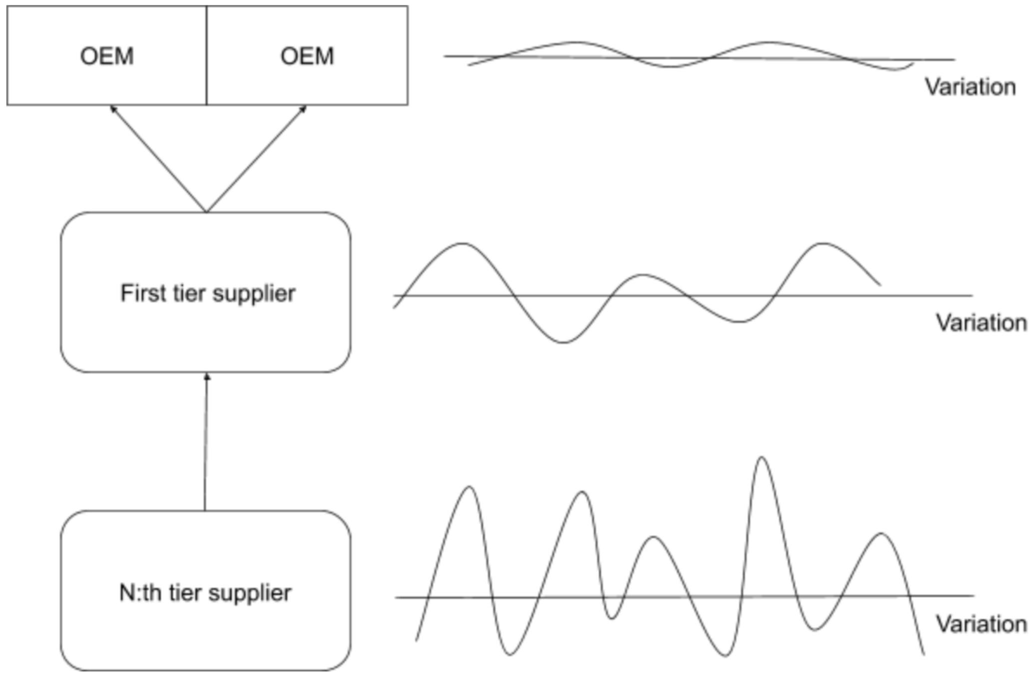

Figure 4.1: An illustration of the bull-whip effect.

To solve the problem companies need to understand what causes that lie behind so they can counteract them (Lee, Padmanabhan & Whang, 1997). They explain that companies in various industries have found that they can control the bullwhip-effect and improve the performance of their supply chains by coordinating information and planning along the chain. According to Jonsson and Mattsson (2009) the main reasons for the bull-whip effect are:

- Large order quantities.
- Few large customers.
- Non-aligned planning and control.
- Price fluctuations and promotion.
- Lack of communication and information sharing.

The causes of the bull-whip effect can lead to that companies either have lack of or an excess of inventory, which can be unfavourable (Sales-academy, 2018). Lack of inventory can lead to poor customer relations due to lower order fulfillment, and excessive inventories can result in higher costs due to tied-up capital and risk of obsolete products if the demand does not increase.

To counteract the causes of the bull-whip effect, companies use different strategies. According to Lee et al. (1997) these strategies can be categorized into information sharing, channel alignment, and operational efficiency. These categories are described in table 4.1

Table 4.1: Explanation of strategies used to counteract the bullwhip effect

Strategy	Explanation
Information sharing	Demand information at a downstream site is transmitted upstream in a timely fashion.
Channel alignment	Coordination of pricing, transportation, inventory planning, and ownership between sites in the supply chain.
Operational efficiency	Activities that improve the performance, eg. reduced costs and lead time.

4.5 Bottleneck identification methods

As stated in section 4.2, all production systems suffer of different constraints and limitations. Quick and correct identification of the bottleneck and its location can lead to improvements in the operation management by increasing the throughput, and minimizing the total cost of production (Chang & Ni, 2007). It is therefore of vast importance that the bottlenecks are detected so the capacity utilization can be maximized. According to Law and Kelton (1991) there are two widely used methods to detect bottlenecks in manufacturing systems, either by measuring the average waiting time in front of a machine, or by measuring the time a machine is active. These two methods will be presented more in detail in the following subsections.

4.5.1 Average waiting time

When measuring the average waiting time, the machine where the products spend the most time waiting in front of the machine is considered to be the bottleneck in the system (Roser, Nakano & Tanaka, 2001). Waiting time cam be decided both by measuring the queue length or pure waiting time, hence both momentary and average bottlenecks can be found by comparing the queue lengths or waiting time (Roser et al., 2002). The method has received criticism since it only considers the processing machines in the system, therefore aspects such as operators and automated guided vehicles (AGV) may not be considered at all or need additional considerations. Further, the available space to place the products in front of the machine is often limited, and the product supply needs to be balanced comparing to the available machining capacity to ensure that the buffers are not permanently filled up.

4.5.2 Utilization rate

When applying this method the machine with the highest workload is considered the bottleneck (Roser et al., 2001). However, many machines within the system may have very similar utilization rates which makes it hard to for sure determine which one that is the bottleneck (Roser et al., 2002). Furthermore, this method is only suitable for steady state systems, and needs data from a long period of time to determine average bottlenecks. On the other hand this gives the possibility to quickly locate the bottleneck (Lawrence & Buss, 1995).

4.6 Little's Law

Little's Law deals with queues in a system and it is therefore a useful formula to see how the different variables affect the outcome of the system. Under steady state conditions Little's Law says that the average number of WIP in a process is equal to the waiting/processing time for an item, multiplied with the throughput rate of the system (Little & Graves, 2008). Little's Law can be seen below:

$$L = \lambda * W$$

$$L \; [units]$$

$$\lambda \; [units/time]$$

$$W \; [time]$$

Where L is equal to the number of items in the queuing system (WIP), λ is equal to the throughput rate of the system, and W is equal to the waiting time. If there is less units than L in WIP, some processes will be starved and the throughput will decrease and if there is more units than L it contributes to an excessive inventory that is not needed to keep the processes running (Holweg et al., 2018). Little's Law therefore provides a structure on how the different variables affect the conditions of the system, e.g. an increased capacity and output will lead to an increased WIP if the waiting time is not reduced (Little & Graves, 2008).

4.7 The Kingman formula

Waiting is a common aspect in production systems and the time that customer spends waiting for the output of the system can be reduced (Holweg et al., 2018). In 1966 the British mathematician John Kingman published an article where he mentions that to reduce the waiting time, attention has to be put on the production rate, process variation, and the utilization of the capacity (Holweg et al., 2018). Kingman found that the waiting time in front of a process can be approximated accordingly:

$$\mathbb{E}(W_q) \approx \left(\frac{\rho}{1-\rho}\right)\left(\frac{c_a^2 + c_s^2}{2}\right)\tau$$

$$\rho = capacity\ utilization$$

$$\tau = mean\ service\ time\ (processing\ time)$$

$$c_a = variation\ of\ arrivals$$

$$c_s = variation\ of\ service\ times$$

Simplified, the waiting time can be said to be equal to the product of the processing time, utilization of the process, and the effects of variation (production and demand) (Holweg et al., 2018). The authors further mentions that the faster the process, i.e. higher production rate and lower mean service time, the smaller the variability, and the lower the capacity utilization, the shorter the waiting time for customers. This relationships is illustrated in Figure 4.2 below.

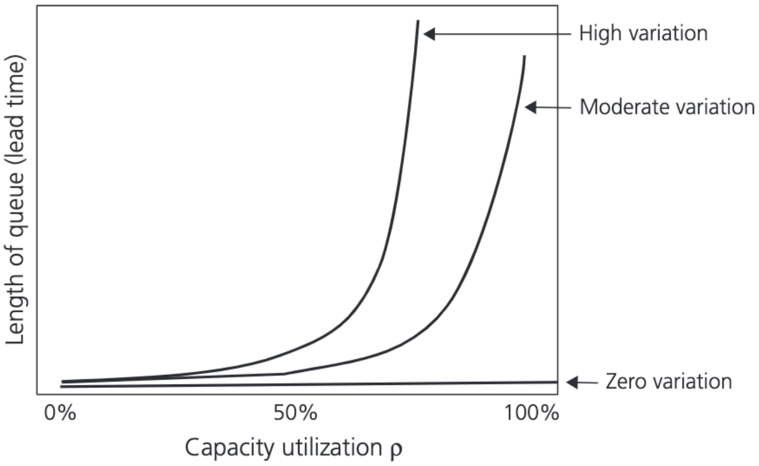

Figure 4.2: The Kingman Formula (Holweg et al., 2018).

As can be seen in the figure, both curve A (moderate variation) and B (high variation) illustrate how the waiting time can become exponential when the capacity utilization moves towards 100%. Curve A is more preferable than curve B since the waiting time is less for the different capacity utilization levels (Holweg et al., 2018). The difference between the curves is the variation, curve A has a moderate variation while curve B has a high variation, where the higher variation leads to a higher lead time in accordance with the formula.

4.8 Push and pull production

In production and material planning there is often a distinction between push-based and pull-based planning. A push-based approach is defined as the manufacturing and material movement taking place without the authorization of the consuming unit, whilst a pull-based approach is defined as manufacturing and material movement taking place on the initiative of the consuming unit (Jonsson & Mattsson, 2009). Thereby, the main difference between the two approaches is related to the authorization of the next step in the process and movement of material (Jonsson & Mattsson, 2009).

The pull-based approach is seen as the ideal state of the lean production principle, Just-In-Time (JIT) manufacturing, which strives to give the customers exactly what they want, when they want it (Dennis, 2007). Dennis (2007) further mentions that the JIT production has a set of simple rules and that it is closely related to pull-based production. First, products should not be produced unless the customer orders it. Secondly, the demand should be levelled so that production is conducted evenly throughout the factory. The third principle says that all processes should be linked with customer demand through a Kanban-system to simplify the tracking of demand, and lastly, the flexibility of machines and people should be maximized. The pull system allows to control the WIP and the amount of Kanban-cards puts a maximum number of WIP in the system (Dennis, 2007). According to Dennis (2007) the control and upper limit of WIP in the system leads to:

- Reduced throughput time (according to Little's law).
- Operating expenses are reduced since the finished good inventory and ordering of raw material are decreased.
- The quality is improved since defect products are easier to find quickly and not produced in large batches.
- Ergonomics is improved since the part bins are smaller and easier to lift.
- Safety is improved when there is less trucks transporting goods in the factory.

Lasa et al. (2008) mentions that a continuous one-piece flow of products should be established where possible. A one-piece flow means producing one product at a time and once the current process is done the product moves directly to the next step without any stagnation between activities. By having a continuous flow, the throughput time is reduced, the cost to cash period is shortened, and the quality can be improved (Liker & Meier, 2006).

The push-based approach is when processes and activities are working on self-reliant schedules, and products are produced and pushed forward into inventory buffers between activities (Liker, 2004) The push production system has no declared agreement between customer and supplier in terms of the number of products that are to be supplied, and at what time that is supposed to happen. Products are therefore delivered to the customer whether he requested it or not, causing problems regarding the control of the process in terms of what and how to control it, e.g. are the production behind or ahead (Liker & Meier, 2006).

In a traditional push-based system, the production scheduling of each department is managed individually (Rother & Shook, 2003). According to the authors, this increases the complexity of coordination of the production compared to only have one production unit to coordinate. By implementing a pacemaker in a bull-based production system, the upstream production can be controlled from this point, hence reducing the need of coordination. (Rother & Shook, 2003). Further, the usage of a pacemaker is beneficial when there is a mix of products in the production flow.

A pacemaker controls the upstream production by sending a signal to the process in the beginning of the flow when there is a demand, and only then will the production be initiated, hence creating a pull-based production flow (Rother & Shook, 2003).

One prerequisite for the downstream processes from the pacemaker need to be in a continuous flow all the way down to the finished product, according to the authors.

4.9 CONWIP

CONWIP (Constant Work In Progress) is a system similar to Kanban that uses signals/cards to communicate when production can be initiated (Spearman, Woodruff, & Hopp, 1990). According to the authors, CONWIP is a system that achieves all the benefits of a pull system while being suitable for production of a high variety of products. The basic principle of CONWIP is that each container is attached with a card at the start of the production, and when the container is used at the final station the card is removed and sent back to the beginning of the line (Spearman et al., 1990). At the beginning of the line the card waits in a queue until it is attached to another container based on the backlog list, where first come first served is used, thereafter the part goes through the production flow (Spearman et al., 1990). According to Framinan, González, and Ruiz-Usano (2003), a production process cannot enter the system unless it is attached with a card. Jonsson and Mattsson (2009) further mentions that compared to a Kanban system, the CONWIP system sends the production signal from the last station directly to the first station, while Kanban sends the signal to the previous process. By doing this the CONWIP ensures a constant work in progress and the ability to handle a variety of products (Jonsson & Mattsson, 2009). The difference between a Kanban system and CONWIP system is illustrated in Figure 4.3.

Spearman et al. (1990) mentions that one of the major advantages of CONWIP is that the flow times for products becomes fairly predictable since the WIP-levels are nearly constant. They further mentions that the coordination of the production becomes easier to coordinate when the WIP is constant and by keeping the WIP at a low and constant level the following benefits can be achieved:

- Increased chances of detection of defective parts.
- Less material on the shop floor, making it easier for operators to find WIP for the next process.
- By reducing WIP problems becomes visible, e.g. machine failures, defects, yield losses.

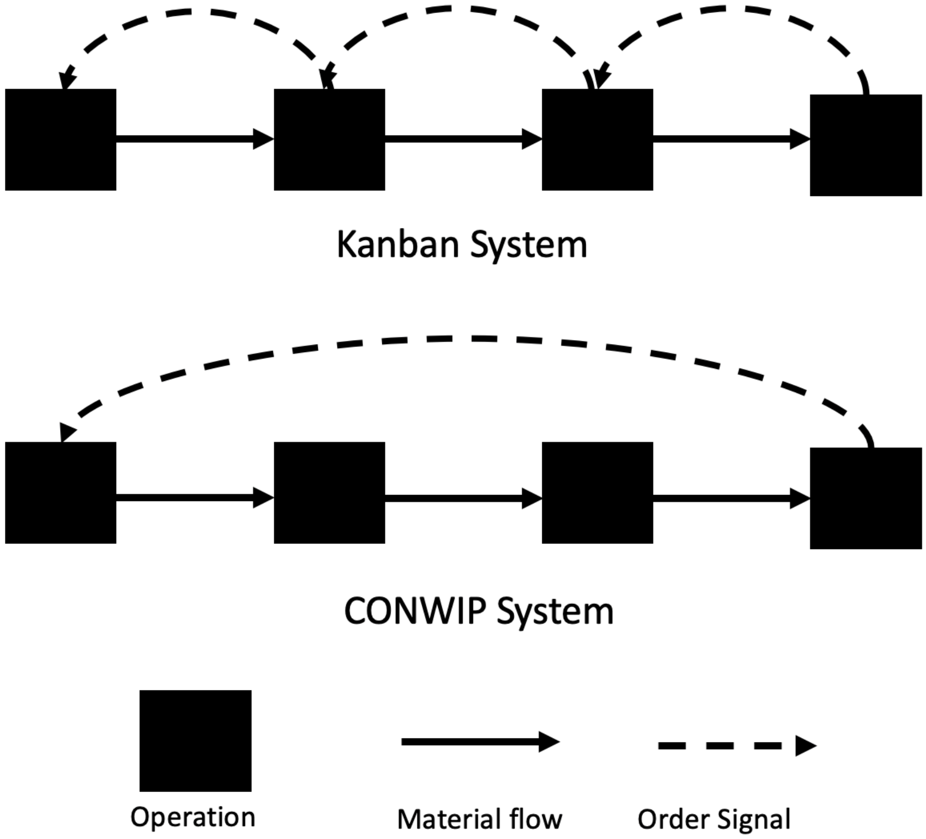

Figure 4.3: Illustration of Kanban and CONWIP system.

4.10 Lean production

Lean production is characterized by an effective and efficient organization. The approach encompasses a vast variety of practices such as (JIT), quality systems, work teams, supplier management etc. into an integrated system (Shah & Ward, 2002). The purpose of lean production is to create a synergy between all these practises in order to facilitate a streamlined system that produces exactly what the customers want at the right time and with as little waste as possible. Lean production originates from Toyota Production System and builds upon the 14 principles founded by Liker (2004). The core of these principles is to eliminate waste. Waste is defined as all activities that does not add value to the product from the perspective of the customer. The principles are divided into four different classifications, which are illustrated in Figure 4.4. The *Process* classification is of particular interest for this thesis since the research doesn't aims at questioning the company's methods or philosophy, but to investigate the production processes and how to make these more efficient.

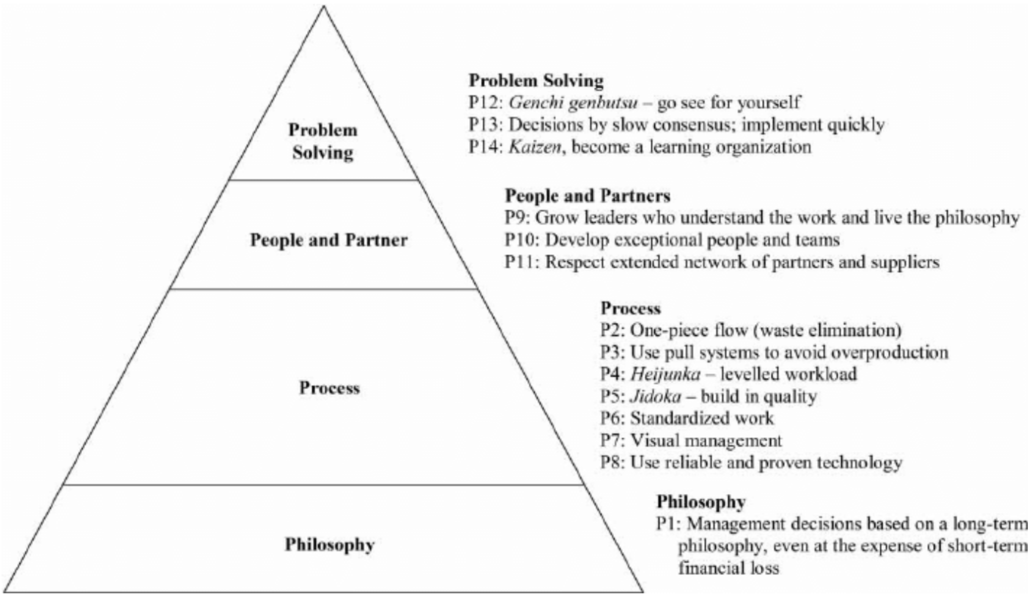

Figure 4.4: 14 principles of The Toyota Way (Liker, 2004).

Lean production focuses on the entire end-to-end value stream rather than sub-optimization of segmented activities in order to achieve high-value and efficient processes with as little waste as possible. By focusing on the entire value flow and eliminate waste, processes will be able to respond to changes in requirements and demands with high quality and agility, and low costs. Slack and Lewis (2015) made a study where they compared a conventional approach to operations and lean production, where the conventional approach assumes that each activity in the flow is independent of the activity downstream the flow. The findings from the study were that the in-dependency between the different activities caused build-ups of buffers in the flow, and the bigger the buffers, the more independent the different activities were. Lean production on the other hand allows activities to be more interdependent, hence the build-up of buffers can be reduced and the flow will become more efficient and agile (Slack & Lewis, 2015).

4.11 Waste in Lean production

In lean production the main concept is to identify and eliminate waste in every process of the whole production system (Chiarini, 2012). In order to understand what waste is, it is important to understand and focus on value (Chiarini, 2012). Value is what the customers are willing to pay for a product, e.g. sheet metal being bent and welded. The opposite of value is waste, which is what the customers are not willing to pay for. One example of this is excess inventory and waiting time (Dennis, 2007). In the following section wastes in lean production will be briefly described.

4.11.1 Transportation

Transportation is a waste linked to transportation of parts between processes, e.g. moving WIP from one place to another in order to process it. This also involves moving material and finished goods in and out of inventories and between processes (Liker & Meier 2006). This type of waste is often related to poor factory layout, large machinery, or ordinary batch production, creating a need for transporting goods between activities (Dennis, 2007). Another factor increasing the need for transportation is excessive inventories which cause a need to move products from one warehouse to another, or moving products from a warehouse to a production process (Chiarini, 2012). To reduce the number of transports, Chiarini (2012) suggests using VSM to redesign the layout, implement U-cells or use multi-skilled workers that can perform several activities.

4.11.2 Inventory

Inventory is related to excessive inventory, finished goods and WIP (Liker & Meier 2006). The authors explain that this leads to longer lead times, cost for transportation and storage, obsolescence and damaged goods. Rother and Shook (2003) further mentions that excessive inventory is one of the main reasons for longer lead times. Inventory is described as products or raw material being stored within the company boundaries for a certain amount of time (Chiarini, 2012). The author further mentions that inventory is a waste connected to producing more than what is actually demanded by the customers. Liker and Meier (2006) mentions that inventory has a tendency to hide problems related to production, e.g. defects and unbalanced activities. It causes slow deliveries from suppliers and leads to longer setup times. Chiarini (2012) states that the best way to identify this type of waste is to observe where there is an accumulation of products and then try to understand why the inventory is stocking up so much at that place. He further mentions some of the main reasons for inventory to be:

- Time consuming changeover time.
- Producing according to large economic lots.
- Production starts early.
- Processes operating at different speed.
- Processes operating inefficiently or creating defects.
- Accepting excessive inventory since it means instant delivery to customers.

Chiarini (2012) mentions that the last reason is specially important since accepting excessive inventory has a tendency to hide problems instead of fixing them and he therefore mentions that it is important for the company and its staff to realize that it is possible to eliminate the excessive inventory.

