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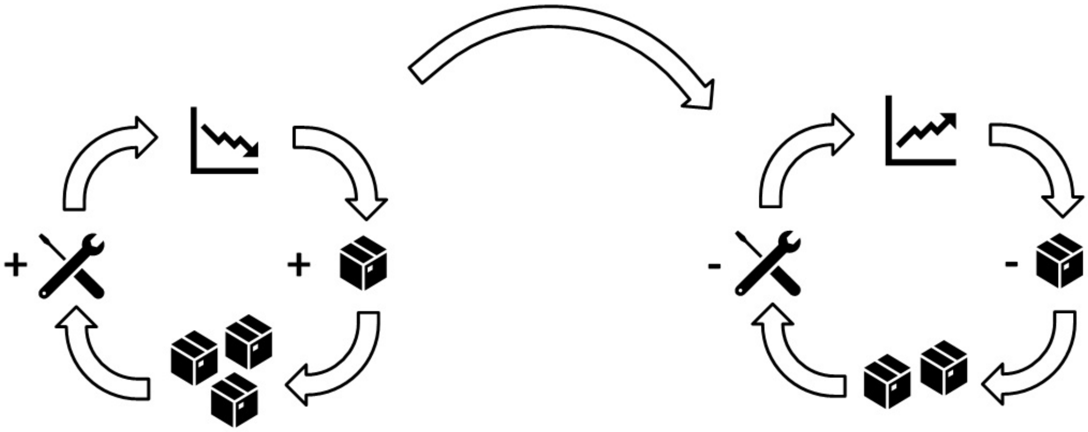

Improve production flow and productivity by increasing predictability and control at an electronics manufacturer

Building a road map towards improved flow, decreased inventory and lead time in a production system

Master's thesis in Production Engineering

AXEL LINDBÄCK

PONTUS JOHANSSON

Department of Industrial & Material Sciences
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

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Supervisor: Maheshwaran Gopalakrishnan, Department of Industrial & Materials Sciences
Supervisor: Anders Jost
Supervisor: Kristoffer Averheim
Examiner: Johan Stahre, Department of Industrial & Materials Sciences

Master's Thesis 2019
Department of Industrial & Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Visualization of concept regarding a vicious cycle of added work due to WIP and the virtuous cycle of removing WIP in order to reduce work.

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Abstract

Being able to produce quality products to the best price possible while still being profitable is the main challenge for manufacturing companies in order to be competitive. To tackle that challenge, it becomes key to use available resources wisely and achieve more with less.

This thesis is a case study of a Swedish electronics manufacturer, focusing on two similar semi-automated final assembly lines in order to understand the difficulties and potentials for improvement. Lean methodology and Theory of Constraints (ToC) was used in order to analyze qualitative and quantitative data and to build a road map with proposals on how to improve the production on a short, medium and long term time span.

It was found that there was frequent disturbances in the processes and that the utilization of the equipment was rather low as a consequence. There was a lot of Work in Progress (WIP) which was very laboursome to handle for operators and managers at the expense of long term improvement work. The disturbances in combination with the WIP lead to frequent and large quality problems. The reasons to why the production system was not performing better was found to be a combination of a relatively immature organizational culture in combination with a high pressure to perform due to rapid growth of customer demand.

Lean Methodology and ToC in combination with results from interviews, observations and available production data was used to propose solutions in the form of a road map. The main points of the road map is to focus on building a strong culture and to continuously lower WIP and amending root causes for disturbances in order to free up resources for long term production improvements.

Keywords: VSM, Lean Production, Theory of Constraints, OEE, Road Map.

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Introduction

1.1 Background

Companies increasingly needs to be able to deliver higher quality products to a lower cost with a shorter lead time in order to stay competitive. Thus, manufacturing companies needs to continuously improve their production system by increasing productivity and flexibility[1].The want to increase productivity and flexibility within manufacturing have led to new trends within manufacturing, moving towards automation and interconnected equipment's into large network of machines, this is commonly known as Industrie 4.0. Industrie 4.0 is implemented with the aim to improve the efficiency, knowledge and responsiveness of a production system[2].

Another trend within the society as a whole is to work towards increased sustainability. The manufacturing area is no exception, and working towards increased sustainability in terms of economy, environment and social factors is viewed as increasingly important. To be able to improve upon sustainability within manufacturing, less resources such as energy and material should be used at the same time as productivity increases. The goal being that the production should reduce all unnecessary consumption of resources[3].

The reason to why these trends have gained momentum is not only because of care about the environment, these trends are important because of that they strengthen the ability to gain market shares. The same is true for the quality movement which have influenced manufacturing companies for a long time and aims to deliver high quality products at the right time to a low cost[4]. The bottom line is that the common denominator between the trends is to achieve more with less in order to improve the economical abilities of the company.

Within lean philosophy, the aim is similar to industrie 4.0, the quality movement and the strive towards sustainability in that the goal is to use less resources to achieve more and create more value. By improving production flow, less resources is needed and quality is more easily managed entailing less scrap and other related waste. At the same time, less resources are tied to inventory which entails to larger operational capabilities due to the larger amount of available resources[5][6].

Furthermore, a study from Ahlmann presents an average of 55-60% Overall Equipment efficiency (OEE) in the Swedish manufacturing industry[7]. This demonstrate that there is a lot of improvement potential in the Swedish manufacturing industry since, Blanchard states that 85% OEE is world class[8].

Against that background, a Swedish electronics manufacturer within the automotive industry is found interesting in order to understand why production flow is so important and why it is not easily achieved. The customer demand of products produced at the factory have been growing fast over the last years. The rapid expansion have been handled by increasing capacity at the existing factory, introducing new lines where space is available. This have led to that consecutive processes have been scattered over the factory. The long distances and poor flow of the products through the factory is recognized by the management as a problem area. Furthermore, they have been struggling with frequent disturbances in terms of machine breakdowns and quality issues. The poor flow through the factory entails to poor predictability and control of production output. The increase in demand of products is estimated to continue, the company have set clear goals on how much they want to be able to produce in order to meet the increasing demand. They do not however have a comprehensive long term plan on how to improve the current production, instead their focus currently lies on expanding with more lines and production facilities.

The company was previously part of another company but became a company of it's own. The old company was known for it's use of lean philosophy and rich company culture. The new organization retained little culture from the old company due to that most of the competence was brought in from other companies and the new organization was changing rapidly, entailing to that old culture and norms did not survive. Thus, the company can be viewed as a company which is not organizationally mature.

1.2 Problem statement

The company currently experiences problems due to a complex production flow in combination with unstable processes and a large amount of work in process (WIP). This entails to that the production output is unreliable and frequently lacking quality and poor delivery precision. The low productivity and flexibility of their current production system will affect their long-term competitive edge[1][6]. They have a plan for expansion by deploying new lines, but they are currently lacking a clear plan on how to and what to improve regarding the current production lines. According to Bellgran et. al. the practise to overlook improvement potential within existing equipment and instead invest in new machinery is common within manufacturing industry[1]. Furthermore, Dadashnejad et. al. concludes that it is common among companies to not have a clear and comprehensive plan for the whole organization in order to improve[9]. Which implies that there is a need of an action plan for improvement of the current lines.

1.3 Purpose

The purpose is to improve the production flow and productivity which is done by achieving larger predictability and control of the production system, in order for the company to stay competitive in an highly international and competitive market.

1.4 Aim

The aim of this Master's Thesis is to improve visibility of value flows and wastes in and around the assembly lines by implementing Value Stream Mapping. The root cause of the problems should be identified and thoroughly articulated, solutions to counter the problems should be developed. Furthermore, the aim is to develop a road map of short-, medium- and long-term improvements in order to create prerequisites for improvement of predictability and control of the production to improve the production flow and the productivity.

1.5 Scope & Limitations

This Master's thesis is limited to focus on the production flow from pre-assembly to the warehouse. Which entails that the assembly of the final product is the main focus and that the manufacture of components is not considered in this report. Data that will be investigated is gathered in a time span of 1 year due to rapid growth of the company and production volumes, which makes older data irrelevant.

1.6 Outline of the report

This report consists of 6 chapters and appendices. This first chapter is supposed to introduce the problem which this report builds upon as well as providing an understanding of what is set out to be achieved in this project. Chapter two is a theory chapter providing the necessary theoretical base for the report. The third chapter is the regarding the methods applied in this project and contains information regarding how and why the project was conducted as it was. The fourth chapter contains all results found, including the current state of the production as well as the future state. The chapter furthermore presents the road map towards the future state. The fifth chapter is a discussion chapter in which the results, literature and methods are critically discussed. The last chapter is the conclusion which contains the most important findings of this project.