4.11.3 Motion

Motion is related to the idea of unnecessary movement (Chiarini, 2012). Motion has two components; human motion and machine motion (Dennis, 2007). Human motion is connected to the idea of wasted time when workers has to do unnecessary movement, e.g. look for a tool that is not close to the operation where it is needed (Chiarini, 2012). In a poorly designed ergonomic workplace Dennis (2007) states that the productivity is affected when there is unnecessary motion in terms of walking and reaching. Further, the quality is affected when the worker has to twist or reach to check a work piece and lastly the safety of the worker is affected when the workplace has a poor ergonomics design and can lead to work related injuries (Dennis, 2007).

The second component of waste related to machine motion, for example if a machine is placed unnecessarily far from the next machine making it an unnecessary motion for the work piece to move from one machine to the next one (Dennis, 2007). Further, Chiarini (2012) explains that some of the reasons for the unnecessary motion is caused by a poor factory layout, low involvement from staff and failure to keep the workplace clean and in order. Changes that can be made to decrease the unnecessary motion is to move towards a production flow, implement 5S (Sort, set in order, shine, standardize, sustain), and design U-shaped cells (Chiarini, 2012).

4.11.4 Waiting

Waiting is related to the concept of workers and machines having to wait before conducting a new activity. It can for example be a worker waiting for a part to be processed in a machine before moving it to the next step (Dennis, 2007). Dennis (2007) mentions that waiting often occurs when there is large batch production, problems with machinery downstream in the process, or when parts needs reworking caused by defects. Waiting also leads to increased lead times, which is the time between customer order and delivery of order (Dennis, 2007). There are several reasons for waiting, but some of the main causes mentioned by Chiarini (2012) are uneven balance between operations, lack of preventive maintenance and large batch production. The author further mentions some potential ways of removing the main causes of waiting, e.g. having a balanced and leveled production and performing preventive maintenance of machinery.

4.11.5 Overproduction

According to Taiichi Ohno, by many seen as the father of Toyota Production System (TPS), overproduction is the root cause of poor manufacturing and means producing products that exceeds customer demand (Dennis, 2007). Chiarini (2012) mentions that overproduction is known as producing products even if there is no customer order. Many firms producing according to a MRP, think that eventually all the produced products in the warehouses will be bought. But there is no guarantee of this and in the meantime, the inventory ties up capital and storage area and the products faces the risk of being obsolete, stolen or damaged during the time in the warehouse (Chiarini, 2012).

Overproduction comes with a number of negative effects, Chiarini (2012) mentions inventory (which is another type of waste), it decreases the flexibility of the production planning, slows down the production process and has an increase in cost caused by transportation, storage and inspection. He further mentions some potential reasons for overproduction, e.g. producing according to oversized economical batches, creating inventory to cope with defects and machines operating to fast.

4.11.6 Over-processing

Over-processing is a profound form of waste in lean production related to the idea of performing more activities to the product than the customer actually requires (Dennis, 2007). Liker and Meier (2006) explain that this involves processing parts with steps that are not necessary. This type of waste is often found in engineering departments when the connection to the customer is lost and the product gets attributes that the customer do not desire. These extra attributes then causes a need for extra processing in the production leading to waste (Dennis, 2007). Some of the main reasons for over-processing is poor analysis of activities and process design, lack of standardization and inadequate material and equipment (Chiarini, 2012). He further mentions some ways of removing this type of waste, e.g. redesigning processes and activities, updating instructions and procedures and using tools such as value engineering.

4.11.7 Defects

Defects are a type of waste related to damage caused during manufacturing, hence a need for repairs and fixing products occurs. This waste involves all the extra time, material and energy needed to repair the defects (Dennis, 2007). Defects is related to quality which is to do the right thing directly, and is therefore a result of bad quality and can result in dissatisfaction among customers as well as damaging the companies reputation (Domingo, 2015). Chiarini (2012) describes that some of the reasons for defects to occur is caused by:

- Specification and instructions not clearly stated.
- Lack of skill and knowledge among employees.
- Processes operating ineffective and lacks control.
- Incapable material and products.

The author further mentions that to eliminate these defects companies can increase the employees' knowledge and skills in quality work, design processes and machines with automation to detect defects or implement *poka-yoke*, which is a process that avoids mistakes being made. All these things can help to eliminate defects, but it is important to identify and find the root causes for every defect occurring in order to fully reduce these and increase the efficiency (Chiarini, 2012).

4.11.8 Unused employee creativity

Originally when talking about waste in lean production there has been a focus on the seven waste identified by Taiichi Ohno, but lately an extra waste has been added to the list, which is about "underutilized people" (Wahab, Mukhtar & Sulaiman, 2013). This waste is about not utilizing the knowledge that the employees possess (Liker & Meier 2006). Liker and Meier (2006) state that by not involving the employees, time, skills, improvements, and development is lost. The authors further mentions that according to Taiichi Ohno the seven wastes mentioned above all have an impact on this last waste, since reducing waste displays problems within the factory and creates a need for the employees to use their knowledge and skills to solve the newly exposed problems.

4.12 Lead time reduction

Lead time is defined as the time from receiving a customer order until the order is shipped (Hopp, Spearman & Woodruff, 1990). Reducing the lead time is therefore a way to increase the competitive advantage (Tersine & Hummingbird, 1995). According to Hopp et al. (1990) shorter lead times can reduce the inventories of in-process material, reduce the frozen zones in production planning and thereby minimize the dependence on forecasts from sales. Tersine and Hummingbird (1995) argue that a major consequence of excessive lead times are problems with planning and scheduling, resulting in longer planning horizons and magnified inventories. They further mentions that reduced lead times can improve the quality management since it enables products to leave the factory quicker and thereby minimize the opportunity for products to be damaged.

Hopp et al. (1990) discuss three main areas in reducing the lead time. The first one is related to throughput time and how long time products spend waiting and in queues. Secondly, the lead time and WIP are related to each other and large inventories leads to excessive lead times. The third reason the bring up is that lead time is affected by the variance of throughput time. The authors thereafter continues by presenting five general methods for lead time reduction:

- **Review WIP.**
  An increase in WIP results in an increased lead time and an analyze is therefore necessary to understand which WIP that is necessary to cope with bottlenecks and which WIP that can be reduced.

- **Make products continuously move towards completion.**
  The general idea is that if the product continuously move towards completion both the lead time and inventories will be reduced. This is largely related to the fact that products spends 90-95% of their time waiting, so by enabling a continuing movement of the product the lead time will be reduced.

- **Synchronize production.**
  Since part assembly cannot be be finalized until all components are accessible, it is important to synchronize between manufacturing and assembly. By synchronizing it will be possible to produce according to what is needed instead of what is available.

- **Level the work flow.**
  By enabling a smooth work flow the inventories and lead times can be reduced. Some easily implemented methods to achieve this are to establish a constant work flow, level the release of orders, and justify line balancing.

- **Eliminate variability.**
  The main reason for variability in processes are related to downtime, rework and production methods with a lack of consistency. Some possible strategies to reduce variability are to minimize rework, analyze the variability in supplier lead time, improve the reliability of machines and processes, and plan for yield losses.

Another aspect related to reducing the lead times is to not only focus on the production and operation areas, but also to understand how constraints related to the supply and demand-side affect the lead time (Tersine & Hummingbird, 1995). They explain that a complete strategy for reducing lead time should focus on all bottlenecks in the system and start with the most inhibiting one for the throughput.

4.13 Value-stream mapping

As briefly mentioned in section 1.1 a value stream is the collection of activities, both value and non-value adding, that are needed to bring a product through the flows of the production (Abdulmalek & Rajgopal, 2007). By looking at the entire value stream, and not only eliminate waste at isolated points, could lead to processes that need less space, capital, and time. In addition, information management becomes more accurate and simpler to mange. One tool that are widely used to map flows, identify waste and redesign the products way through the production is Value Stream Mapping (VSM) (Lasa, Labure & de Castro Vila, 2008). VSM helps companies to understand where they are (Current state), where they want to go (Future state), and map a way to get there (Implementation plan) (Chen & Meng, 2010). According to the authors, this create a high-level perspective and look of the total efficiency, and not independent efficiencies of individual departments or production processes.

The main objective while using VSM is to find and take steps towards eliminating all the wastes found in the value stream in order to minimize the amount of non-value adding activities and increase the amount of value-adding activities (Rother & Shook, 1999). Hines and Rich (1997) mentions that in order to make improvements in the value-stream it is important to have an understanding of different wastes in the flow, and VSM is therefore a suitable tool. Rother and Shook (2003) state that "Value-stream mapping is a pencil and paper tool that helps you to see and understand the flow of material and information as a product makes its way through the value stream". They further state that a VSM is a visual representation of the products path through the production, from supplier to customer, involving all processes in the flow of material and information. When looking at the production flow, the flow of material is usually what is focused on, but the flow of information is just as important to look at since it express the next step for each process (Rother & Shook, 2003). Rother and Shook (2003) present four steps for value stream mapping:

1. Select a product or product family that the VSM will focus on.
2. Create a current state map.
3. Create a future state map.
4. Develop a plan on how to implement the future state map.

By starting with selecting a product or product family the map becomes more focused and this is important since the customers only care about the specific product that they are buying and not all the products that the company produce (Rother & Shook, 2003). This product narrowing also avoids making the map too complicated. The authors explain that a product family is a series of products that goes through the same type of processes in the downstream flow of products but with slightly different attributes and components. Both step two and three involve mapping different states, and although the current state map is conducted first it is important to know that these two activities are not strictly after each other but has some overlapping tendency. This means that while conducting the current state map, future state ideas might arise and likewise drawing the future state map will often result in new information that has been overlooked in the current state, and therefore there are some overlapping between these two activities (Rother & Shook, 2003). The last step is to establish an implementation plan on how to minimize the gap between the current and future state. The plan should tell what actions that are needed to move from current state to future state (Bicheno & Holweg, 2000). They further state that after the improvements from the implementation plan has been made and has achieved stable results, the process starts over again, by generating new current and future state maps and this continuous process continues to progressively move towards the vision of lean processes.

On a products way through the factory it passes through several different production processes and in the VSM the product processes are visualized by product process boxes. Rother and Shook (2003) mentions that if the components for the chosen product family goes through different production flows, it is the component with the longest lead time that should be used in the VSM. When the mapping is performed on a factory level, the product process boxes represent a continuous flow without any stop (Bellgran & Säfsten, 2009). The authors clarifies that this implies that an assembly line with several different stations connected with a conveyor belts is seen as one process and it is therefore visualized with a single product process box. For each process data should be gathered, e.g. cycle time (C/T), number of operators, set-up time (S/T) and amount of time available for work (Bellgran & Säfsten, 2009). Furthermore, the authors mentions that the products lead time and tact time through the production are to be calculated and determined. In Table 4.2 below, tact time, cycle time, lead time and set-up time is explained according to Bellgran and Säfsten (2009).

Table 4.2: Explanation of data used for VSM

Measure	Explanation
Tact time	Production rate is synchronized with the corresponding sales tact, customer needs per shift or available work time per shift.
Cycle time	Time needed to finish an article in a sub-process, e.g. the time it takes for an operator to finish his operations.
Lead time	Required time for an article to pass through an entire process or the whole value stream.
Set-up time	The time needed to change and set-up equipment when changing to a new product variant.

After all the data has been collected the map is visualized, as seen in Figure 4.5 below. In the bottom of the map the total lead time is visualized, from raw material entering the factory, through production and finally a finished product ready to be delivered to the customer. By mapping the value-adding time it becomes possible to compare it against the total lead time and see how much of the process that is value-adding (Bellgran & Säfsten, 2009).

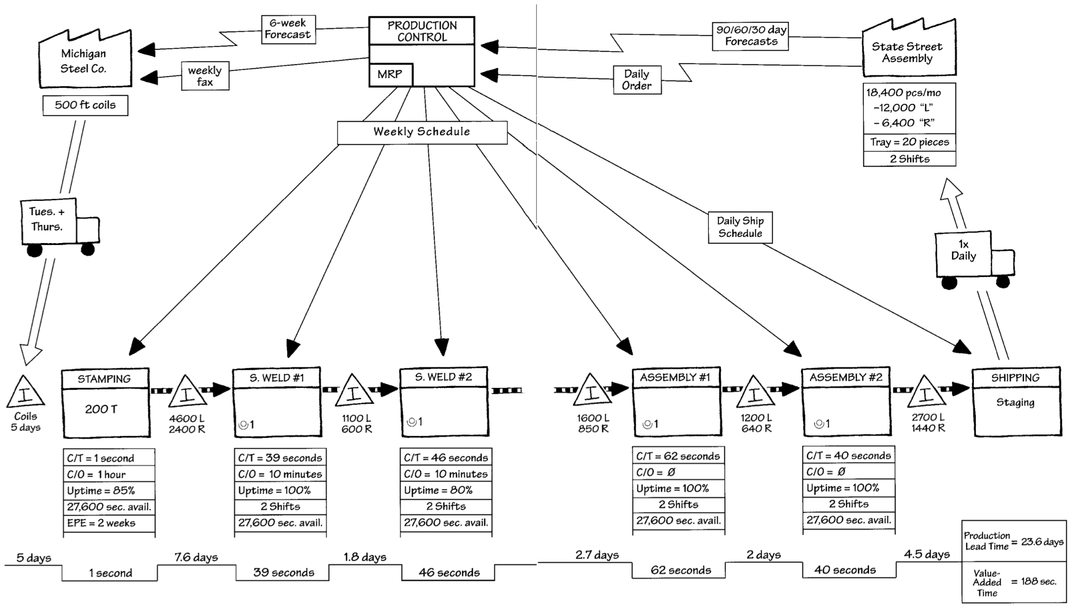

Figure 4.5: An example of a Value stream map (Rother & Shook, 2003).

4.13.1 Current state

The current state phase of a VSM illustrates the as-is situation and is done by collecting information directly from the shop floor (Rother & Shook, 2003). A wide range of data is needed to perform a value stream map, all the way from cycle times and repair times and failures to production planning and order information. According to Skoogh and Johansson (2008) the data collection process includes identifying the parameters that are relevant for the study, but it is also important to decide an appropriate level of detail for the study depending on the complexity.

The mapping process is highly reliant on the quality of the collected data, which makes the collection process a timely but important task (Banks, 1998). To ensure the quality of the data, Rother and Shook (2003) stress the importance of obtaining the information personally through in-person observations since data received from the company rarely reflect and describes the reality in an objective way. The data collection approach is recommended to follow the one presented by Rother and Shook (2003) where the data is collected backwards in the studied process, from shipping back to the beginning of the flow. By doing this the customers will be the starting point and will prevent that the upcoming changes provide something that are not feasible for the customers (Rother & Shook, 2003). To be able to capture the whole picture of the flow, it is preferred that the same persons map the whole stream, but several more people need to be involved to collect the required information if the stream is complex and require much data to be analyzed (Rother & Shook, 2003). When the data is gathered Tapping (2002) suggests that all collected data are discussed and analysed, it is also important to check that all necessary data is collected. If not, repeat the data collection process once more. To avoid delays, it is suggested that the drawing should be done by hand with the usage of predefined symbols and notations (Rother & Shook, 2003). An example of some predefined symbols are presented in Figure 4.6.

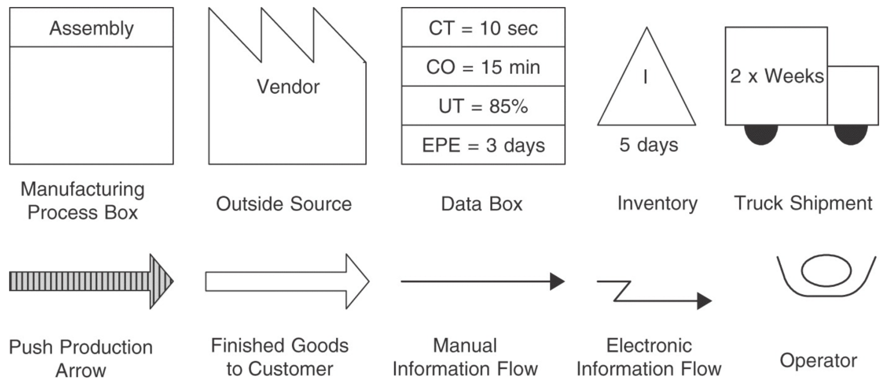

Figure 4.6: Example of common VSM icons (Braglia, Carmignani, & Zammori, 2006).

4.13.2 Future state

The next step after mapping the current state is to map the future state. The future state map is a depiction of how the system should look after all the waste and inefficiencies have been removed (Abdulmalek & Rajgopal, 2007), and consists of analysing the displayed non-value adding activities with the goal to create a production flow where the individual processes gets as close as possible to producing exactly what the customers want and when they need it, either by continuous flow or pull (Rother & Shook, 2003). To assist the creation of the future state map the authors presents a number of guidelines needed. A summary of these guidelines are shown below:

- **Production rate must be matched with takt-time.**
  The takt-time is how often a product or part should be produced and is based on the sales rate. The takt-time helps to match the production rate with the customer demand, specially at the *pacemaker process*, and can be used as a reference as how the production is going. To produce according to the takt-time efforts needs to be focused on providing quick response to errors and elimination of unplanned downtime and changeover time in downstream processes.

- **Establish a continuous one-piece flow wherever possible.**
  A continuous flow means producing one part at a time and each part passing on to the next process step immediately after being finished without any stops. Hence, in a VSM the aim is to combine processes from the current state to the future state. An appropriate approach is to start with combination of continuous flow and a pull-system/First-In-First-Out (FIFO). Once the reliability of the process is improved, the continuous flow can be extended.

- **Establish supermarkets between processes when a continuous one-piece flow is not feasible.**
  In the value stream there are points in which a continuous flow is not feasible due to e.g. different cycle times between processes, thus batching may be needed. To control this process a pull-based supermarket can be implemented.

- **The pacemaker process should authorize the production of parts and direct and control the pace for the whole value stream.**
  The pacemaker process, the one that receive the customer schedule, should control the production rate when applying a pull system. When selecting this process, it determines what elements of the value stream that becomes part of the lead time. This process will thereafter set and control the pace for all the upstream processes in the value stream.

- **The pacemaker process should also plan the maximization of production with regards to leveling volume and variety of products.**
  The more levelled the product mix is at the chosen pacemaker process, the shorter the lead time will be due to smaller inventories. Therefore, the production will be more flexible to respond to changes in customer requirements.

- **Release and withdraw a limited amount of work instructions at the pacemaker process**
  Creating a consistent and leveled production leads to a expected production flow, which shows problems and enables corrections to be made quickly. A suitable start is to do regular releases of a certain amount of production instructions and at the same time remove the same amount of finished products. Releasing a large amount of orders leads to the possibility of processes shuffling orders, hence the lead time could increase.

- **Develop the capability to create *every part every interval.***
  Every part every interval describes the frequency of changes in order to produce different variants. The goal is to minimize the interval over time, e.g. moving from every week to every day. By minimizing the changeover times and using smaller batches the processes will have the capability to respond to changes more quickly. This will lead to supermarkets with less inventory.

Further, Chen and Meng (2010) introduce a few principles practically used when drawing a future state map: *Combine process steps, adopt continuous flow, think parallel not linear, reduce sources of variation*, and *re-design processes.* The authors continue by stressing the importance of making a great effort to realize the future state. An estimation of benefits and implementation costs for all identified improvements is needed to be able to prioritize them considering necessary skills, available resources, and thoughts of plant management. Also, they state that a master plan needs to be developed in order to put the prioritized improvements into practice as projects.

4.14 The seven value stream tools

According to Hines and Rich (1997) there are seven different value stream mapping tools that are suitable to identify the seven wastes of lean production. The different tools have different correlation and usefulness for the different wastes and it is therefore important to understand what waste that exists in order to choose the most appropriate tool. In the following section Hines and Rich's (1997) seven VSM tools will be briefly described.

4.14.1 Process activity mapping

The process activity mapping (PAM) is a tool that aims to develop solutions that can be used to remove waste (Alaca & Ceylan, 2011). According to Hines and Rich (1997) PAM consists of five stages:

1. Study the current flow of the process.
2. Identify wastes in the process.
3. Consider if the process can be rearranged in a more efficient way.
4. Analyze how a better flow can be achieved by mapping the different flows and transport layouts.
5. Consider whether the activities at each stage is required and what will happen if excessive activities are removed.

PAM also involves a preliminary analysis of the processes and thereafter a detailed documentation of all the required items for every specific process (Hines & Rich, 1997). The authors state that this analysis and documentation results in a map of the process and is later used to record which machines and areas that are used, combined with distance moved, number of people involved and time taken. This can thereafter be used for further analysis and following improvements (Hines & Rich, 1997). The basis of this approach can therefore be said to eliminate unnecessary activities, or combine or simplify activities in order to reduce waste (Hines & Rich, 1997).

4.14.2 Supply chain response matrix

The supply chain response matrix seeks to visualize the critical lead-time for a specific process in a diagram. In the diagram the cumulative lead-time for a distribution company, as well as its suppliers and downstream retailers is visualized (Hines & Rich, 1997). In the diagram the x-axis shows the internal and external lead time for a product while the y-axis show the average number of standing inventory at a certain point in the supply chain. By plotting out the lead times and inventory amounts improvement activities can be targeted where needed (Hines % Rich, 1997).

4.14.3 Production variety funnel

The production variety funnel (PVF) originates from the operations management area and is a method with similarities to IVAT analysis and seeks to understand how different products are produced (Alaca & Ceylan, 2011). IVAT views the internal activities in companies that conforms to I, V, A or T plant shapes, where I-plants have an unvarying production of several identical products (Hines & Rich, 1997). According to Hines and Rich (1997) a V-plant "consist of a limited number of raw materials processed into a wide variety of finished products in a generally diverging pattern" (p.53). A-plants consists of a wide range of raw material with a limited range of finished products. The raw material is typically processed in different streams using different facilities. This is typically found in large assembly industries such as aerospace (Hines & Rich, 1997). Lastly, the T-plants is plants with an extensive combination of products, made from a limited number of components. The plant holds a number of semi-processed parts ready to be used in a large range of products, these type of plants are typically found in industries producing electronics and household products (Hines & Rich 1997).

PVF allows to understand how the company operates and how to manage the complexity of the operations (Hines & Rich, 1997). Further, the authors explain that this mapping process can be useful when doing comparisons with other industries that have been more widely researched. Lastly, it is stated that the approach is useful when companies want to gain an overview of the supply chain or target inventory reduction and process changes.