2
Theory

This chapter will describe the most relevant theory that will be applied during this Master's thesis. This theory is necessary to understand in order to get better understanding of methodology that was applied during this Master's thesis. Theory is also used to strengthen the findings from the data analysis and results.

2.1 Total Quality management

During the 60's and 70's the Total quality management (TQM) became a popular concept that originates from the quality gurus Deming, Juran and Ishiwaka. TQM is a philosophy where quality thinking permeate the whole organization and that focus is on to satisfy the customer needs instead of productivity[10]. TQM is based on Deming's 14 points for management and Deming's chain reaction, which states that improved quality leads to lower cost due to fewer delays and less rework. This leads to a productivity increase and an increased market share due to lower price and improved quality. Which in turn entails to competitiveness and more jobs[4][11].

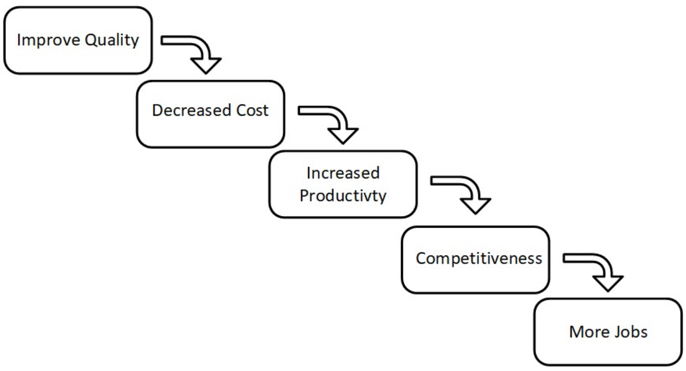

Figure 2.1: Deming's Chain reaction [4]

Quality is a fundamental factor in order to being an competitive company. It is key to get the organization to internalize the importance of quality, find and bring forward quality issues as early as possible in order to minimize the potential consequences. By implementing one piece flow and decreasing the WIP the problems becomes visible and forces everyone to solve quality issues directly instead of dealing with the problem later[12]. Even though one piece flow may be sensitive to disturbances and can lead to stops of the production it diminish the risk of over production and amassing products with unsatisfied quality that needs rework. As the disturbances also get handled directly, the long term effects of this approach is improved production and reduced disturbances[12].

2.1.1 Deming's wheel

Deming's wheel is a tool that is commonly used in order to continuously improve in all levels in a organization[13]. Deming's wheel, also known as the PDCA cycle includes the steps plan, do, check and act[14]. The first step is to plan the change, analyze and predict the outcome of the change. The second step is to implement the change in the organization. The third step is to observe the implementation and analyze the actual outcome of the implemented change and the last step is to introduce a new improved work standard to replace the existing one. By applying the systematic approach of the PDCA cycle will incorporate continuous improvements in the daily work, which will elevate the quality over time[15]. The concept of the PDCA cycle is visualized in figure 2.2.

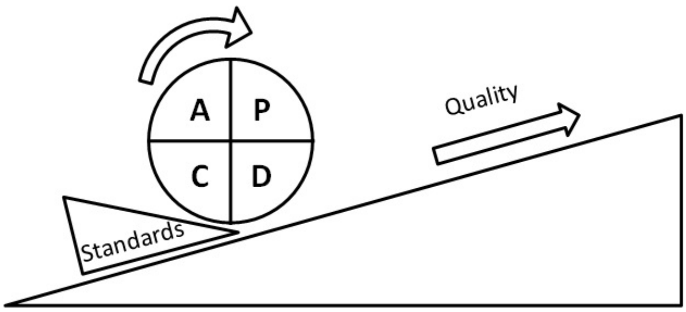

Figure 2.2: The PDCA cycle - A systematic approach to elevate quality

2.2 Lean Manufacturing

The Lean philosophy originates in the Toyota production system, and it can be described by four main principles; philosophy, process, people and problem solving (see figure 2.1). The principle of Philosophy means that there is long term thinking in every decision and that long term results is considered as more important than short term profits. The second principle, is about process oriented work, developing more effective methods using standardization and continuous improvement, creating even production flows and eliminating waste. The principle of people is about to respect, challenge and develop employees so that they can develop themselves both as professionals bot also as people. The fourth principle, problem solving, is about continuous improvements and continuous learning[16]. By building an organization

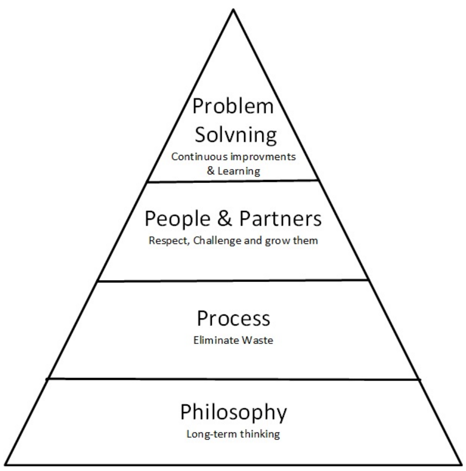

Figure 2.3: The four P's of Lean production[5]

around the four principles and building an organization that primarily focus on value flow, creates possibilities to reduce non-value adding time. This leads to a decrease in the time from the point where the customer makes an order of a product to that the point where the company get paid for it[5].

Hoshin Kanri is a concept within lean which is used to spread and implement strategies within a organization. The terms roughly translates to compass administration and the purpose of it is to make the goals and ambitions of the company available for all workers so that they can make decisions that move the company closer to it's goals [5][17]. Another important aspect of Hoshin Kanri is that it counters tendencies of sub optimization, which happens when each department or worker does not have a common goal. Instead they make their own goals which leads to that different parts of the company works towards different goals, entailing sub optimization.

Yokoten is the practise of sharing information and knowledge within the organization. The idea behind the concept is that knowledge extracted from an idea or mistake should be spread so that the mistake do not reoccur and the learning's from the idea can be reaped by the whole company[17].

2.2.1 Kaizen, work standards and the learning organization

Standardized work is the core of continuous improvement in lean manufacturing [18][19]. Standardization of work tasks is considered as a tool to eliminate waste and is used as a way to define a work procedure to be able to work continuously to improve it. A critical aspect of work standards is to find the right balance between a strict work procedure and at the same time let the employees have the freedom to be creative and improve the process. The key aspects to find the right balance lies in how the standards are written, involving the employees and those who are contributing to developing the standards. It is also important to audit the work standards in order to see that they are followed correctly and give feedback in order to improve[19][20]. Managers should be role models that live as they learn and encourage operators by explaining the importance of continuous improvements, and demonstrate it in their own actions[21][22].

The goal with the 4 principles, that was discussed in section 2.2.1, is to become a learning organization. Where mistakes are not necessarily a bad thing, but rather an opportunity for learning. Therefore, continuous improvement that occur on a daily basis is important and involve all employees. However, becoming a learning organization does not come easy. It requires long term commitment from top management all the way down to the operators. It takes decades to evolve the organization into an learning organization. The hard work is however worthwhile as the potential rise in operational efficiency is large[21].

2.2.2 Wastes

In lean philosophy there are three main wastes, Muda, Mura and Muri.

Muda is the work and consumption of resources which is not directly value adding i.e. the work that the customer is not willing to pay for[5].

Mura is the unevenness of the production flow, which causes resources to be strained at some times and idle with nothing to do at other times. This unevenness have a negative impact as the available resources is not utilized in an effective manner[5].

Muri is the over-utilization of the resources, which is when the machines and personnel works at a faster pace than what is optimal, which over time will cause attrition on both the personnel and the machines. Over time this will cause breakdowns and high turnover of staff which results in loss of valuable experience and know-how[5].

One of the founders of the Toyota Production System which is the foundation for lean production was Taichii Ohno, he identified seven different wastes (Muda) as seen below[23][6]:

1. Over Production
2. Transport
3. Inventory
4. Motion
5. Waiting
6. Over Processing
7. Defects
8. Unused Creativity

Over production is viewed to be the worst of all waste's as it leads to the other wastes. It leads to that more components have to wait in storage and be transported between processes. It decreases visibility as it becomes harder to get an overview of the cluttered lines. Mistakes becomes more frequent and more severe as the material becomes easier to mix up and mistakes takes longer to detect. Quality issues becomes worse as they are not detected as fast, they also become harder to deal with as the ability to track causes to defects becomes poorer. The lead times becomes longer and more and more orders needs to be expedited, leading to further disturbances and even more work [24] [12].