4.14.4 Quality filter mapping

Quality filter mapping (QFM) is a new tool to identify where in the supply chain that quality problems arise, the result is a map that shows where the three types of quality problems appear (Hines & Rich, 1997). The three types of quality problems that exist are *product* defects, which is defects that reaches the customers, *service* defects which is defects that is related to the service and not the product itself (e.g. late deliveries), and *internal scrap* which relates to defects that have been found in the production line inspection (Hines & Rich, 1997). The authors mentions that a QFM helps to identify where in the supply chain that defects occur and helps to focus improvement activities in the following area.

4.14.5 Demand amplification mapping

Demand amplification mapping (DAM) is a tool that helps to analyze how the demand varies and increase as one moves further up in the supply chain, commonly known as the bullwhip effect (Alaca & Ceylan, 2011). Hines and Rich (1997) mentions that a result of this amplification of demand is excessive inventory, production, labour and capacity. They further mentions that the DAM tool helps to visualize how the demand changes in the supply chain and provides information that can be used to improve the decision making and analyze how the value stream can be designed to minimize the fluctuation.

4.14.6 Decision point analysis

Decision point analysis (DPA) is a tool that is appropriate to use for the above mentioned T-plants or for supply chain with similar features. The decision point helps to see where in the supply chain that the pull demand gives way to a forecast driven push. Simplified, it is the point where products stops being manufactured based on demand and instead are solely based on forecasts (Hines & Rich, 1997). The purpose of knowing where the decision point is located is according to Hines and Rich (1997) useful for two reasons: firstly, it makes it possible to assess how the process operates both up- and downstream and thereby helps to ensure that they are coordinated with the proper push or pull philosophy. Secondly, it provides the possibility to create different "what if" scenarios and thereby making it possible to see how the operation is affected if the decision point is moved, this helps to design a better value stream.

4.14.7 Physical structure mapping

Physical structure mapping (PSM) is a tool that is useful to give a high-level understanding of how a particular supply chain looks like at an industry level. This information makes it possible to see how the firm looks and operates and most importantly it gives attention to areas that are not receiving enough developmental attention (Hines & Rich, 1997). The authors explain that the tool is divided into two parts, namely, volume structure and cost structure. In the volume structure map the different suppliers and distribution areas can be seen and how many firms that are involved in each step and in the cost structure map the industry is illustrated on how the cost-adding processes is located, hence it is possible to see if there is any of the activities that are costly and non-value adding that are possible to reduce or remove (Hines & Rich, 1997).

4.15 Spaghetti diagram

Spaghetti diagram is a tool to view and map the movements of an object such as an operator or a product in a system with help of a line (Kanaganayagam, Muthuswamy & Damoran, 2015). With the help of a spaghetti diagram one can track the movements of the object studied and identify number of movements, the length of each movement, and the characteristics of the movements defined after a chosen classification (Senderská, Mareš & Vtháclav, 2017). According to the authors the results from a spaghetti diagram can be applied to identify inefficient movements and areas, hence create the possibility to make changes in layout to increase the efficiency and eliminate non-value adding activities.

4.16 RFID

Radio frequency identification, from now on referred to as RFID, is a technology that uses radio waves for automatic identification of goods and products (Yatinkumar, 2017). The technology has many benefits compared to traditonal barcode scanning; it is able to track moving products since the RFID tag can provide location and specific location, as well as it enables identification from a distance by identifying radio waves (Yatinkumar, 2017). Due to the extended data RFID can carry, it is able to collect real time information about the products, hence the visibility of the production flow increases according to the author.

Khan (2016) explains that RFID can increase the production output while minimizing the cycle time and improve processes by increase the tracking capability, visibility, and velocity at the same time as it will reduce the variation. But, as stated by the author, in order to achieve this, the challenge is to integrate this technology with the firm's IT systems. Wang (2014) argues that RFID is a necessity for increasing the productivity of a manufacturing company due to that data collected through RFID supports the decision-making which affects the production efficiency. The author further states that one of the main functions of the technology include WIP management, which means that you are able to obtain a better overview of WIP through quality query, product tracking and positioning, and prediction of the remaining processing time.

5

Current state

In this section the current state of the factory will be presented and visualized. The information is gathered from observations and interviews held with people from production planning, purchasing and sales department, and people responsible for the different shop floor departments. The section contains information about the current production and information flows.

5.1 Current production flow

As stated earlier, the water heater factory is divided into three different departments; metal sheet and painting, welding, and final assembly. All the metal parts are either manufactured in-house or outsourced through contract manufacturing and supplied to the facility by external logistics partners. When leaving the metal sheet shop, the components are either moved to the painting shop, or to an inventory ready to be supplied to the final assembly line. At the welding shop all operations are performed in-house, and the vessel is manufactured. Between the welding shop and the final assembly, the finished vessels are stored in an inventory before being supplied to the production line by the internal logistics department. Components such as insulation, valves, bolts and nuts, and electrical components are sourced via external suppliers.

Since the *Compact* product family can be produced in different sizes and in either copper, stainless steel, or enamel the production flow can vary. The operations at the final assembly line are shared between all the different models, but the flows are separated at the welding shop. The enamel models are purchased as finished vessels from a supplier, whilst the other models are manufactured in-house. The production flow for the copper models is the most complex of the two, with a few parallel processes, and the production flow of the stainless steel models is more simple and only contains a few operations before being stored in the inventory in front of the final assembly line. According to Rother and Shook (2009) the component with the longest lead time is the one that should be considered in the VSM if the components comes from various sources or have parallel processes. And since the production flow for the copper vessel at the welding shop contains of parallel production steps, the part of the flow that has the longest lead time will be mapped in the value stream map.

A general issue that NIBE has to deal with is that currently the production rate increases faster than they are able to expand, leading to lack of resources at certain locations throughout the flow. And instead of solving the root causes of the problem, they temporarily solve the problems that occur. Further, one of NIBE's strategies is to cover as large proportion of the market as possible, hence phasing out products that still are demanded by some customer segments is not an option. This results in a large product assortment with a lot of low-volume products occupying valuable space and process steps that can not be applicable for the new products, and this is something that limit the potential to expand since these old process steps constrain the capacity for the new ones.

In the following sections a more detailed description of the production flow will be presented, where each department will be described and the specific issues they experience and how these affect the production flow.

5.1.1 Welding shop

At the welding shop the mantles and gables are manufactured for both the copper and stainless steel models, and in the following sections these processes will be explained and visualized.

5.1.1.1 Copper vessel

The copper vessel has a inner coating of copper and a outer sealing of steel and the vessel consists of four major parts with parallel flows. These are; *copper mantle, steel mantle, copper gable*, and *steel gable*.

The production flow of the copper mantles can be seen in Figure 5.1 and starts with a copper coil being processed in cutting operation *00102*, where the coil is cut into smaller pieces, thereafter it is moved by truck to inventory *XS51/52* before being processed in the longitudinal welding operation (*60306*). At operation *60306* the edges of copper plate are welded together. The welded copper mantels are then placed back in inventory *XS51/52*. From here, the mantles are then moved to the next process step, operation *60332* (Mantlecentra) where the copper mantle is merged with the steel mantle and the mantles are then welded together, thereafter *Compact 100* (visualized in orange) is moved to welding operation *01052* and *Compact 200/300* are moved to welding operation *05110*. At these stations the copper gables are attached to the copper and steel mantles. Thereafter all *Compact* models are moved to production line 2 (*60302*), where the final steps for the four main parts are performed and it will therefore be described in the end of this section.

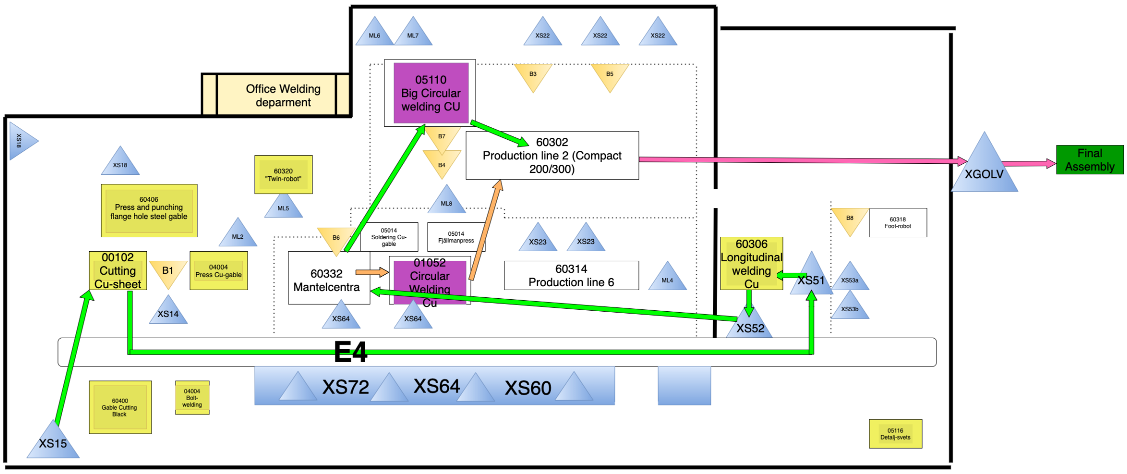

Figure 5.1: Illustration of the production flow of the copper mantles.

The production flow of the steel mantle is shown in Figure 5.2 and starts with a metal sheet coil being cut to metal sheets in process *60400*. Thereafter the metal sheets are moved to inventory *XS64* where it is stored until it is time for the next operation. The *Compact 100* (visualized in orange) moves to process *60337* where the steel mantle is rolled into a cylindrical shape and the edges are welded together. Thereafter it is moved to the end of the *Mantlecentra* station for insertion of the copper mantle. The *Compact 200/300* are moved directly from *XS64* to *60332 Mantlecentra*. At this station the same operations are performed as in operation *60337*, and thereafter a leakage control is performed to ensure the edges are welded together properly. At the end of *Mantlecentra* the copper mantle is inserted into the steel mantle and welded together. After all the activities are performed at *Mantlecentra*, the steel mantles can take two different routes depending on the size of the vessel. The *Compact 100* moves to welding operation *01052*, whilst the *Compact 200/300* moves to welding operation *05110*. At both these stations the steps described for the copper mantle is performed and thereafter the vessels move to Production line 2 (*60302*).

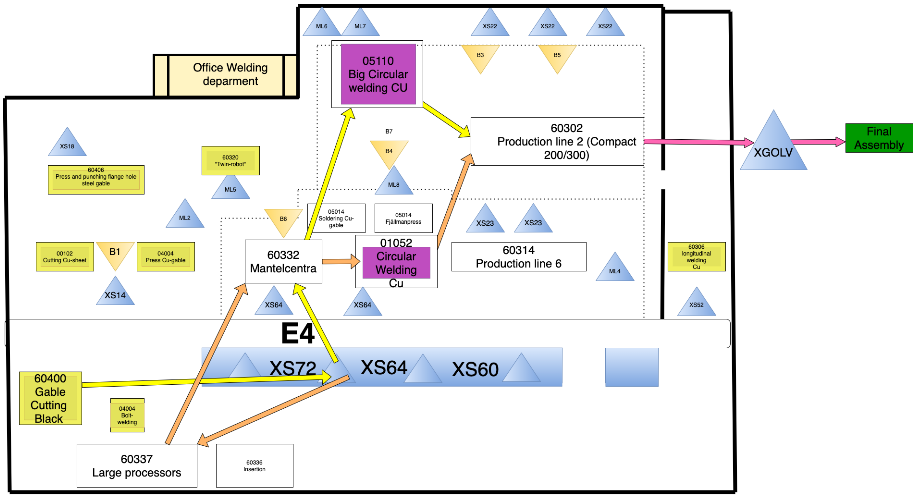

Figure 5.2: Illustration of the production flow of the steel mantles.

The production flow for the copper gable is shown in Figure 5.3. The flow starts at the same process as the copper gables, at operation *00102*. Here the copper coil is cut into small rectangular sheets and thereafter moved to inventory *XS14*. Thereafter, the copper sheets are sent to operation *60404* where they are pressed and shaped into half spheres. After the pressing operation, half of the copper gables (the so called mother gables) are sent to inventory *XS64* and the other half is sent to press and punch operation *00302*, which is located at the metal sheet shop. At this operation the hole for the flange is punched and the flange is attached to the gable. Thereafter, the processed copper gables are transported to inventory *XS22* before being moved to the soldering operation *05014*, where pipes for hot and cold water are attached. After this, the copper gables are sent back to inventory *XS22* once again until the next process is ready. From here the gables for *Compact 100* are moved to welding operation *01052* and gables for *Compact 200/300* are moved to welding operation *05110*. At these stations both the mother gables and the processed gables are welded together with the copper and steel mantles. Thereafter the vessels are moved from operation *01052* and *05110* to the production line (*60302*), which is the final operation within the welding shop.

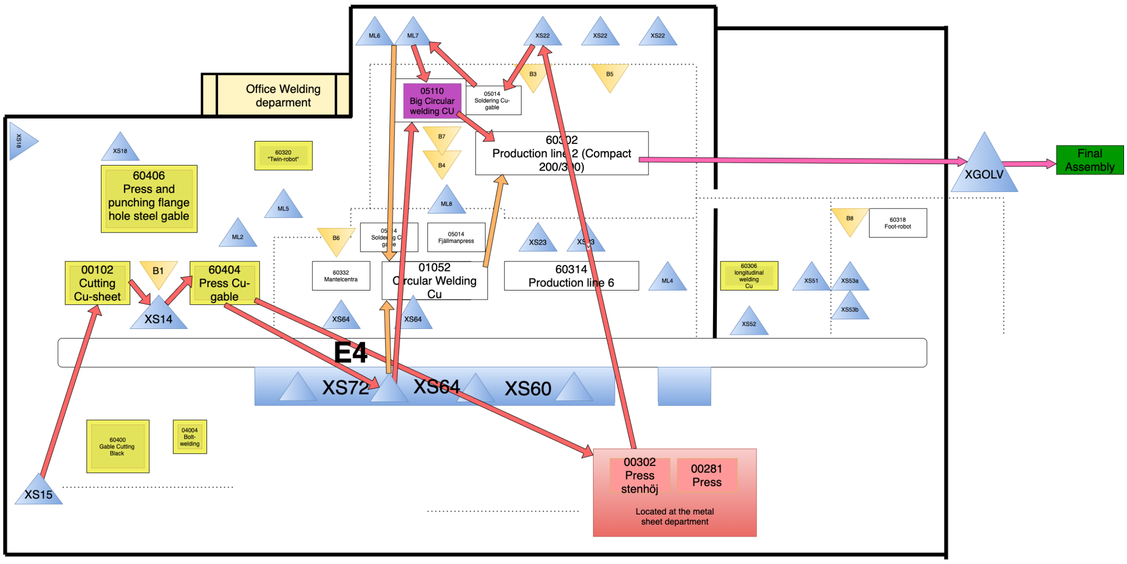

Figure 5.3: Illustration of the production flow of the copper gables.

The production flow of the steel gables is illustrated in Figure 5.4. The production starts with steel plates being cut into circular plates at *60400*. These are then moved to the inventory at *XS18* where they are stored until they are processed in *60406*. At this station the cylindrical steel plates are pressed and formed into gables. From here half of the gables are processed further where a hole is punched and a flange is attached, whilst the other half (the mother gables) are moved to inventory *XS64*. Thereafter, the processed gables are moved to the twin robot (operation *60320*) where a robot performs some minor operations such as welding on attachments onto the gable. After that an ocular examination is conducted by an operator to make sure the welding is correctly performed and that the weld is sealed. When this is done the gables are transported to inventory *XS22*. Thereafter the gables from both inventories are moved to Production line 2 (*60302*) where the gables are merged together with the other components.

At Production line 2 *(60302)*, the final steps of the vessel is performed. At this station the four different flows are merged together. The steel mantel, now merged together with the copper mantle and copper gables who acts as corrosion protection, are moved from welding operation *05110* or *01052*, and thereafter the steel gables are attached and a circular welding is performed to make sure the gables are properly attached to the rest of the vessel. Thereafter some minor attachments and mounts are attached to the vessel before it is finished and ready to be moved to the final inventory at *X-Golv*. Here the finished vessels are stored until they are requested by the final assembly. The final assembly will be described at section 5.1.4.

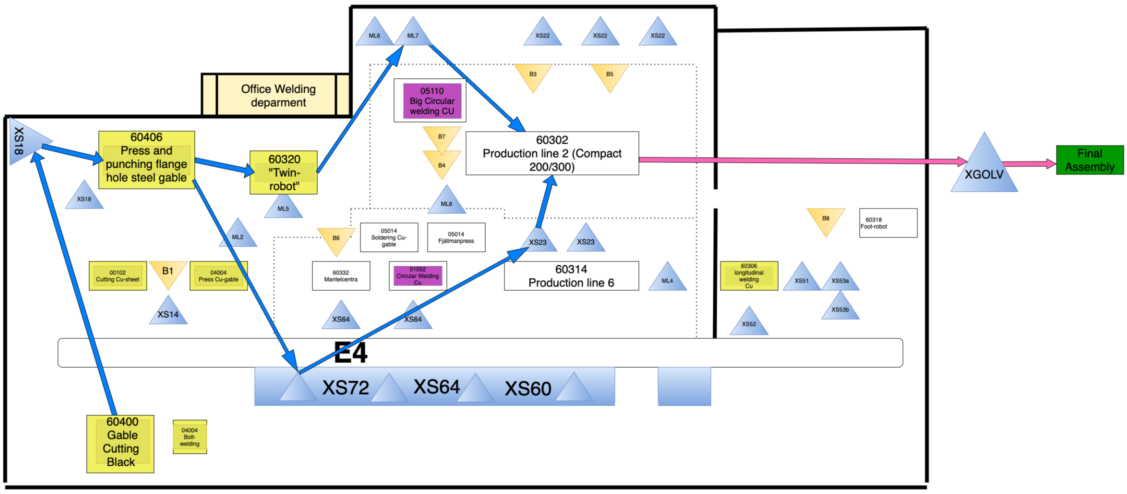

Figure 5.4: Illustration of the production flow of the steel gables.

In the majority of the operations at the welding shop, a change over for the machine is required when switching between the different vessel sizes, since the diameter of vessel changes between the different product families. Due to the fact that a change over is required when switching between sizes, this implies that the priority list is not always followed exactly and that operators chose to rearrange some of the orders so that orders with the same diameter is produced in the same sequence. Thereby, the operators do not have to perform change overs as often as if they would have followed the priority list completely. This leads to that orders are produced at another time than planned and therefore a need to store the components that has been produced earlier.

Another problem related to capacity is that all *Compact* products have to pass through the operations *Mantlecentra (60332)* and *Circular welding Cu*, and currently they only have one resource for *Mantlecentra* while they have two circular welding operations *(01052/05110)*. This causes a mismatch in capacity between the processes which results in that inventories occurs if they don't take this into consideration.

The lack of available factory space has caused problems when new machines are to be implemented in the facility. The machines are therefore placed where there is an available spot, which often leads to a production layout that is not optimal where machines and processes are spread out, hence causing an extra need for transportation between the processes.

5.1.1.2 Stainless steel vessel

The stainless steel vessel consists of two major components, the two gables and the mantle, making this production flow considerably shorter compared to the copper vessel. The production flow for the stainless steel vessel will be described in the following section and is illustrated in Figure 5.5.

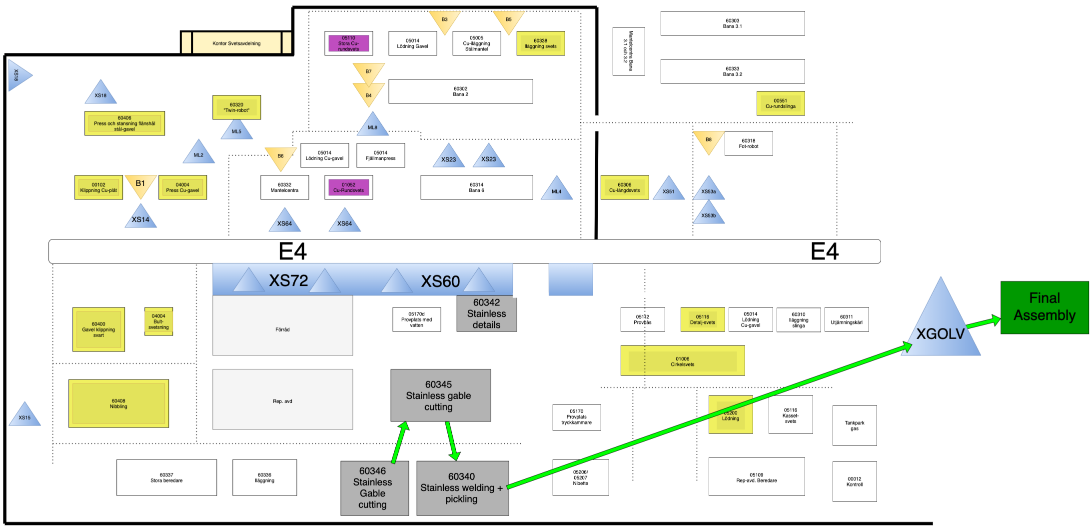

Figure 5.5: Illustration of the production flow for the stainless steel vessel.

The production starts with stainless steel being cut to circular pieces in operation *60346*, thereafter they move to operation *60345* where the circular pieces are pressed into gables. From this operation the gables then move to operation *60340*, where sheets of stainless steel are formed into cylindrical mantles and thereafter the gables are attached and welded together with the mantles. After this station the vessel is finished and ready for assembly, before moving to the assembly the finished vessels are moved to *X-Golv* where they are stored until it is time to produce at the final assembly.

This is a relatively short and simple flow with few involved operations. During interviews it has been stated that this flow is well planned and no long transportation between the different operations is needed. Further, the decision to have a high focus on customer orders in order to be able to deliver on time has resulted in that customer orders are highly prioritized and therefore products that are not assigned to customers are removed from the processes as soon as a customer order is received, resulting in large WIP and intermediate inventories.

5.1.2 Metal sheet shop

In the metal sheet and painting shop components for all products in NIBE's product portfolio are manufactured. For the product family *Compact*, the main components that are manufactured are the front, side, top and back plates that covers the vessel (as seen in Figure 3.2) as well as the foot frame holding the vessel. These are also the components with the longest lead time and therefore these are the components that will be further described in this section.

The flow of the front plate is illustrated in Figure 5.6. The production starts in one of the two machines at operation *04034*, where the metal sheets are cut and punched to obtain the correct form. After that they are moved to *00428* where the next step is performed, and then moved to the buffer zone where they are placed until it is time for components to be painted. Thereafter they are moved to an intermediate inventory located at *PTRAN3*, before being moved to the buffer area for the final assembly.

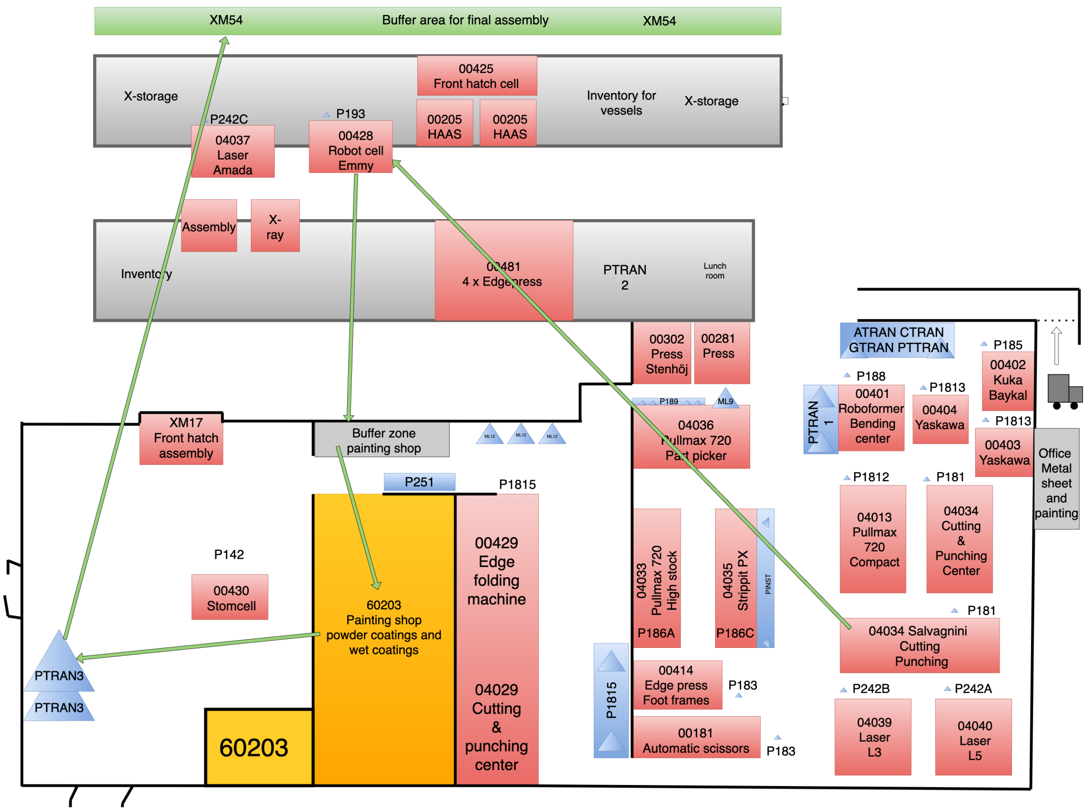

Figure 5.6: Production flow for the front plate.

For the side and top plates, the flows involve the same process steps and these are therefore shown together in Figure 5.7. The only difference between the production of these components is that the machines are using different settings for the two parts, since they have different sizes. The process starts with metal sheets being cut and punched in *04029*, thereafter it moves to *00429*, where the edges are folded and bent. These two machines are connected via a conveyor belt, so the components moves directly from the first process to the next without being placed in inventory. After these steps are done the components are placed in material racks and lifted out from the machine by truck and thereafter moved to the buffer zone located next to the painting shop. From the buffer the plates are then moved to the painting shop and thereafter to *PTRAN3* and finally moved to the buffer area located next to final assembly.

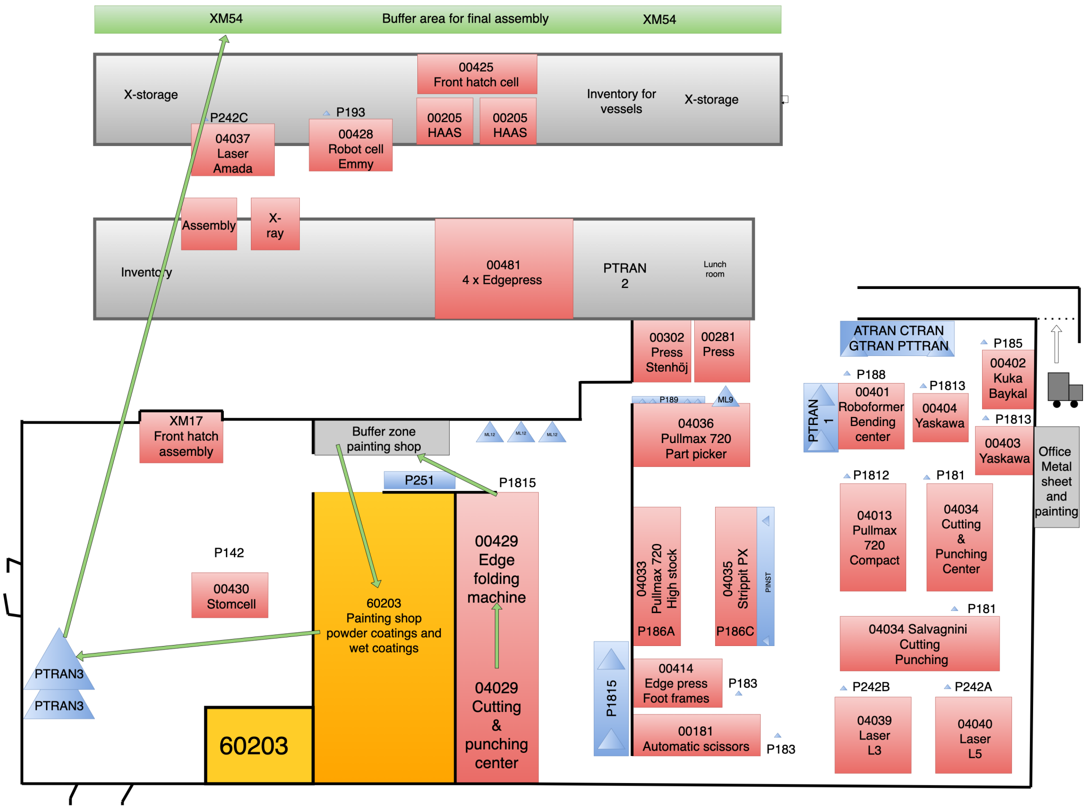

Figure 5.7: Production flow for the side and top plate.

The foot frame the vessel stands upon is produced according to the flow illustrated in Figure 5.8 below. The production starts at operation *00181* where metal sheets are cut and thereafter it is bent to a rectangular frame at *00414*. Thereafter the frames are moved to the inventory at *XS53b* where it is stored until it is processed at operation *60318*. Here the left side and right side of the frame are welded together. After this the foot frame is moved to the inventory at *XS53a*, and thereafter moved to the buffer area at the painting shop. From here it is then moved to the painting shop and thereafter to *PTRAN3*, before moving to the buffer at the final assembly.

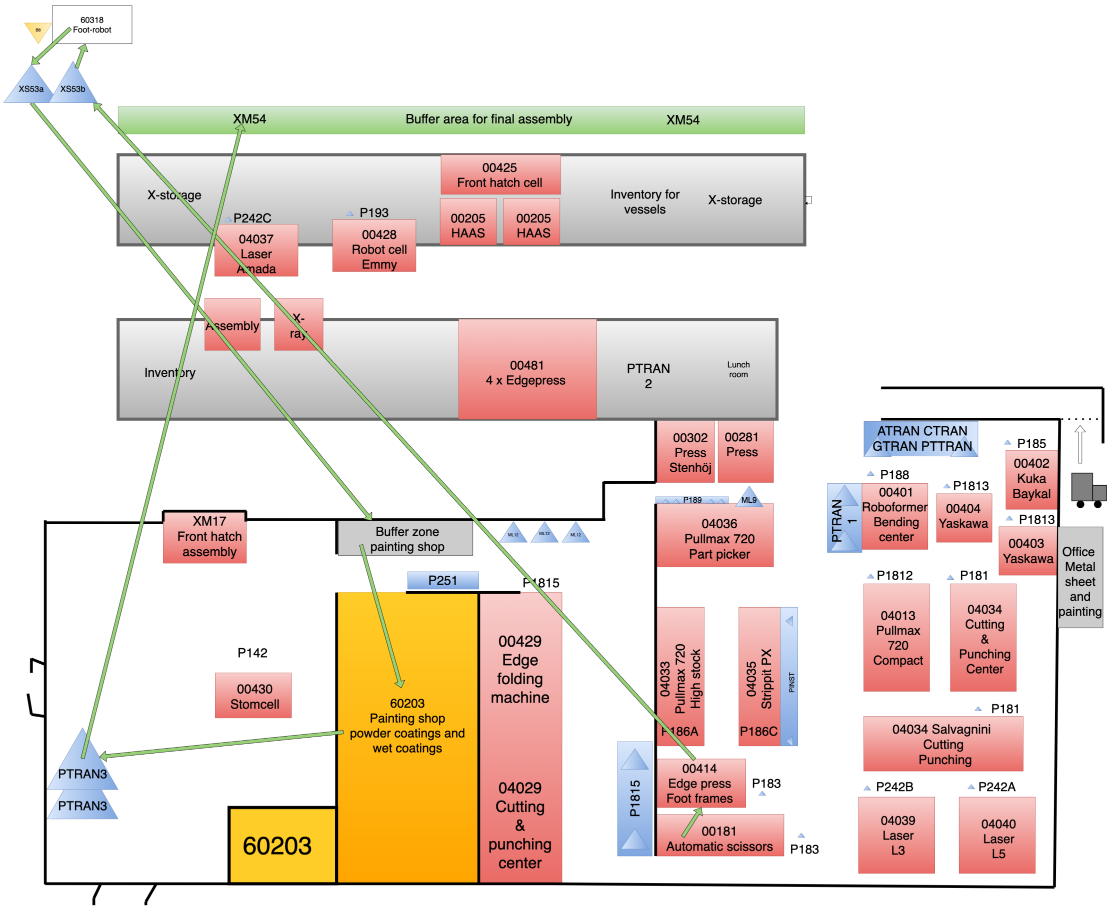

Figure 5.8: Production flow foot frame.

The production of the back plates is seen in Figure 5.9. This is the flow with the least amount of processes involved regarding the main components within the metal sheet shop. The production starts at operation *04029* where a metal sheet is cut and bent, and is thereafter moved via the conveyor belt to operation *00429* where the edges are folded and the back plate gets its final form. Thereafter the components are placed in material racks and moved by truck to inventory *XM54* at the final assembly.

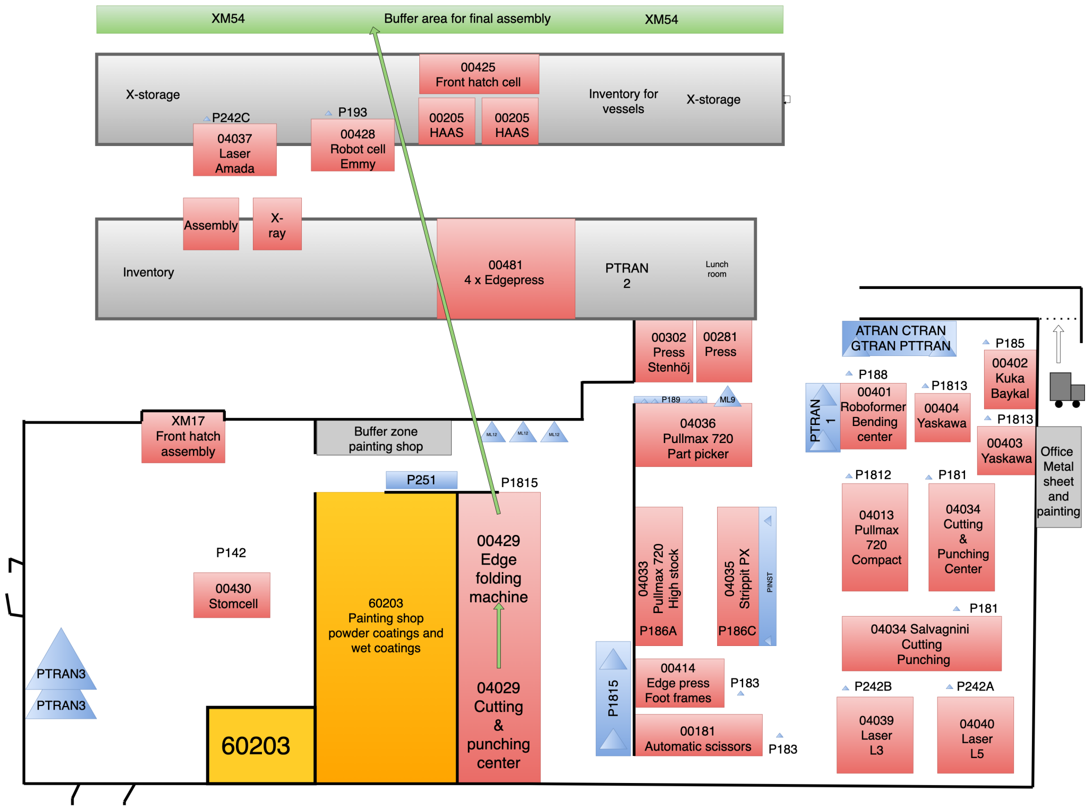

Figure 5.9: Production of the back plates.

In general the operators at the metal shop are supposed to follow the priority list to the greatest extent possible, but in order to minimize the number of changeovers and to minimize the amount of material that needs to be scrapped, the operators can merge an earlier order with a later order if they use the same material. This creates a need to store the components produced earlier than planned. Problems also arise when a re-prioritization of the priority list occurs that do not match with the material currently available in the machines, causing a need for a changeover which causes disturbances and results in a delay so that the orders that were supposed to be produced during the day are not finished. When a re-prioritization occurs the unfinished material that are currently being processed are removed from the machines and placed as inventory between processes until it is needed again. This further increases the need for factory space and leads to lack of space.

5.1.3 Painting shop

At the painting shop, the material racks are moved from the buffer zone located next to the station to the area where the plates are attached to the painting line. Thereafter, an operator lifts the components from the material racks and hangs them on the hooks that are attached to the line that transports the components through the whole painting operation, which is illustrated in Figure 5.10. At this station the components go through a number of steps, such as; washing, surface treatment, painting, hardening, and cooling. After the components have moved through the painting line they are placed at inventory *PTRAN3*, before being transported to the buffer area located next to the assembly line.

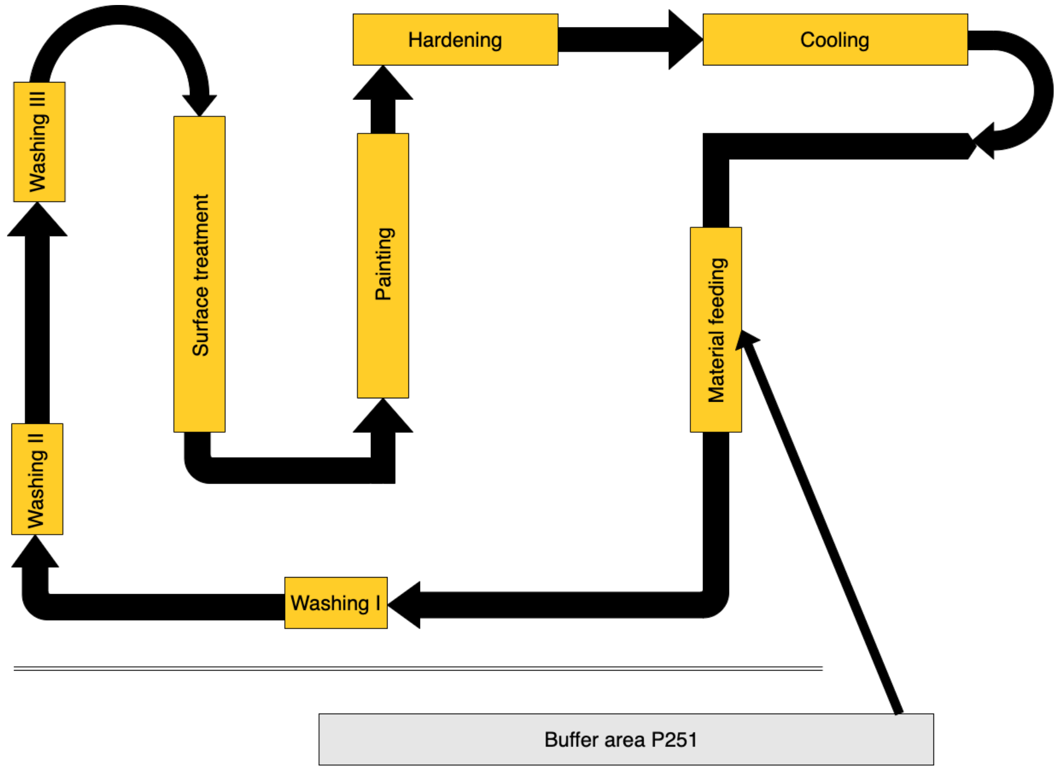

Figure 5.10: Layout of the painting line.

The components can be painted in seven different colours and a changeover takes roughly 20 minutes. The goal is therefore to minimize the number of colour changes between orders to minimize the changeover time. But, this affects the buffer area *P251* since their strive to minimize the number of changeovers results in that the amount of different products stored increases due to that orders that shall use the same colour are being prioritized. This problem was noticed since it was visible that the buffer area has no clear structure and that it often causes problems such as material racks blocking each other leading to additional movements and traffic congestion.

5.1.4 Final assembly

The final step in the production process is the final assembly. This part is a line-based production flow, where parts from the different sources are brought together into the finished product. The layout of the final assembly is illustrated in Figure 5.11

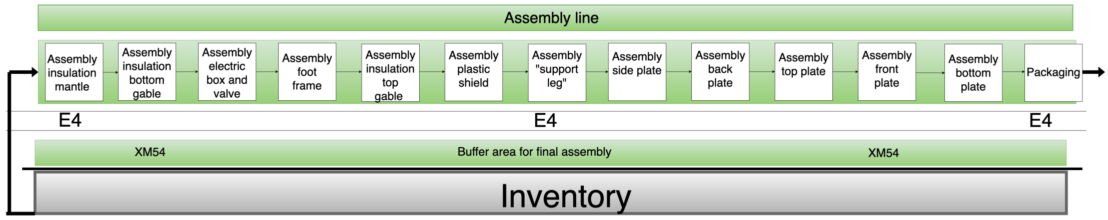

Figure 5.11: Layout of the final assembly.

From the inventory between the welding shop and the one illustrated as the grey area in the figure, the finished vessels are brought to the assembly line by the internal logistics department. Further, components such as various plates are brought from the painting shop and placed at the buffer area at the other side of the traffic passage. From this area components are then supplied to the production line when needed. When all process steps are complete, the finished product are brought to the loading dock by the two available AGVs before being transported to the warehouse.

One major issue that was brought up that affect the production flow is the disturbances in the material supply. At present, material are stored in inventories that are wide spread, e.g. in Strömsnäs and Markaryd. This makes the material flow not as efficient and reliable as they would like it to be. The warehouse in Strömsnäs is ran by a third party which affect NIBE's possibilities to control the material supply. Further, the continuous changes in the production plan makes it hard for the third party to follow the plan that NIBE have provided, resulting in that wrong material are delivered and material shortages occur. NIBE express a wish to have more material at the production facility before it is needed in order to increase the control over the material flow and reduce the disturbances. But due to the lack of space this is not possible in the as-is situation. As stated earlier, the current solution also affect the planning work since there might be a request to produce a certain amount of the same product, but this might not be possible to do since there is not enough material at hand.

5.2 Current information flow

As stated earlier, the water heater heater factory is divided into three different departments; metal sheet and painting, welding, and final assembly. Currently all these departments are operating as isolated units with their own production objectives. The production planners are responsible for what should be produced for each department. The production orders are sent to the corresponding departments daily, and the information is sent directly to the department managers and the orders are then distributed to the operators as priority lists.

To plan the production NIBE uses two separate systems, Kompass and Infor XA. These two systems form the basis for the planning activities, and input to the systems are sales forecasts produced by the sales department to create a production plan. Together with the production plan generated from Kompass, Infor XA uses the product structure to determine what material that is needed and when in time it is needed to be able to initiate the production. This information is then sent to the purchasing department and to the production departments to give them information when to purchase third party material and when to start the production. But even though the ERP systems are updated correctly and the forecasts are somewhat accurate, there is a prevalence of mismatch between the available capacity and the capacity needed to follow the plan due to the limitation that the planning program does not take the available capacity into consideration when creating the production plans. The consequences of this become visible through overcrowding which further results in that the they reduce the ability to produce the required output in time. Further, overcrowding can lead to occurrence of intermediate inventories. This has a negative impact on the throughput of the products. Also, inventories throughout the production flow take up valuable space, tie up capital, and decrease the overview of the production flow.

The information between the planning department and the production departments mainly flows through the ERP systems. The orders are released through the ERP systems, and are thereafter visible in the operators' priority list. When changes happen these are visible directly in the priority lists. These forecasts are provided monthly to the planning department via meetings, and then embedded in the system. Further, people from both the planning department and the production departments have daily meetings where they discuss the schedule, how they perform compared to the set objectives, and if there are any special events that require additional attention.

One of the major issues in the flow is the fact that the production planning is never completely fixed, i.e. there is no frozen time period, and changes can thereby be made relatively close to the planned production start. The prioritization of what orders to produce is conducted by the ERP system and is based on the forecast and the desired safety stock. But, since NIBE has an approach to prioritize customer orders over make to stock orders, it can lead to changes in the production plan on a short notice. So, when a customer order is received it is moved to the top of the production plan and initiates a process where required material is being requested. Since these changes can happen on a short notice it often leads to lack of material and causes delays in the production.