The over production leads to large amounts of work, mainly related to managing material and quality. It is not value adding and thus something that do not benefit the customer. It takes resources from long term improvements and entail pure cost without benefits for the company[25][12].

2.2.3 Continuous production flow

The creation of a continuous flow is done in order to make problems visible and to reduce the waiting time between processes[26][27]. The nature of the one piece flow entails that wastes becomes visible and thus can not be ignored. When implementing continuous flow, unnecessary non value adding work is reduced as WIP becomes lower and disturbances fewer. The system becomes more oriented towards the work that actually creates value for the customer. As the value adding activities increase relative to non value adding work, the system will become more cost effective.

By producing in large batches by the principles of traditional mass production the results are commonly over production and large WIP, over production being the most fundamental waste within the lean methodology [24]. The goal is therefore to minimize the batch sizes and level out the model mix in order to approach continuous flow, which leads to higher flexibility [28][24].

Furthermore, creating a continuous flow using pull mechanisms is important to improve stability and reliability of the lines. To be able to produce using one piece flow or very small batches, the line needs to be flexible in order to cope with the small batches. The main threat towards flexibility is long change over times, which is the time needed to set up the line to be able to produce another product type[29]. By actively working to reduce the change over time using Single Minute Exchange of Die (SMED) methodology it is possible to drastically reduce the change over time and provide increased flexibility[30][31].
In the ideal lean system the material flow is controlled using an pull system. A pull system would entail that when a product is removed from inventory to be shipped to the customer. The pacemaker, which is the point in production that sets the pace for the rest of the production, trigger a signal to start the production to replace the consumed product[27].

The consumption of one product or component would trigger a signal to the upstream process to produce a replacement, this is what is known within lean as a Kanban system. The purpose of the Kanban system is not only to automate the ordering of components from different processes, the main purpose is instead to limit the amount of WIP within the system. Which is done in order to make disturbances visible and reduce the amount of resources tied up in production [27] [5].

The concept of flow is illustrated by a metaphor which is known as the Japanese lake [32]. Where the production system is a ship, underwater cliffs are inefficiencies and disturbances and the water is the inventory. When having a poor flow and excessive WIP, the water (inventory) hides the cliffs (disturbances) which perhaps enable relatively smooth sailing, but is actually just hiding the ineffectiveness. When improving flow and thus reducing WIP, the water level gets lower and reveals the cliffs, i.e the disturbances becomes visible and needs to be handled in order to make it possible for the ship to continue sailing [25][5].

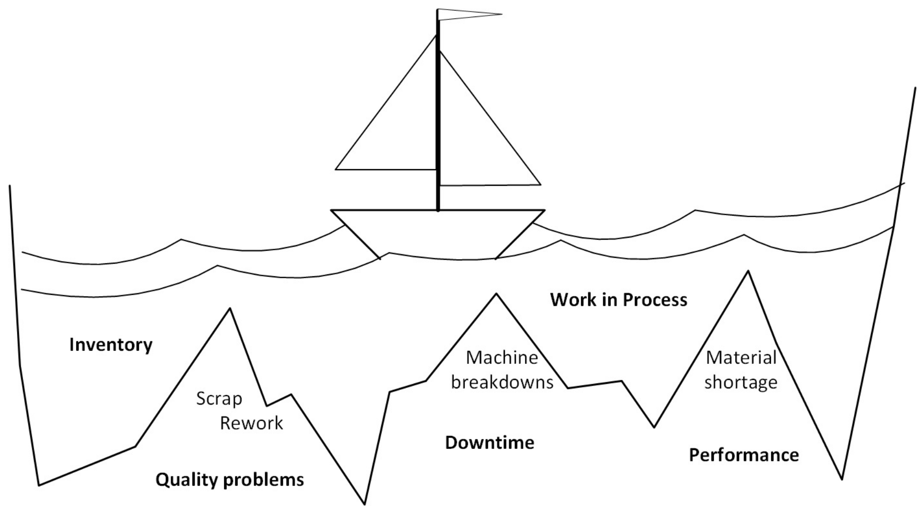

Figure 2.4: Hidden problems under the surface due to high inventory [32]

2.2.4 Value-Stream Mapping

Value Stream Mapping (VSM) is a method for improvement of the work and information flow within a production system. VSM identifies losses and the lead time within the system and aims to decrease the non-value adding time, elevate the quality and long term cost reduction[9].

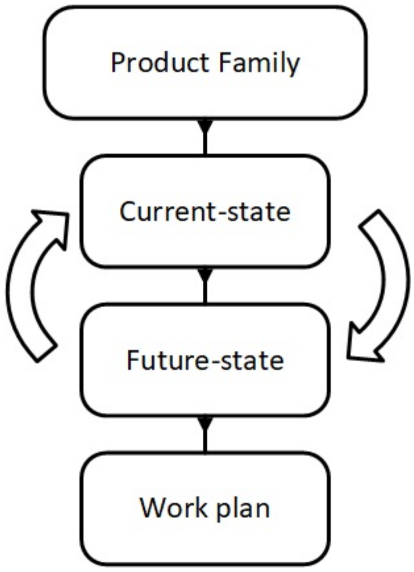

Figure 2.5: VSM work flow according to 'Learning to See'[27]

The idea of creating a current state map of the system is to make losses visible, a map of the future state is then created, which shows what to improve in the system. The future state map works as an initiator to improvements that needs to be done. The process is iterative, which entails that when the future state is achieved, the current state is mapped again and new goals of improvement are set in the form of a new future state map [27].

The VSM-Methodology have a lot in common with the PDCA cycle, both being tied to the concept of continuous improvement which is heavily emphasized within lean production philosophy. The idea being that small iterative improvements leads to large improvements over time. The work flow proposed by Rother & Shook in their book "Learning to see" can be seen in Figure 2.5[27].

The idea with value stream mapping is to get understanding of the value stream and to shorten the total lead time. The shorter lead time there is, the faster the turn over of the material. This will then lead to decreasing the time between paying for raw material and getting paid for products from the end customer[27].

VSM is also closely connected to the wastes identified by Ohno, as the goal of VSM is to make the waste visible in order to be able to eliminate the waste and improve upon the production system.

2.2.5 5 Why?

The lean methodology is all about lifting up problems to the surface in order to increase the quality and productivity by reducing waste within the system. When the problems are visible it is important to permanently solve them, not only applying a short term remedy. By using the 5 why methodology it is possible to find the root cause and ensure that the problems never occur again[33]. The methodology is about finding the root cause the problem by asking "why?" five times, the method is designed to entail deeper analysis of a problem[13]. This method will lead to the root cause of the problem, which then can be solved. By solving the underlying problem instead of focusing on the symptoms, there is prevention for similar problems will occur in the future[13].

The 5 why method is designed to be a way for oneself to deeply reflect on why a problem occurs rather than settling for a tempting good-enough explanation which can be remedied with a quick-fix. Instead one should ask why something is as it is until the true underlying reason is discovered. Only when this is done solutions for the problem can be considered. This method is a way to apply the lean principle of basing decisions on facts [5].

2.3 Theory of Constraints

The Theory of Constraints (ToC) is a holistic way of thinking when working towards improving the performance of a production system. Performance in this case would be measured in number of produced products of good quality in a specific time period which there is a customer for.

To achieve the goal, i.e the wanted performance, the work process is conducted in five steps. The first step is to observe the whole system and identify the constraint which is the bottleneck of the system. The next step is to find a way in which the capabilities of the bottleneck could be exploited to it utmost potential. When the process have been thoroughly investigated, all available resources should be invested in raising the performance of that particular process. The next step is to elevate the system constraint, i.e improve the available capacity of the bottleneck. When the system performance is no longer improving at the same rate as the bottleneck, it means that the bottleneck has moved to another process. To continue allocating resources to the process will no longer improve performance of the entire system. Which entails that the next step is to start over again at the first step and identify the new system constraint [25]. The ToC way of thinking builds upon the mechanism that when the capacity of the bottleneck is raised, the capacity of the whole system is raised.

Figure 2.6 is a visualization by Goldratt on how time buffers affect the amount of work required to keep operations going [25]. The time buffer corresponds to the relation between the amount of WIP in the system, i.e the lead time and the due date of delivery. If the time buffer/WIP is extremely low i.e at the far left of the curve in Figure 2.6, then a lot of work is required to keep the system working as it is very sensitive to disturbances. If the time buffer is large, and there is a lot of WIP, i.e on the far right of the curve the amount of work needed will be really large as well. This is due to all the extra work that arises when the system is overflowing of material and mistakes occurs more frequently, a lot of time is spent on managing and finding material, orders needs to be expedited due to the long lead time and quality issues is harder to detect thus making the consequences of errors much larger. According to Goldratt it is instead favourable to be in between the two extremes, with enough buffers to counter the worst of the disturbances but not so much that material related issues arise [25].