Another issue that was stated during the interviews was that when a change is made in Kompass, this shows up in the priority list with one day delay due to that Kompass and XA only communicate with each other during the nights. This can cause major problems since one order that was released the day before may not suddenly be needed, ending up in that lots of semi-finished goods are stored in the factory.

5.2.1 Current state map

When mapping the current state with parallel production flows, Rother and Shook (2003) explain that it is the component with the longest lead time that should be visualized in the VSM, and by comparing the different flows, illustrated in Appendix B, it can be seen that the production for the copper gables have the longest lead time in the welding shop. Therefore this is the current state map visualized in Figure 5.12 below. The inventory levels between the different operations are calculated by taking the daily inventory levels during a period of four weeks, and then calculate the average inventory levels. For some inventory locations data was missing and these have therefore not been able to evaluate. For the inventory (*P251*) next to the paint shop the inventory levels for specific components have not been available, but during interviews it was stated that a simulation model have been developed and through this it was possible to calculate that the components on average spends 36 hours in the buffer, hence this is therefore the number that has been used for this specific inventory.

The same reasoning goes for the different plates within the metal sheet shop. The component with the longest lead time is the foot frame, hence this flow will be included in the current state map illustrated in Figure 5.13 below.

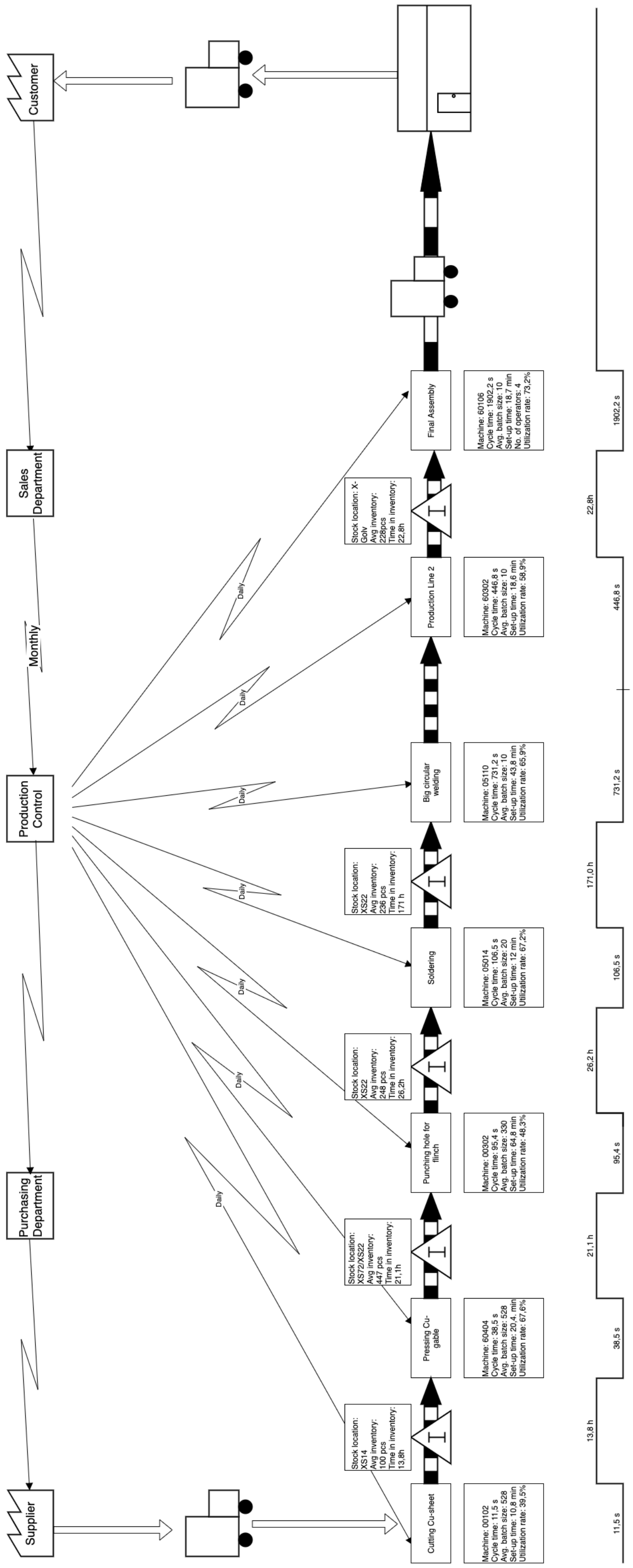

Figure 5.12: Current state map for the welding shop and the final assembly.

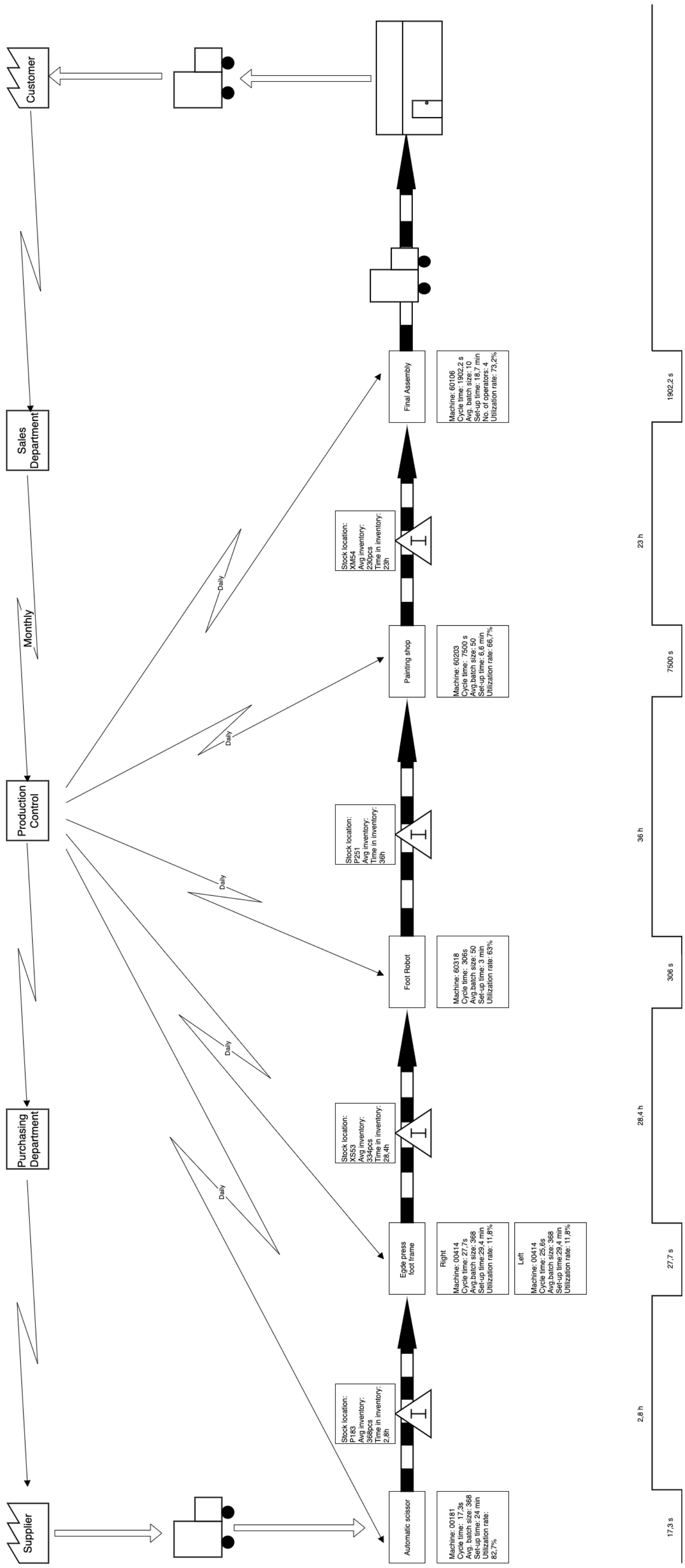

Figure 5.13: Current state map for the metal sheet and painting shop and the final assembly.

6
Analysis

This section contains an evaluation and an analysis of the current state map.

6.1 Utilization rate

By looking at the planned utilization for the different processes within each production flow, it becomes possible to analyze if there is any process that operates at a higher level than the other processes and hence may become a bottleneck if the capacity is to be increased. It has been stated during the interviews that the objective when planning the production is to have an utilization rate around 80 %, mainly due to cope with variation in production rate, and to cover temporary disturbances in the production.

6.1.1 Welding shop

At the welding shop, the utilization rates for the production flow of the Cu-gables varies between 67,6 and 39,5 %, hence one could see that an increase in the production rate would not entail that a bottleneck would occur since there are available capacity at all the operations. Roser et al. (2002) state that when the workload between different operations is very similar it becomes hard to identify which operation that is the bottleneck. In order to determine the bottleneck, the average waiting time method is used, hence the operation where the products spend the most time in front of is considered the bottleneck (Roser et al., 2001). By looking at the current state map, the operation with the longest waiting time is operation *05110* (Circular welding). The major reason for this is the long cycle time compared to the other operations, as stated earlier. This is aligned with Holweg et al. (2018) since they explain that insufficient capacity due to variation is one of the major causes to why bottlenecks arise. The authors further mention that variation in cycle times between different operations is one of the configurations that variation can appear through. This gives an additional explanation and support the findings. Also, as explained by Little's Law, the long waiting time could harm the capacity of the production flow since it constrain the throughput.

The three other flows in the welding shop, presented in Appendix B, follows the same pattern. The utilization rate rarely exceeds 80 %, except for operation *60406* (steel gable press), and operation *60320* (twin robot) that have utilization rates just over 100 %. As illustrated by Kingman's formula (Holweg et al, 2018), these operations can lead to increased waiting time if the throughput is increased and therefore contribute to increased WIP in the production flow. When analyzing the current state map, a possible explanation for the high utilization rate for these two operations could be that the first operation, operation *60400* (gable cutting), has an average batch size of over 800, compared to around 100 for operation *60406* and operation *60320*. Also, when studying the average waiting time, the longest time the products spend in front of an operation is in front of operation *60320*, hence one can argue that this operation can be seen as the potential bottleneck.

The planned utilization rates for all operations within the welding shop is presented in Table 6.1 below.

Table 6.1: Planned average utilization for the operations at the welding shop. The standard deviation is measured in percentage points (pp).

Process number	**Process name**	**Utilization Rate**	**Standard Deviation**
00102	Copper Cutting	39,5 %	19,9 pp
60404	Press Copper Gable	67,6%	34,5 pp
00302	Press and Punch	48,3 %	22,4 pp
05014	Soldering	67,2 %	29,9 pp
05110	Big Circular Welding	65,9 %	28,3 pp
01052	Circular Welding	56,4 %	18,5 pp
60302	Production Line 2	58,9 %	22,4 pp
60306	Longitudinal Welding Copper	67,1 %	38,6 pp
60332	Mantlecentra	80,1 %	26,0 pp
60400	Gable Cutting	66,1 %	46,2 pp
60337	Large Processor	42,7 %	20,6 pp
60406	Steel Press	105,6 %	44,8 pp
60320	Twin Robot	102,3 %	46,1 pp
60345	Stainless Gable Press	156,9 %	64,7 pp
60340	Stainless Welding + Pickling	80,0 %	29,0 pp
60346	Stainless Gable Cutting	7,6 %	2,4 pp
60106	Final Assembly	73,2 %	46,3 pp

When studying the flow for the stainless steel vessels, one could identify that operation *60345* (stainless gable press) has a utilization rate that lies nearly 160 %. By comparing this number with the utilization rate for the other processes in the flow, operation *60346* (stainless gable cutting) , and operation *60340* (stainless welding + pickling), these processes have an utilization rate of 7,6 % and 80,0 % respectively. As mentioned by Roser et al. (2001), the operation with the highest workload should be considered the bottleneck, and as can be seen in this particular case, operation *60345* has a much higher workload compared to the other two operations in the flow. As explained earlier, Kingman's formula visualizes that this operation runs the risk to contribute to a higher waiting time, strengthening the facts that this operations is a potential bottleneck. By calculating the standard deviation for process *60345*, it is noticed that the production is far from levelled since the standard deviation of the utilization rate is 64,7 percentage points. Further, by analyzing these numbers, it reveals that the operation during some periods is heavily over utilized, and at some time periods not. This results in that there is a build up of inventory after this operation during the periods of high utilization rate. This is something that could be reduced by having a more levelled production, and therefore a more evenly distributed utilization rate.

To summarize the findings, the main bottleneck that was identified when analyzing the production flows at the welding shop was operation *05110* (circular welding), mainly due to that the average waiting time in front of this operation was the highest. As stated earlier, this can be linked to the high variation in cycle time compared to the surrounding operations, as mentioned by Holweg et al. (2018). According to Little's Law (Little & Graves, 2008), this bottleneck could harm the capacity of the production flow at the welding shop since a long waiting time implies an increase in WIP, or that an increase in the throughput is not possible.

Other potential bottlenecks, other than operation *05110*, could be the ones with high utilization rates. As stated in section 1.2, NIBE is planning to double their production volumes, partly by increasing the efficiency of the current production. According to Kingman's formula, illustrated in Figure 4.2, the lead time increases rapidly when the utilization rate approaches 100 %. Therefore, the operations with the highest utilization rates might become possible bottlenecks in the future. And in order to increase their capacity with existing resources this is something to pay attention to since it might become a problem when the volume increases and the available capacity is constrained.

6.1.2 Metal sheet and painting shop

For the metal sheet and paint shop the planned utilization rate for all processes are presented in Table 6.2 below.

As can be seen in the table below, operation *04034* (Salvagnini Cuttings and Punching) operates at the highest utilization rate. According to Kingman's formula, this operation may contribute to long waiting time since the utilization in the as-is situation already is very high, and a future increase in the production rate may imply that this operation will be one of the primary bottlenecks at the metal sheet shop. Also, operation *00181* (automatic scissor) and *04029* (cutting and punching) have been identified as potential future bottlenecks due to that their utilization rates lie above 80 % respectively. This is also aligned with Roser et al. (2001) who claim that the operations with the highest workload should be considered as bottlenecks. It can also be noted that for these processes the planned utilization varies since the standard deviation for the utilization rate range between 21,5 and 30,2 percentage points, indicating that the production is not entirely leveled. Hopp et al. (1990)

Table 6.2: Planned average utilization for the operations at the metal sheet and paint shop. The standard deviation is measured in percentage points (pp).

Process number	**Process name**	**Utilization Rate**	**Standard Deviation**
04029	Cutting and Punching	81,1 %	21,5pp
00429	Edge Folding	63,2 %	17,3pp
04034	Cutting and Punching (Salvagnini)	102,9 %	25,7pp
00428	Robot Cell	73,9 %	30,0p
60203	Painting Shop	66,6 %	21,9pp
00181	Automatic Scissor	83,8 %	30,2pp
00414	Edge folding foot frame	9,6 %	16,4pp
60318	Foot Robot	65,5 %	20,7pp

mention that to reduce waiting time and inventories a leveled work flow should be established.

Another aspect to look at when evaluating bottlenecks is where the components spend the most time waiting, as stated earlier. By looking at the current state map for all flows within the metal sheet and painting shop it can be noted that the components spends the most time waiting before operation *60203* (painting shop), where they spend around 36 hours. Therefore, this operation can also be seen as a potential bottleneck when increasing the capacity. The main reason for the long waiting time is related to the fact that the painting shop paints components for all the products produced in Markaryd. It therefore handles a wide variety of products, leading to a number of different set-ups to cope with regarding the different components. According to Little's Law (Little & Graves, 2008), this bottleneck could harm the capacity of the production flow at the metal sheet and painting shop since a long waiting time implies an increase in WIP, or that an increase in the throughput is not possible. Further, an increase of the production portfolio could imply that the number of set-ups at the painting shop could increase and therefore also the waiting time, leading to an increase in WIP.

6.2 Inventories and buffers

As stated by Liker and Meier (2006), excess inventory leads to increased need for storage, and increased costs due to transportation, tied up capital, obsolescence, and damaged goods. Further, as explained in section 4.12, excess inventory is one of the major sources to long lead times (Rother & Shook, 2003), and Hopp et al. (1990) express that shorter lead times can reduce work in progress and thereby reduce the need of storage space. According to Little's Law (Little & Graves, 2008), this imply a potential to increase the throughput. In the current state map for the welding shop it can be seen that the total throughput time for the copper vessels is 10,65 days, where the value-added time is 39,15 minutes. This implies a total share of the total throughput time of 0,26 percent. The majority of the the production lead time can be derived to the many intermediate inventories that are located throughout the production flow. From the current state, 5 major inventories and buffers have been identified. When analysing the current state map for the metal sheet and painting shop, one can identify 4 major inventories contributing to a total lead time of 3,87 days with a value-added time of 162,6 minutes. The much larger share of value-added time at this flow compared to the production flow at the welding shop can be explained by that operation *60203*'s (the painting shop) whole cycle time is considered as value-added time.

Table 6.3 and Table 6.4 show the distribution of value-added and non value-added time of the total lead time for the flows with the longest lead time for each department.

Table 6.3: Parameters for the as-is production situation at the welding shop.

Total lead time	Value-added time	Non value-added time	Value-added time as share of the total lead time
10,65 days	39,15 minutes	10,62 days	0,26 %

Table 6.4: Parameters for the as-is production situation at the metal sheet and painting shop.

Total lead time	Value-added time	Non value-added time	Value-added time as share of the total lead time
3,87 days	162,6 minutes	3,76 days	2,92 %

The largest inventories are the ones that are located between the different departments, e.g. between the welding shop and the final assembly. The inventory called *X-golv* includes all the finished vessels before they are transported to the final assembly line, and on average the inventory stores 228 *Compact* vessels. Currently the synchronization between the welding shop and the final assembly is off due to the problems with the material supply from Strömsnäs. This leads to rapid changes in the production plans and transpositions of orders, hence the inventory increases due to that the required products and components are not available. According to Hopp et al. (1990) synchronized production is a prerequisite for less inventories since assembly cannot be finalized until the right products and components are accessible, and by synchronizing the different departments it will be possible to produce according to what is needed instead of what is available.

The inventory that contributes the most to the average waiting time is *XS22*. This inventory includes all the copper gables that are pressed in operation *60404*. The most obvious reason to that this inventory contributes to the long lead times is that many of the copper gables are shared among many different products, hence the inventory do not contain gables that are solely related to the *Compact* products. Another reason that was identified when studying the cycle times was the big difference between the processes before and after the buffer. The cycle time for welding operation *05110* is roughly seven times longer compared to the previous operation, *05014* (soldering). This is aligned with Chiarini (2012) who states that processes operate at different speed is one of the main reasons for inventory build ups. Also, the previous operation in the flow runs at a reinforced two-shift, compared to the normal two-shift that the succeeding operation runs at. This variation contributes to the high inventory levels in this particular inventory. This is aligned with Holweg et al. (2018) who claim that variation in capacity require more space, inventory, and labour.

At the metal sheet and painting shop, the largest inventory that was identified was *P251*, the buffer area in front of the painting shop. The two main explanations that were identified was the long cycle time compared to the other operations, and that the painting shop paints components for all of NIBE's factories in Markaryd, hence there is a vast mix of products that pass through leading to a lot of changeovers and other disruptions, forcing components to wait in front. The variety in cycle time between the operations and the variation of products passing through the painting shop is identified as the main reasons to the build up of inventory in front of this operation, hence harming the capacity of the flow.

The general analysis regarding inventories is that if the production capacity should increase, the average waiting time need to be reduced according to Little's Law (Little & Graves, 2008). This implies that in order to reduce the waiting time, the time spent in inventories must be reduced if the WIP should not increase. As visualized earlier, the total time spent in inventory in the current state is rather high due to the many inventories throughout the production flow. Suggested improvements regarding this matter, and how the capacity could be increased, will be presented in section 7.

6.3 Transportation

As mentioned in section 4.11.1, excessive inventories is one of the major reasons for the increased need for transportation. Transportation is related to a cost of both the truck and the operator, reducing the need for transportation is therefore a potential way to reduce the cost for the production. Further, a reduction of transportation will decrease the average waiting time for the products, thereby reducing the need for transportation could also lead to an increase in capacity due to an increase in throughput, as stated by Little and Graves (2008).

By looking at the illustrations of the different production flows above in section 5, it is possible to see that products move all over the factory, indicating that the components needs to be handled and transported between each activity. The major reason for this is related to the layout of the factory and the fact that the following process often is located at another location than the previous process, therefore causing a need for the components to be handled and transported.

By analyzing the data from *Flow Planner*, a software tool used to visualize and calculate transportation and movements, it is possible to calculate and see all the material transportation needed for the production. The average amount of vessels that are produced each day at the final assembly is 80, hence this is the number that will be used for calculations in *Flow Planner*. The report from *Flow Planner* can be seen in Appendix C.

For the copper models, the total transportation of material is equal to 10 750 meters, and the handling and transportation of components is estimated to take around 60 minutes. In these calculations only the distance when the truck is transporting material is measured, the total distance that the truck moves during a day can therefore be longer.

With the information from *Flow Planner*, it becomes clear that the component with the longest transportation is the foot frame. As can be seen in Figure 5.8, the production starts in the metal sheet shop where the first two operations are performed, thereafter the components are moved to an inventory next to *60318* at the welding shop. After being processed in *60318*, the components are transported back to the metal sheet shop where they are placed at the buffer area next to the painting shop. After being painted the components are either moved to *PTRAN3* or directly to *XM54* at the final assembly. The transportation between the different departments and processes amounts to a total distance of roughly 4227 meters and a total transportation time of 23,5 minutes.

7
Future recommendations

In this section the future recommendations and suggested actions are presented to achieve the improvements in the future state. The section contains both process level improvements, as well as system level improvements for the proposed future state.

7.1 Process level improvements

After the analysis of the current state map, the researchers came up with some process level improvements to be able to achieve the future state map. These improvements are described more in detail in the following subsections.

7.1.1 Inventories and buffers

As explained in section 1.2, NIBE currently are struggling with the available space in the water heater factory due to their high expansion rate. To cope with this problem, and also reduce the waiting time for the products in order to increase the throughput, the main aim while developing the future state map was to identify the main causes for the high inventory levels, as well as provide suggestions regarding how to reduce the inventory levels to cope with the problems with the lack of factory space. Rother and Shook (2003) list some reasons why inventories are needed in the production flow:

- Uncertainties in the production lead time.
- Differences in the cycle time between processes in the value stream.
- The upstream process operates in batch mode.

As mentioned in section 5.2, the different departments within the factory acts as isolated islands, causing a mismatch in the order prioritization which results in increased inventory levels. To reduce the number of inventories throughout the production flow, the researchers focused on the guidelines that was introduced in section 4.13.2 by Rother and Shook (2003). By analyzing the VSM for the current state, the researchers identified the possibility to combine operation *00102* and operation *60404*, and thereby eliminate the inventory between the two processes. The difference in cycle time between the two processes is though rather significant since operation *60404* takes roughly 3,5 times longer to complete. But, since operation

00102 produces components for both the Cu-gables and Cu-mantles, the difference in cycle time enables operation *00102* to produce to both these components without the need to build up an inventory in front of operation *60404*.

As stated in the guidelines by Rother and Shook (2003), a continuous flow means that the produced part is passing on to the next process step immediately after being finished without any disruptions. But since both processes are producing at batch mode, some modifications to the suggested guideline are needed. Instead of each part being transported directly to the next operation, each batch that is manufactured should be transported and the production at the following operation can be initiated. To ensure that operation *60404* not will be starved an AGV is suggested so that the transportation between the operations not needs to rely on that operators are at hand and available since both operations are automated.

To cope with the problems regarding the high inventory levels in the remaining inventories, some policies and guidelines will be suggested. At present, it has been stated by managers within NIBE that they don't have any specific recommendations about their inventory management. By establishing supermarkets between the processes where a continuous one peace flow is not feasible, the inventory levels will be kept at a lower lever compared to the as-is situation since these supermarkets are pull-based, meaning that production will be initiated only when products are taken from the supermarket and the inventory level goes below the desired safety stock level. This is believed to reduce the waiting time throughout the production flows, thereby initiate a possibility to increase the throughput without an increase of WIP as well as free up valuable space in the factory.

Based on the recommendations presented by Rother and Shook (2003), the inventories in the future state map are placed at 3 locations; at *X-Golv*, before operation *05110*, and at the final warehouse where all finished products are stored and delivered to the customers. The main cause of placing a supermarket both at *X-Golv*, and before operation *05110* is that the different flows have different lead times, and that there are differences in cycle time between the processes, hence placing supermarkets at the points where all flows are merged seems appropriate.

7.1.2 Transportation

To reduce the number of transportation, the researchers present a future state where the layout of the factory is redesigned. This is supported by Chiarini (2012) who mentions that a VSM can be used to redesign the layout of a factory. In the future state, the goal is to place processes close to each other and thereby enable a production that increase the feasibility to implement a continuous flow compared to the current state.

By using *Flow Planner* it is possible to evaluate how the amount of transportation will change depending on the layout. This is supported by Senderská et al. (2017)

who say that the results from these type of diagrams can be used to identify inefficient and unnecessary movements, hence create the possibility to make changes in layout to increase the efficiency and eliminate non-value adding activities. In Figure 7.1, the researchers have made a new layout where some processes are moved to achieve a production flow where the following process is located closer, this will lead to a production flow where the amount of transportation is reduced and this can further lead to a minimized inventory between the involved processes.

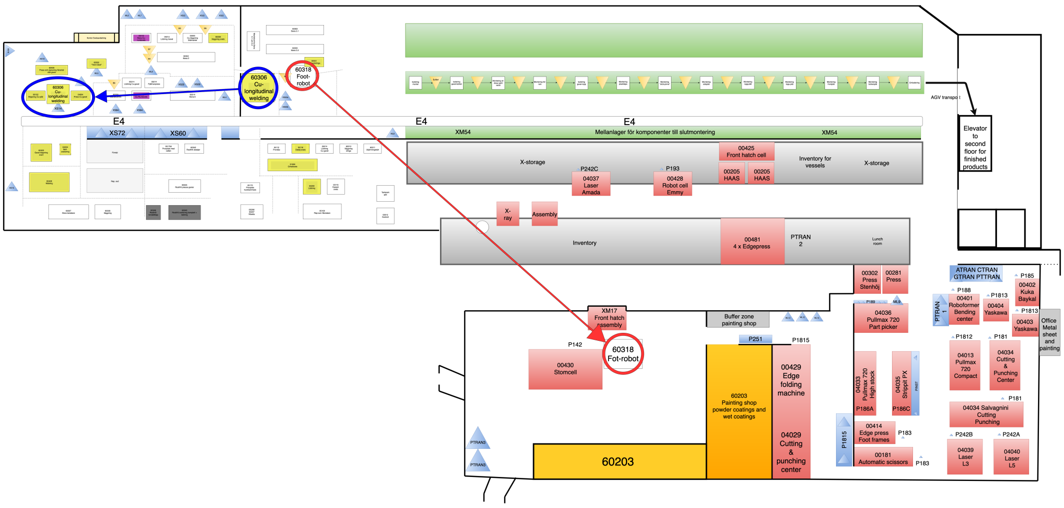

Figure 7.1: New suggested layout.

The first change made in the future state is to move operation *60318* from the welding shop to a new location in the metal sheet and painting shop. The previous and the new suggested location for operation *60318* is marked with a red circle in Figure 7.1. This location is suggested since it will reduce the distance between all the different operations for the production of the foot frame. This placement will also make the production move more towards a continuous flow since the components can move directly from process *60318* to the painting shop, and thereby minimize the time spent in inventory. This is supported by Hopp et al. (1990), as they mention that making products continuously move towards completion will reduce both lead time and inventories. By moving this process the transportation will be reduced by 2 286 meters and the transportation time will be reduced by 13 minutes. The cost reduction caused by the reduced transportation can thereby be used as a reference to calculate the payback time for moving the specific process. Since operation *60318* is only used for the production of the foot frame, the displacement of the process will not affect any other production flows.

Another change is to move operation *60306* from its current location to the location marked by a blue circle in Figure 7.1. By fully utilizing the space between operation *00102* and *60404* it should be possible to place *60306* at this location. This relocation will make the production move more towards a continuous production since the first three operations used for the Copper mantle will be placed next to each other and thereby the need for inventory between the processes are removed.

This will also remove the need for transportation between theses processes, hence the transportation of material for this part will be reduced by 545 meters per day and 3 minutes.

These changes in layout indicate that the total transportation of material is decreased by 2830 meters. This will also decrease the transportation time by 16 minutes. In Table 7.1 the changes from the current state and future state is presented. The report for the future state from *Flow Planner* can be seen in Appendix C.

Table 7.1: Current state vs Future state.

State	Total transportation	Time for transportation and handling
Current	10 750 meters	60 Minutes
Future	7 920 meters	44 minutes
Difference	2 830 meters	16 minutes

In regards to the total throughput time a change of 16 minutes may not seem too much, but the idea is to continuously strive towards a more efficient and effective production, and by redesigning the layout the production will move more towards a continuous flow. This will, as Hopp et al. (1990) mention, lead to effects such as reduced lead time and inventories which furthermore will enable an increase in capacity according to Little and Graves (2008). Dennis (2007) further mention that another positive effect by reducing the number of transports is that the safety within the factory is improved.

7.1.3 Pacemaker

As stated earlier in the section, one of the major purposes is to reduce the inventories in the production flow in order to increase the capacity and space utilization. It is therefore suggested that the production system should be converted from a push-based system to a more pull-based system. This conversion will, according to Dennis (2007), lead to a reduction of the WIP in the production flow, as well as improved quality due to better control. When applying a pull-based system, Rother and Shook (2003), explain that a pacemaker process should be implemented in order to control the production rate.

As stated by Rother and Shook (2003), the downstream processes from the location of the pacemaker need to be in a continuous flow. To enable this, the pacemaker is therefore placed before the final assembly in the future state map, at *X-Golv*. When the inventory levels at the pacemaker drops below the safety stock, a CONWIP signal is sent to operation *05110*, thereby enabling the start of the next product. Moreover, as stated in section 4.8, the usage of an pacemaker is beneficial when there is a mix of products in the production flow, and since this is the case in this situation the researchers find it appropriate to place the pacemaker at the suggested location.

7.1.4 CONWIP

In the as-is situation, the information flow is sent out to each operation individually, resulting in that all are working independently and hence the WIP between processes increases. This independency also contributes to a bull-whip effect, and in order to improve the performance Lee et al. (1997) explain that coordinating information and planning along the production chain is a feasible actions. By introducing a CONWIP system, one can ensure a constant work load between the different operations, and allow better control over the material flow which decrease the chances of pile up of unwanted inventories in the flow, thereby contributing to better space utilization. And according to Little's Law (Little & Graves, 2008), a reduction of inventories imply a reduction in waiting time, hence an increase in throughput can be achieved.

The researchers suggests to implement CONWIP system to ensure a constant and controlled level of material between the processes. By doing this, production is only started when there is a need for the products, thereby ensuring that no work is started without permission. As stated in section 7.1.1, supermarkets will be placed in two locations throughout the production flow. The major supermarket will be located at the suggested pacemaker at *X-golv* before the final assembly. The main reason for the placement of a supermarket at this location is that this is the point in the production flow where parts from the welding shop and metal sheet and paint shop are stored before the final assembly, hence parts with different lead times and batch sizes are combined here. Since the lead time for the different parts varies, it is hard to achieve a continuous flow, and as stated by Rother and Shook (2003), a supermarket should be placed when a continuous flow is not feasible. Another reason for this placement is that it reduces the final assembly's reliance on the welding and metal sheet and paint shop since it will have material available in the supermarket and therefore work even if the other departments have disturbances. At the supermarket, the inventory levels for the different products will be based on demand and lead time. When the final assembly removes material from the supermarket, and the number of components falls below the desired inventory level, a CONWIP signal is sent to operation *05110* in the welding shop and to the metal sheet shop enabling production to be started.

The other supermarket is suggested to be located before operation *05110*. The main reason for this is that at the welding shop, the lead times for the four different flows varies, and to cope with a potential issue that products could be aggregated in front of this operation the researchers find it appropriate to place a supermarket at this location. As stated in section 6.1, operation *05110* was identified as the obvious bottleneck at the welding shop due to its high cycle time compared to previous operations in the flow. This is supported by Rother and Shook (2003), who claim that supermarkets should be placed at locations where there is a difference in cycle time, and therefore a continuous flow is not feasible. Further, as stated by Goldbratt and Cox (2004) when a bottleneck or constraint is identified, the focus should be on exploiting the constraint and prevent that the constraint never lack materials which strengthen the decision to place a supermarket in front of this operation. Moreover, the placement of a supermarket at this location will coordinate the production of the products that are manufactured at the welding shop in order to minimize the inventory levels and reduce the independency between the different flows. When a signal is received from the supermarket at *X-golv*, the production at operation *05110* will be initiated. And when the inventory level goes under the safety stock level a new signal from this supermarket is sent out to operation *60400* and operation *00102* depending on what product that are required from the supermarket. As stated earlier, this will prevent a unnecessary large inventory in front of operation *05110* since it will increase the control of the number of WIP compared to if a supermarket only would have been implemented at *X-golv*.

The calculated inventory levels at the supermarkets are based upon the average daily demand for each component in the supermarkets and their individual manufacturing lead time. For the supermarket located before operation *05110*, this one stores the following components: copper gables, steel gables, and merged copper and steel mantles. The average demand for these components and the manufacturing lead times vary, hence the calculated safety stocks will vary. The components that contributes to the longest average waiting time at this supermarket is the copper gables, therefore this number will be used when calculating the new lead time in the future state map. At the supermarket located at *X-Golv*, the individual inventory levels for both the vessels *Compact - Cu* and *Compact - R*, and the different plates were calculated and then summarized when calculating the contribution to the new total lead time for respective future state map.

7.1.5 Levelled production and optimized batch sizes

As presented in section 6.1, the utilization rate for the different operations varies and the standard deviation is high. A more levelled production is an viable option when striving for a more evenly distributed utilization rate and reduced variation. Further, as explained by Kingman's formula (Holweg et al., 20018), this would also imply that the waiting times could be reduced. Levelled production can be achieved by placing production order that are based on demand, hence preventing piling up of unnecessary inventories of products that are not in demand and therefore contribute to unnecessarily high utilization rates. Also, to increase the flexibility in the production, the batch sizes should be optimized. Currently the batch sizes varies from around 800 at operation *60400*, to batch sizes of 10 at operations downstream the production flow. As stated by Rother and Shook (2003), non-optimized batch sizes can lead to overproduction, hence causing not just excess inventory but also requiring space and handling and therefore impair the flexibility to respond to changes in demand and requirements. An optimization of the batch sizes could therefore contribute to the reduction of unnecessary inventories of products that are not in demand as well as free up valuable space in the factory. Even though optimizing the batch sizes is not included in the scope of this thesis, the researchers find it appropriate to point out that this is something worth investigating further in the future.

7.2 System level improvements

Besides the process level improvements, the researchers provide some further improvements related to the systems currently used. These system improvements for the future state will be described in this section.

7.2.1 More comprehensive data collection

During the data collection, the researchers came to the insight that some data regarding inventory and WIP were hard to collect, e.g. due to that the traceability of products between processes is limited. Because of this, the overview of the total WIP is limited since not all the products are stored in the default stock locations, hence the ERP system does not showcase the correct inventory levels. One of the main issues that arises from this is that the consequences from the changes in the order planning does not become visible. Further, it becomes difficult to track which products that are the oldest and at risk of running obsolete.

To increase the traceability of the products in the production flow, the authors suggest to implement RFID tags on all pallets and racks. By integrating RFID with the current ERP-system, it will enable more accurate inventory data since RFID is a technology that can support a larger collection of data compared to barcodes that are used today, e.g. track the location of products and provide information regarding specific identifications (Yatinkumar, 2017). Furthermore, since RFID enables real time information about goods and products, the visibility of the production flow will increase and provide a better overview.

To collect data from the production NIBE currently uses a system called *Axxos*, which makes it possible to track up-time and collect data regarding disturbances making it possible to see how the machines are utilized. As of today, only a few of the processes within the water heater factory are connected to the system, making it hard to gather data and perform analysis for the whole production. The researchers therefore suggest to extend the usage of this system and connect more processes to it. This would facilitate an increase in the data collection, and therefore make better analysis of the performance of the production flow. Further, the researchers suggest to implement more tools to enable and increase the data collection from the production. This would make it possible to base decision on data and thereby perform more accurate decisions.

7.2.2 Frozen planning period

As explained in section 5.2, a frequently mentioned problem during interviews and discussions was that the production planning often changed on a short notice, thereby causing a change in the priority list. These changes force the operators to change both the set-up and material for the processes. As stated by Graves (2011), changes in the order prioritization leads to inefficiencies in the production flow due to that semi-finished goods are put aside to expedite the higher priority orders, hence the amount of WIP increases. These consequences are identified in the water heater factory since the material that is currently being processed is removed and put in inventory in order to make place for the newly prioritized orders. Another problem with these changes is that the material needed for the updated priority lists is not always at hand, which further initiate changes in the priority list.

Moreover, another big issue with the constant re-planning of the order prioritization is that it leads to a bullwhip effect that is amplified upstream the production flow. As explained by Sales-academy (2018), companies try to forecast demand by collecting a significant amount of raw materials and resources in order to satisfy the customer requirements, but when the order prioritization changes, the acquired material may not be needed. This results in excessive inventories, which has been identified when analysing the production flow. This can, according to Jonsson and Mattsson (2009), lead to higher costs due to tied up capital and risk of obsolete products. It also leads to a lot of semi-finished goods that cover valuable space throughout the production flow.

To cope with these problems regarding the production and order planning, the researchers suggests to evaluate the possibilities to implement a frozen time period. By implementing a frozen time period the production during this time period is fixed, and it thereby becomes possible to plan the production ahead and to make sure the material needed is at hand when the production is planned to start. This is supported by Graves (2011) who explains that a frozen time period provide short-term stability since all changes are accumulated and postponed beyond the frozen time period.

7.3 Future state map

With all recommendations considered, two new future state maps were drawn. The future state map for the welding shop is seen in Figure 7.2, it differs from the current state map in the sense that the majority of the identified buffers and inventories have been replaced by two supermarkets, and a two CONWIP loops have been implemented. The inventory levels at each of the supermarkets are based on the average daily demand and the manufacturing lead time, as stated earlier. For the supermarket located before operation *05110* the inventory level is: 139 steel gabels, 65 copper mantles/steel mantles, and 193 copper gables. The contributing, non value-added time from this supermarket is 70,0 hours. For the supermarket located at *X-Golv*, the average inventory level is 143 vessels, contributing to a lead time of 14,3 hours. A comparison with the current state map is presented in Table 7.2 below:

Table 7.2: Comparison of the future state map and the current state map at the welding shop.

Total lead time Current state	Total lead time Future state	Reduction
10,65 days	3,54 days	66,8 %

The future state map for the metal sheet and painting shop have one CONWIP loop implemented, hence all inventories except the one in front of the painting shop can be eliminated. The reason that there still is a need for an inventory there is due to the reasons explained in section 6.2. The future state map is illustrated in Figure 7.3, and a comparison with the current state map is presented in Table 7.3 below:

Table 7.3: Comparison of the future state map and the current state map at the metal sheet and painting shop.

Total lead time Current state	Total lead time Future state	Reduction
3,87 days	2,55 days	34,1 %

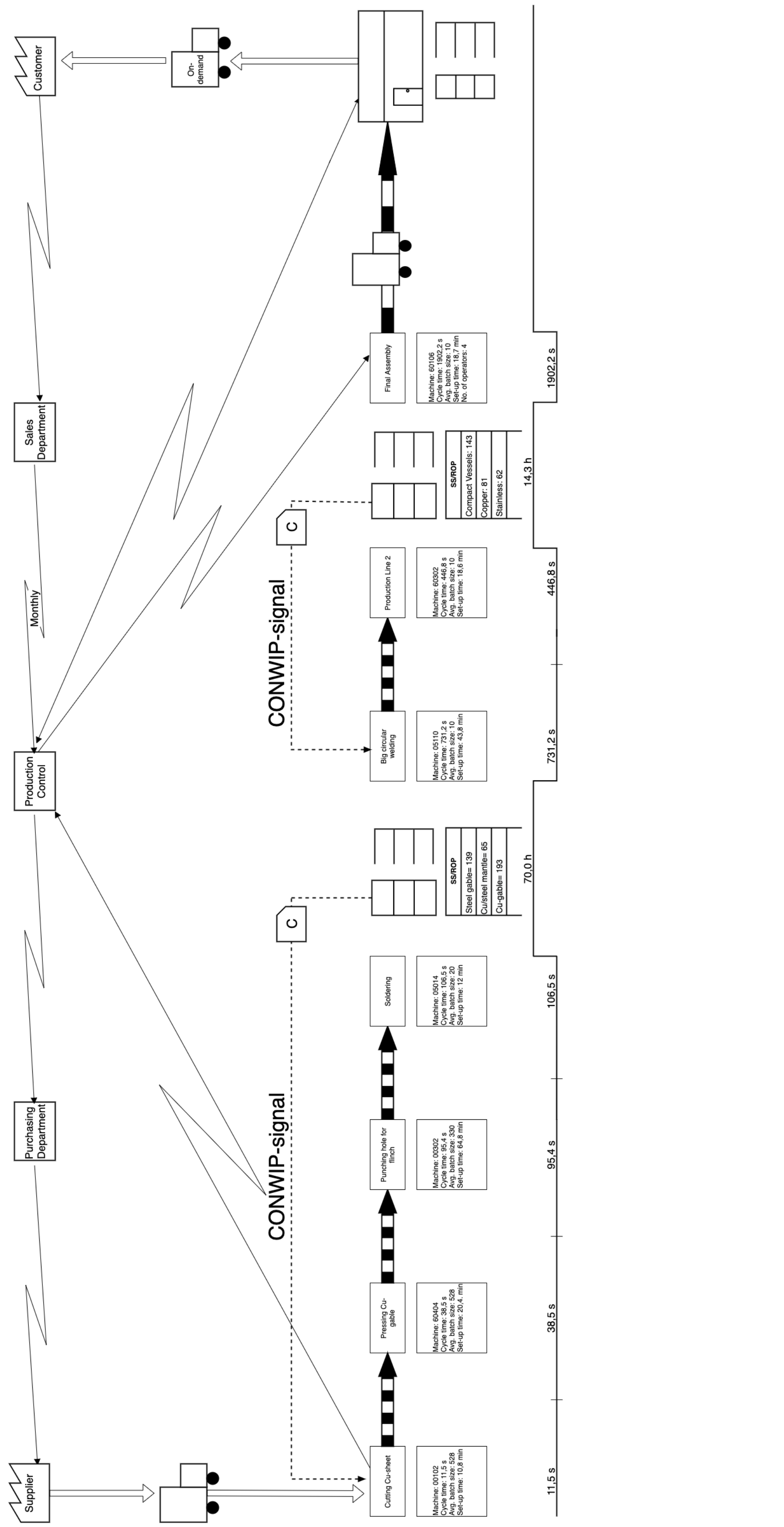

Figure 7.2: Future state map for the welding shop and the final assembly.

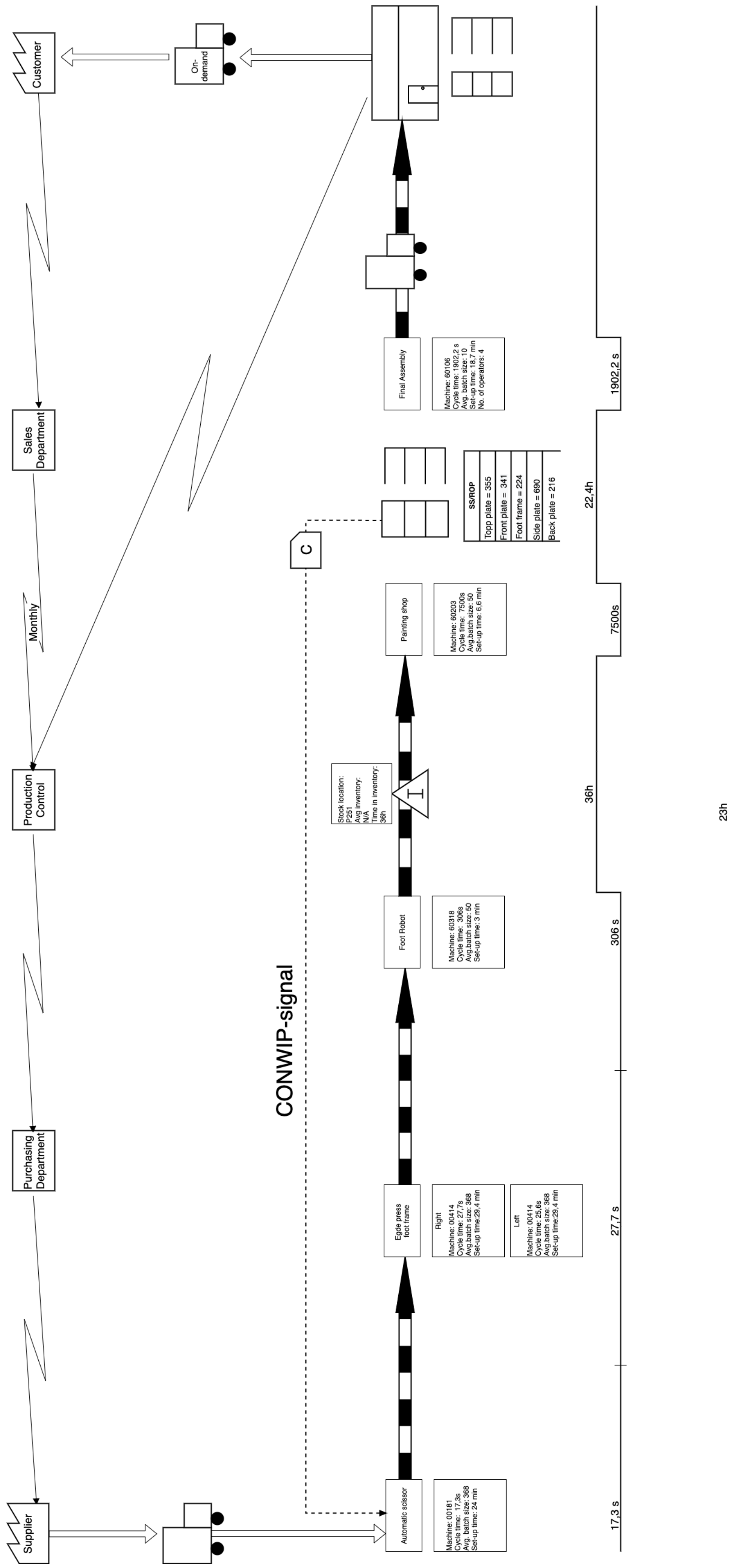

Figure 7.3: Future state map for the metal sheet and painting shop and the final assembly.

8

Discussion

In this section, a discussion regarding the thesis and the results will be provided, and at the end, suggestions for future research and will be given, together with the shortcomings of the thesis.

The project was successful in mapping the current state and provide NIBE with an overview of the production of the *Compact* product family within the water heater factory. The purpose of the project was, besides mapping the current state, to find and suggest improvements regarding how NIBE can increase the capacity of their existing resources within the water heater factory to cope with their problems regarding limited factory space in order to enable their future growth vision. The method that was chosen to accomplish this was value stream mapping, which is a commonly used method for visualizing production flows. This allowed the researchers to illustrate the value added time in relation to the non-value added time such as unnecessary transportation and time spent in inventory, as well as bottlenecks and constraints in the production flow. The researchers believe and hope that the thesis will provide NIBE with valuable insights and a comprehensive overview about the production flow, and contribute in their strive to always improve by presenting well-founded and appropriate improvement actions and suggestions.

The research method that was used for this thesis was a case study since this enabled the researchers to explore and evaluate a process (production flow) in depth. The characteristics of a case study, is that it can be used to increase the the knowledge about a quite unknown or poorly understood situation, and explain, describe, or explore causes in an everyday context in which they occur seemed to be aligned with how the researchers wanted to approach the stated problem description. In order to understand the everyday context interviews were held with employees at NIBE and thereby their view of the everyday context was described. The interviews were semi-structured which enabled the interviews to take on different approaches depending on the interviewees knowledge and experience. This interview format was also chosen since it enabled the participants to speak relatively freely within the context and thereby bring up their view on different situations and problems. The interviews were held with employees from different departments which enabled the researcher to collect data from all involved parts for the production. This resulted in a wide and varying data collection, which sometimes were out of the scope of the research but this enabled the research to gather all the different views and explore different causes for the problems identified.

Something the researchers see as a strength for this research is the several factory visits that have been done. This enabled the researchers to make their own observations and see the factory in a real life context. This also enabled the researchers to meet the different employees face-to-face and thereby made the communication more personal.

For this thesis the researchers used the *Process activity mapping* (PAM) tool as a base for conducting the research. This enabled the researchers to study the current flow, identify waste in the different processes, analyze if any changes could be made and how these would lead to a better flow. The result of this thesis is therefore shaped by the different steps of the PAM and what aspects that the tool focuses on. It should therefore be mentioned that another tool could have led to another focus for the thesis and thereby resulted in other conclusions. The reason for choosing this particular tool was that it was in line with the aim of this thesis, which was to study the current flow and provide NIBE with a flow chart of the different production activities as well as an approach on how these activities could be improved and how waste could be removed.

The major uncertainty and challenge in this thesis has been the data collection. The data have been difficult to collect due to the systems not have been easy to navigate within, hence the researchers have been dependent on people within NIBE, and that these people have the required competences to be able to provide the requested data. Some of the data that were considered important were only available in a limited amount within the systems, it could therefore be difficult to verify the accuracy of the data. All data regarding cycle times for the processes can be validated and considered accurate since these are fundamental for NIBE. But due to the lack of standardization when it comes to inventory data for example, the data not only need to be collected, but also re-worked, which is time-consuming and limits the researchers to collect data for a longer time period to ensure better accuracy. The current state map is founded upon the collected data, hence the accuracy and how well it agrees compared to the real situation can be questioned. Further, since historical data were not always available assumptions regarding how much data that was needed to draw general conclusions. The researchers assumed that one month of inventory data were enough. This matter has been discussed with both tutors and people within the organization, and it has been concluded that the results should have been somewhat similar even if the data should have been collected during another time period, or a longer time period should have been included in the research. Afterwards, the researchers feel that they could have started data collection earlier in the process since a need of new data always arise throughout the way, and that could have given more time to cope with the difficulties regarding the collection of some specific data.

The general simplifications that were made for the current state map were to consider only the main flows for the products within the metal sheet shop. At this department, there are a lot of minor components manufactured, and the researchers found it appropriate to focus on the major parts such as the cover plates, mostly due to that these components have the longest lead time, and that they pass through several operations at the metal sheet shop. Another simplification that was made was regarding the calculations for the inventory levels at the proposed supermarkets. Because not all of the requested parameters were used and stored in the different systems, the researchers had to do some simplifications and only consider the lead time and the average demand, hence neglecting the included uncertainties for both the lead time and the demand.

The results from the study can be argued to be quite general compared to other similar studies due to that many of the suggested improvements were founded upon the guidelines presented by Rother and Shook (2003), and other relevant literature such as Chiarini (2012). The results from the current state map illustrated that there are buffers and inventories nearly after every operation due to the push-based production flow. This is presented in the literature as a common consequence and to cope with this, the researchers founded their suggested improvements on proven theories and methods. This facilitated a comparison of the results with other studies within the subject of research. By comparing this thesis to Saraswat, Kumar and Sains' (2015) study on reduction of production lead time using VSM, their findings and results are well in line with the findings from this thesis. To implement inventory supermarkets in order to achieve an easy flow and therefore facilitate a pull system was one of the major improvement suggestions in their study as well as in this study .

Regarding possible and feasible improvement suggestions, CONWIP was brought up early in the process as a viable option to cope with the issue concerning the many inventories and buffers throughout the flow. In the thesis description, it is stated that within the water heater factory, there is a mix of a functional layout and line-based production. Therefore, the researchers evaluated the possibilities to implement a more pull-based approach. One could discuss that an implementation of a KANBAN system could have been evaluated more in detail, but due to the vast product mix CONWIP was considered more feasible since this system will ensure a constant work in progress between the deployed supermarkets. Moreover, the project aimed at identify waste and provide suggestions regarding how to eliminate them. Despite the inventories, transportation was identified as a major waste since operations are located far away from one another, hence resulting in long transportation back and forth. To gain an overview of all the transportation, a software named *Flow Planner* was used. This enabled the researchers to calculate the transportation distance, and create new possible layouts and see how the distances were changed. Moreover, it needs to be mentioned that the researchers do have limited experience from the factory, and that the suggested layout therefore may not be possible to realize, or that there are other factors influencing the movement of the operations that not have been exhibited in the research. Also, to be able to perform these calculations, some assumption were made since not all data that the program needed were collected. Therefore, one could question the accuracy of the results. But, the main purpose here was to illustrate how a change in the layout could facilitate a continuous flow, and through that eliminate wastes such as unnecessary transportation and inventories.

The shortcomings of this thesis is that it only considers one of the product families that are manufactured in the water heater factory, the *Compact* family. This implies that the effects on the production flow from the other products that are manufactured in the water heater factory were not considered and analyzed as this what out of the thesis' scope. Neither have any economic aspects been taken into consideration when constructing the future state map, i.e the suggested improvements may be too expensive to implement. Also, it would have been interesting to evaluate how much the potential cost saving could generate, e.g. through the reduced transportation distance and inventory levels. This was not possible to evaluate due to the time frame of the thesis, therefore a future work could be to implement and evaluate the proposed improvement. Further, as stated above, not all the products within the water heater factory were included in this research. To extend the research, and evaluate the complete overview and how the different products affect each other, the researchers suggest to take these aspects into consideration and continue this initial work.

The findings from this thesis hope to have improved the overview perspective of the water heater factory by mapping out the current state, and give the management a better understanding over the non value-adding activities that occur in the production flow as of today. Also, the researchers hope to have arranged valuable and feasible improvement suggestions and concepts, that one way or another can contribute to the development of their production flow and organization in the future.

Regarding sustainability, and how this thesis relates to it, the researchers have compared the outcomes with the 17 sustainable development goals. First of all, the thesis hopes to contribute to responsible consumption and production by minimizing overproduction by trying to produce only what is demanded. Also, the reduction of overproduction and reduced inventory will lead to that more factory space will be available and could be utilized. Therefore, the need for acquisition and the need to build new facilities can be reduced. This is aligned with sustainable development goal number 9 that contains sustainable industry, innovation and infrastructure with increased efficiency. Furthermore, an improvement of the layout would lead to less transportation and, as a result, less use of resources and cost savings. Less transportation will also increase the safety within the factory and thereby improve the social sustainability for the employees at NIBE. By increasing the efficiency of the production and fully utilizing the factory space, NIBE will be able to increase their capacity and production of sustainable products and hence be able to meet a greater demand. By meeting a greater demand the products will be accessible for more people and this can therefore be said to be in line with goal 7 that wants to ensure access to sustainable and modern energy for all.

9
Conclusion

This section presents the conclusions that have been drawn from this thesis, and evaluate to what degree the research questions have been answered.

The purpose of this thesis was to answer the following research questions:

- **What is the current state for *Compact* water heater production process regarding capacity, bottlenecks and variation?**
- **What improvements can be made to cope with the identified improvement potentials in the current production flow?**

The first research question was answered in sections 5 and 6 with two maps over the current state; one for the welding shop, and one of the metal sheet and painting shop. These maps gave an indication of the distribution between value-adding and non value-adding time, an overview NIBE previously lacked. The conclusions that could be made is that in order to increase the capacity of the current production, the time spent in inventory and buffers need to be reduced if the throughput should increase. Otherwise, the WIP will increase and the space utilization will decrease, in accordance to Little's Law (Litter & and Graves, 2008). One of the major reasons to the long waiting times, in the current state map illustrated as non value adding lead time, depends on the lack of synchronization between the different departments within the water heater factory, and that they are using a push-based approach. The other major contributor is the transpositions in the order planning. To evaluate a future increase in production rate, potential bottlenecks were analysed. The conclusions from this analysis is that the primary bottleneck that was identified is operation *05110* (Circular welding), mainly due to the high cycle time as stated earlier. Other potential future bottlenecks is concluded to be the ones with the highest utilization rates in the current state maps.

In order to provide a solution to the contributing factors identified in the current state map, the researchers came up with a few improvement recommendations. The major recommendations proposed are to convert the push-based production system to a more pull-based production by implementing a CONWIP system together with supermarkets as governing inventories, and to introduce a frozen time period in the order planning where no order transpositions are allowed. These changes are aimed at increasing the synchronization between the departments, as well as reduce the number of changes in the priority and hence make it easier to plan and make sure that the right components are available when the production is planned to be initiated. Through these improvement suggestions, the researchers hope to provide NIBE with valuable and applicable concepts to increase the utilization and capacity of their current facilities in Markaryd.

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A
Appendix

A.1 Interview questionnaire planning department

Interview planning department

- What products are manufactured in the water heater factory?
- Are there any products with a low order frequency?
- How does the planning work today? - how is it carried out?
- What planning base do you have when planning the production?
- How long-term is the production planning?
- How often is the planning "released" into production? (Daily, weekly, etc?)
- Do you experience any problems with the planning today?
- How does the flow of information between planning and production work?
- Do you experience any problems with the planning never being “locked” in order to be able to update the plan to obtain a high flexibility towards the customer?
- How big batches do you run and how often? (Why?)
- How is the utilization rate planned on different machines?
- Are there any order priorities?
- Are there many common articles between the different products and the product families?

A.2 Interview questionnaire production departments

Interview production departments (Welding, sheet metal, painting, final assembly)

- How do you think the production flow works today?
- Any bottlenecks restricting the flow?
- Do you have problems with disturbances in the production?
- Any unplanned production stoppages?
- Do you feel that you have large variations in production?
- As we have understood it all, the operators have the opportunity to choose orders themselves to a certain extent, how would you say that this affects the production flow?
- Production kanban - how does it work?
- How are you affected by the increased production rate?
- Are there any quality problems in production?
- How are quality controls performed in the flow?
- We feel that there is a lot of buffer and intermediate storage in the production, do you think this is a problem and what do you think the reasons for this are?
- Do you have any rules, routines or restrictions regarding buffers and intermediate storage?
- If an intermediate warehouse is full, where is the WIP placed?
- How does the flow of information in production work?
- How is it announced when materials and products are to be moved from A to B?
- How do you prioritize orders?
- Is there a big difference in complexity between the different products? Is there any model/product that is perceived as more difficult and takes longer time to manufacture?
- How does it affect that the order planning can be changed at short notice?
- How do you work with maintenance work, is it for preventive purposes or when something breaks?
- Are there many common process steps for the different products/product families?

B

Appendix

Value stream maps for all the parallel flows in the welding shop, as well as in the metal sheet shop.

B.1 Value stream map for the copper mantle

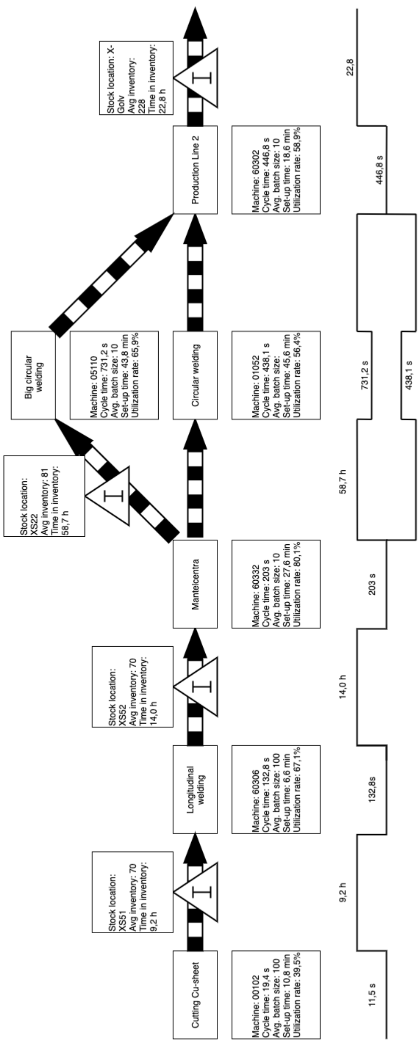

Figure B.1: VSM Copper Mantle.

B.2 Value stream map for the steel mantle

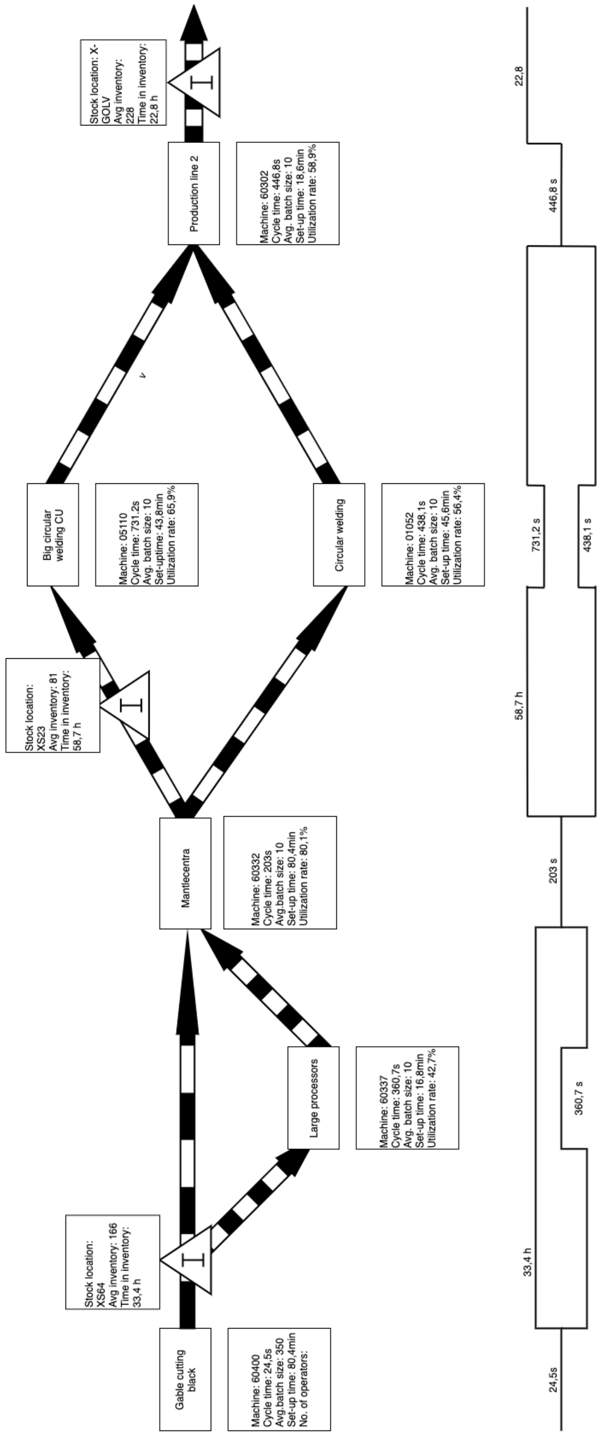

Figure B.2: VSM Steel Mantle.

B.3 Value stream map for the steel gable

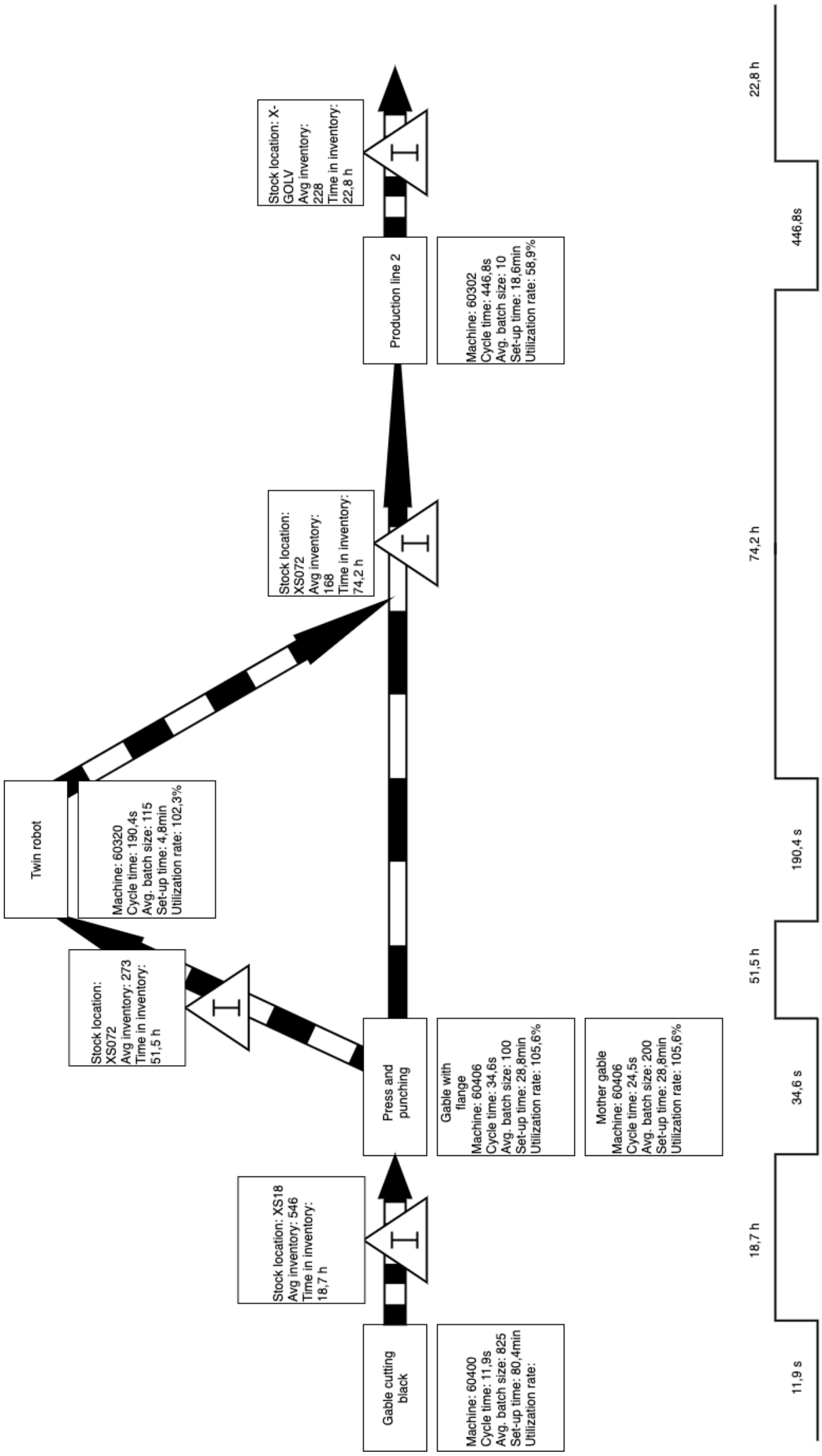

Figure B.3: VSM Steel Gable.

B.4 Value stream map for the stainless steel vessel

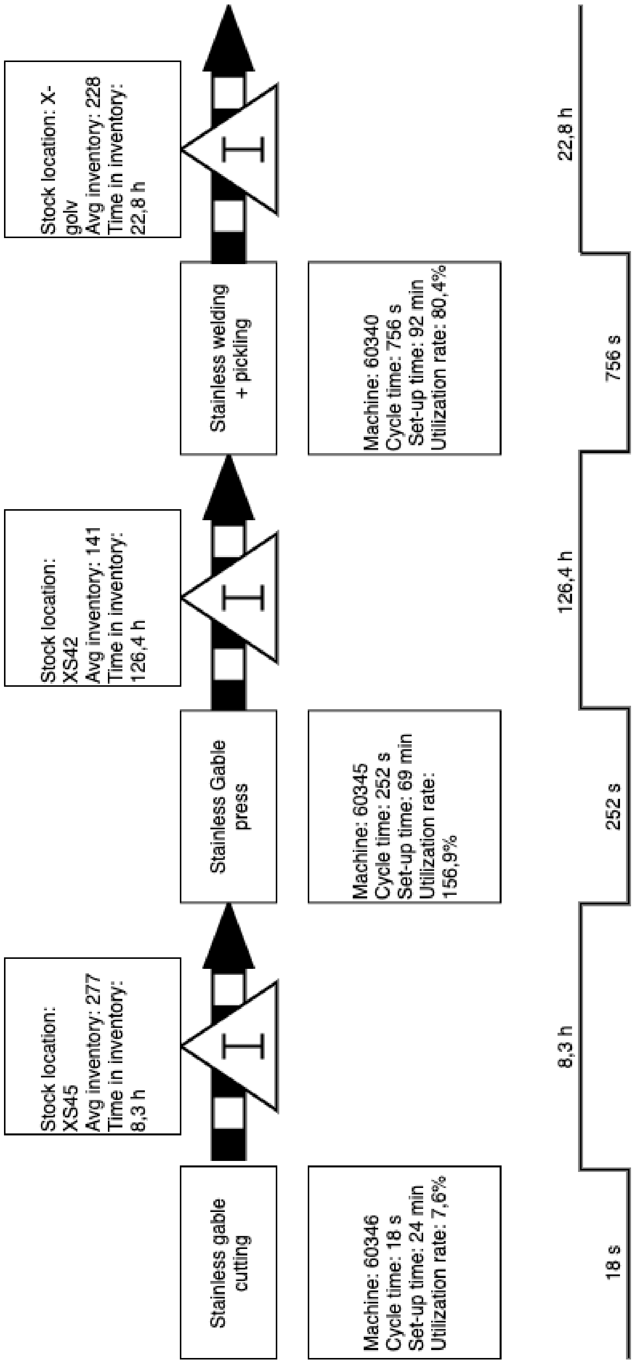

Figure B.4: VSM Stainless Vessel.

B.5 Value stream map for the top plate

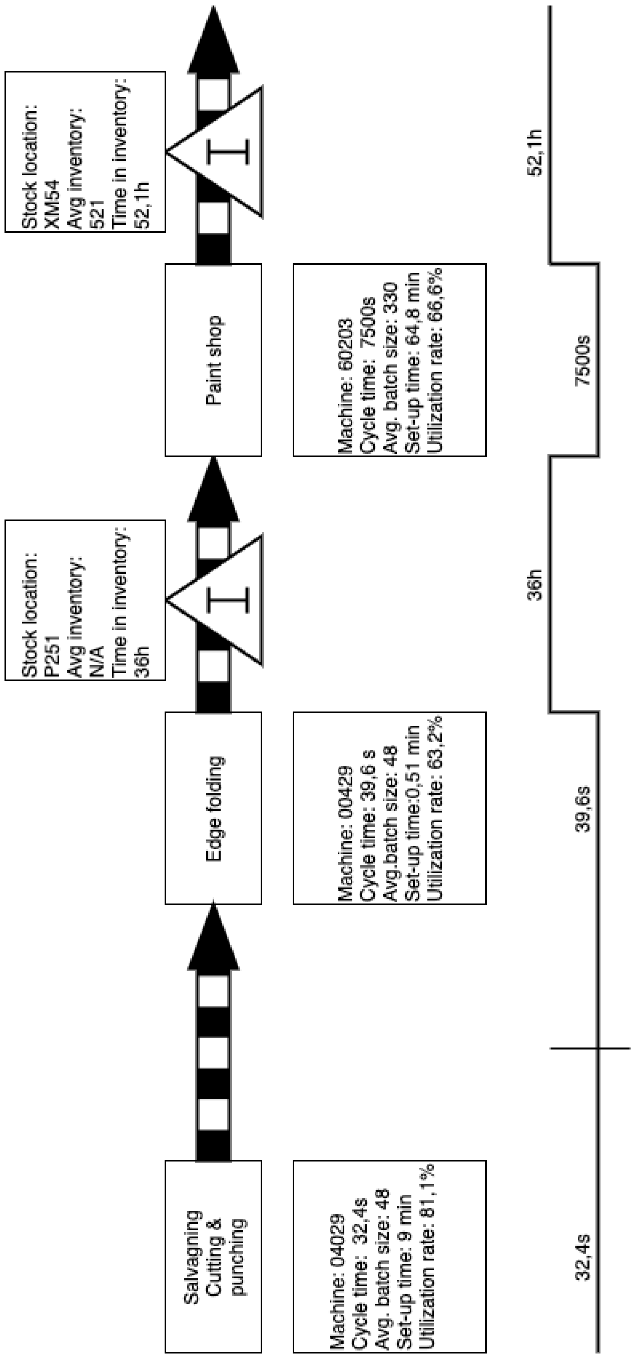

Figure B.5: VSM Top plate.

B.6 Value stream map for the side plate

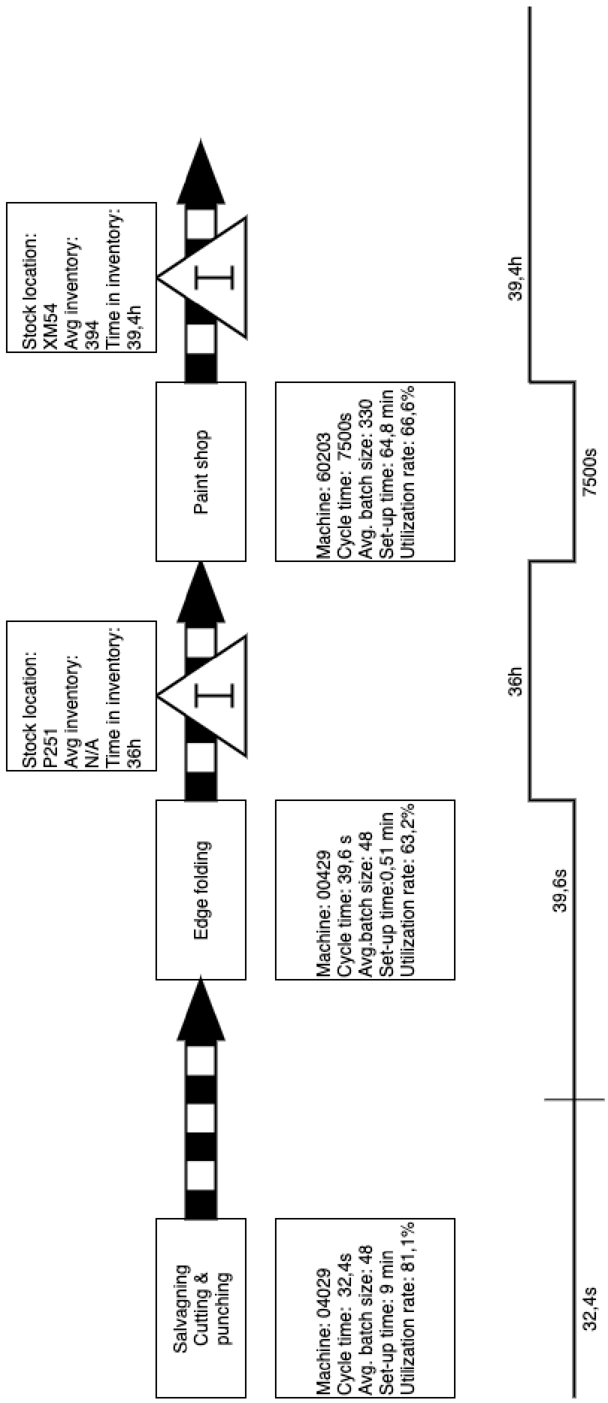

Figure B.6: VSM Side Plate.

B.7 Value stream map for the back plate

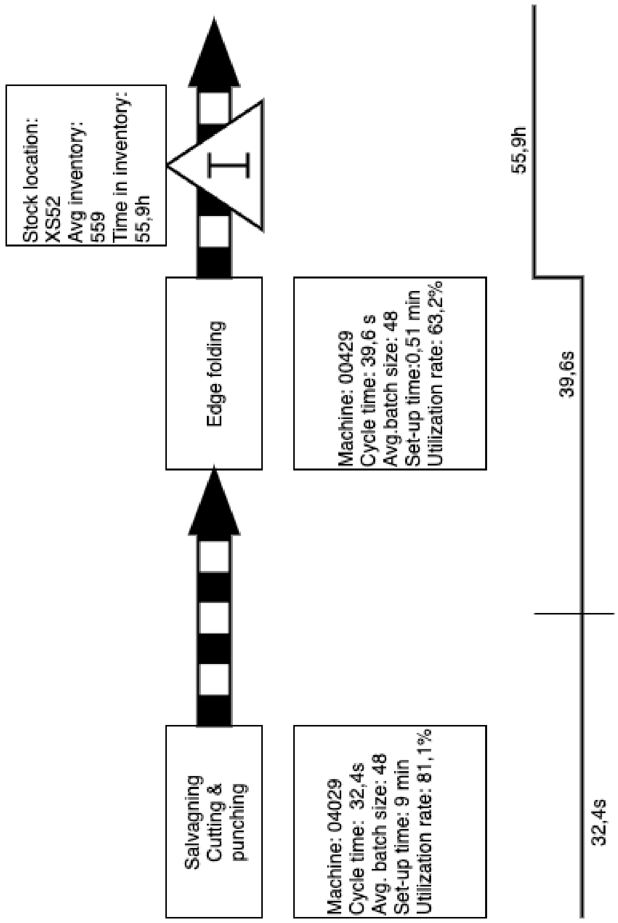

Figure B.7: VSM Back Plate.

B.8 Value stream map for the front plate

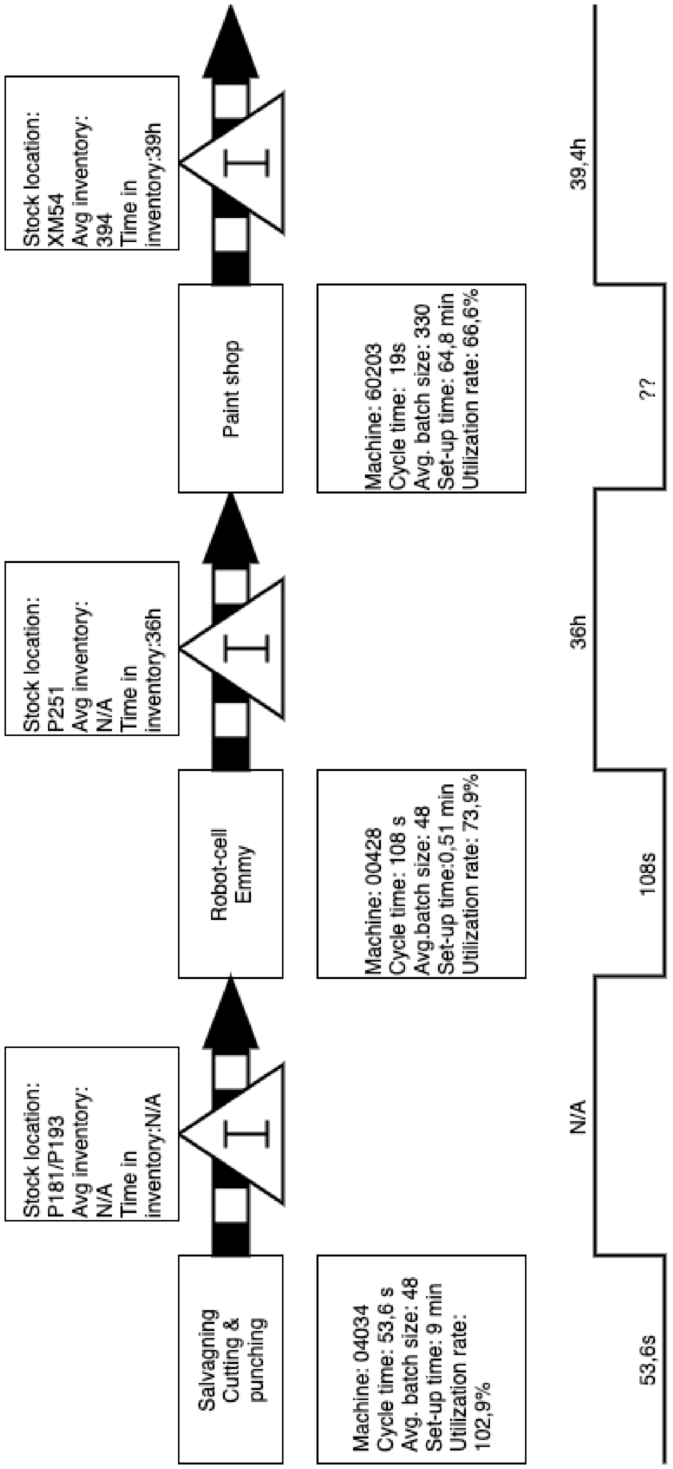

Figure B.8: VSM Front Plate.

C
Appendix

C.1 Flow Planner Report Current State

SIMPLE AGGREGATE SUMMARY : Day (Current State)						
AGGREGATE	**FROM**	**TO**	**FREQUENCY**	**TOTAL DISTANCE METER**	**TRIP DISTANCE METER**	**TRAVEL TIME SECONDS**
BackPlate	4029	XM54	0,53	84,44	159,33	28,33
SUB TOTAL			**0,53**	**84,44**		**28,33**
Cu-Gable	00102	60404	3,20	94,37	29,49	31,46
	60404	00302	1,25	347,26	277,81	115,75
	00302	05014	1,25	300,04	240,03	100,01
	60404	01052	0,13	6,37	48,99	2,04
	60404	05110	1,13	97,08	85,91	32,22
	05014	01052	0,13	16,49	126,83	5,28
	05014	05110	1,13	31,54	27,91	10,47
	01052	60302	0,25	25,38	101,50	8,46
	05110	60302	2,25	84,80	37,69	28,27
SUB TOTAL			**10,72**	**1 003,32**		**333,96**
	00102	60306b	4	469,32	117,33	156,44
	60306b	60332	4	307,36	76,84	102,46
Cu-Mantle	60332	01052	0,4	11,35	28,37	3,78
	60332	05110	3,6	342,68	95,19	114,23
	01052	60302	0,89	90,34	101,5	30,07
	05110	60302	8	301,52	37,69	100,51
SUB TOTAL			**20,89**	**1 522,57**		**507,49**
FootFrame	00181	00414	0,22	6,68	30,36	2,20
	00414	60318C	4,00	983,16	245,79	327,72
	60318C	60203	8,00	2 030,16	253,77	676,72
	60203	XM54	8,00	1 207,28	150,91	402,43
	SUB TOTAL		**20,22**	**4 227,28**		**1 409,07**
FrontPlate	04034	00428	1,78	202,97	114,03	67,57
	00428	60203	1,78	286,46	160,93	95,37
	60203	XM54	1,78	268,62	150,91	89,43
SUB TOTAL			**5,34**	**758,05**		**252,37**
SidePlate	04029	00428	2,11	357,33	169,35	118,85
	00428	60203	2,11	339,56	160,93	112,94
	60203	XM54	2,11	318,42	150,91	105,90
SUB TOTAL			**6,33**	**1 015,31**		**337,69**
SteelGable	60400	60406	1,60	51,44	32,15	17,15
	60406	60320	1,25	44,20	35,36	14,73
	60400	XS072	1,25	31,28	25,02	10,43
	60320	60302	1,25	43,61	34,89	14,54
	XS072	60302	1,25	81,90	65,52	27,30
SUB TOTAL			**6,60**	**252,43**		**84,15**

SteelMantle	60400	XS64	0,80	27,14	33,93	9,05
	XS64	60337	0,08	6,91	86,36	2,30
	XS64	60332	0,72	9,42	13,09	3,14
	60337	60332	0,89	84,32	94,74	28,07
	60332	01052	8,00	226,96	28,37	75,66
	60332	05110	8,00	761,52	95,19	253,84
	01052	60302	0,89	90,34	101,50	30,07
	05110	60302	8,00	301,52	37,69	100,51
SUB TOTAL			**27,38**	**1 508,13**		**502,64**
TopPlate	04029	00428	0,80	135,48	169,35	45,16
	00428	60203	0,80	128,74	160,93	42,92
	60203	XM54	0,80	120,73	150,91	40,24
SUB TOTAL			**2,40**	**384,95**		**128,32**
TOTAL			**100,41**	**10 756,48**		**3 584,02**

C.2 Flow Planner Report Future State

SIMPLE AGGREGATE SUMMARY : Day (Future State)						
AGGREGATE	FROM	TO	FREQUENCY	TOTAL DISTANCE METER	TRIP DISTANCE METER	TRAVEL TIME SECONDS
BackPlate	4029	XM54	0,53	84,44	159,33	28,33
SUB TOTAL			**0,53**	**84,44**		**28,33**
Cu-Gable	00102	60404	3,20	94,37	29,49	31,46
	60404	00302	1,25	347,26	277,81	115,75
	00302	05014	1,25	300,04	240,03	100,01
	60404	01052	0,13	6,37	48,99	2,04
	60404	05110	1,13	97,08	85,91	32,22
	05014	01052	0,13	16,49	126,83	5,28
	05014	05110	1,13	31,54	27,91	10,47
	01052	60302	0,25	25,38	101,50	8,46
	05110	60302	2,25	84,80	37,69	28,27
SUB TOTAL			**10,72**	**1 003,32**		**333,96**
	00102	60306	4	81,84	20,46	27,29
	60306	60332	4	149,80	37,45	49,93
Cu-Mantle	60332	01052	0,4	11,35	28,37	3,78
	60332	05110	3,6	342,68	95,19	114,23
	01052	60302	0,89	90,34	101,5	30,07
	05110	60302	8	301,52	37,69	100,51
SUB TOTAL			**20,89**	**977,53**		**325,81**
FootFrame	00181	00414	0,22	6,68	30,36	2,20
	00414	60318	4,00	366,48	91,62	122,16
	60318	60203	8,00	361,28	45,16	120,43
	60203	XM54	8,00	1 207,28	150,91	402,43
	SUB TOTAL		**20,22**	**1 941,72**		**647,22**
FrontPlate	04034	00428	1,78	202,97	114,03	67,57
	00428	60203	1,78	286,46	160,93	95,37
	60203	XM54	1,78	268,62	150,91	89,43
SUB TOTAL			**5,34**	**758,05**		**252,37**
SidePlate	04029	00428	2,11	357,33	169,35	118,85
	00428	60203	2,11	339,56	160,93	112,94
	60203	XM54	2,11	318,42	150,91	105,90
SUB TOTAL			**6,33**	**1 015,31**		**337,69**
SteelGable	60400	60406	1,60	51,44	32,15	17,15
	60406	60320	1,25	44,20	35,36	14,73
	60400	XS072	1,25	31,28	25,02	10,43
	60320	60302	1,25	43,61	34,89	14,54
	XS072	60302	1,25	81,90	65,52	27,30
SUB TOTAL			**6,60**	**252,43**		**84,15**

SteelMantle	60400	XS64	0,80	27,14	33,93	9,05
	XS64	60337	0,08	6,91	86,36	2,30
	XS64	60332	0,72	9,42	13,09	3,14
	60337	60332	0,89	84,32	94,74	28,07
	60332	01052	8,00	226,96	28,37	75,66
	60332	05110	8,00	761,52	95,19	253,84
	01052	60302	0,89	90,34	101,50	30,07
	05110	60302	8,00	301,52	37,69	100,51
SUB TOTAL			**27,38**	**1 508,13**		**502,64**
TopPlate	04029	00428	0,80	135,48	169,35	45,16
	00428	60203	0,80	128,74	160,93	42,92
	60203	XM54	0,80	120,73	150,91	40,24
SUB TOTAL			**2,40**	**384,95**		**128,32**
TOTAL			**100,41**	**7 925,88**		**2 640,49**