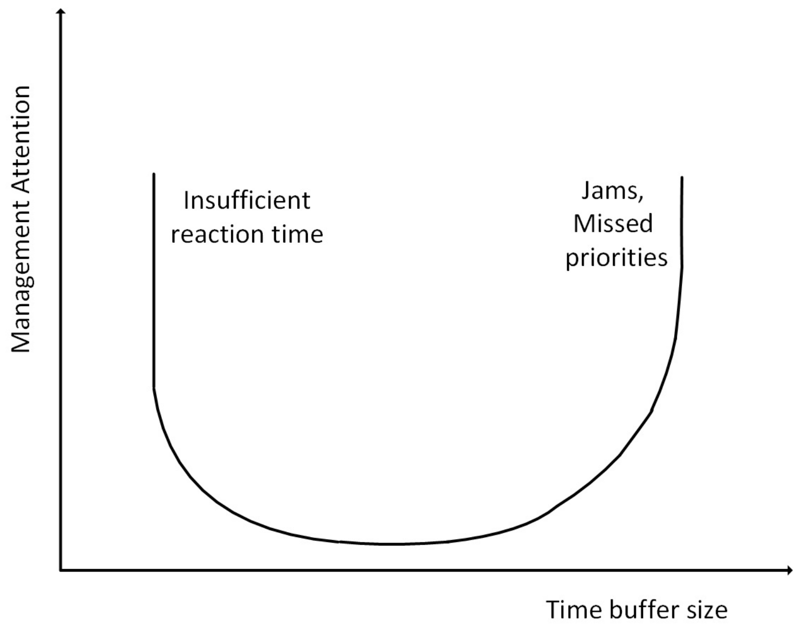

Figure 2.6: Time buffer diagram [25]

2.4 Performance measurements

Performance measurements are used in order to follow up how well a system is performing and how effective it utilizes available resources. Performance measurements can be seen as the fundamental of improvements work and can be considered as a key to create a competitive leverage in a rapid changeable environment[34][35].

2.4.1 Overall Equipment Efficiency

A common performance measurement that is used in manufacturing is Overall Equipment Effectiveness, (OEE). This performance measurement was developed by Nakajima and can be described as a measurement to monitor the production performance and how a company utilize their resources. The OEE measurement includes Availability, Performance and Quality and can be calculated by following[1]:

$$Availability = \frac{Available\ Time - Down Time}{Available\ Time}$$

$$Performance = \frac{Ideal\ Cycle\ Time \cdot Processed\ Products}{Operations\ Time}$$

$$Quality = \frac{Processed\ Products - Defects}{Processed\ Products}$$

$$OEE = A \cdot P \cdot Q$$

OEE can be understood as a measurement that shows how much of the available time that the equipment is actually used for value adding operations. The rest of the time, the machine is either waiting, producing defective products or have broken down. Average OEE among Swedish companies have been found to be between 50% and 60% [7][36]. An OEE of world class is however as high as 85% [8]

Dadashnejad et al. found that VSM and Lean Production could be implemented with benefit in terms of OEE improvements [9]. The idea being that with the use of VSM identify improvements which improve flow and the amount of value adding work which is conducted. This implies that VSM could be used as a tool in order to make OEE improvements on equipment and improve flow.

2.4.2 Lead time

Lead time is the total time for incoming material to be produced and then delivered to the customer. The lead time is a common measurement used in lean to see how long products are waiting in the value stream. It can also be used and compared to the total value adding time to get a sense on how much waste there is in the system[27].

Lead time can be calculate by the sum of all throughput time for every process in a value stream. Throughput time is calculated according to Little's law[34].

$$Throughput\ time = WIP \cdot Cycletime$$

Lead time is then calculated by summarize all the throughput time for every single process[27].

$$Lead\ time = \sum Throughput\ time$$

3
Methodology

This chapter presents the methodology that was applied during this Master's thesis.

3.1 Designing the study

The project was conducted during a 20 week period, the data for the current state analysis was collected during a five week period. The first step was to get an understanding of the current state at the company by using Value stream mapping methodology. The data for the Value stream mapping was collected by observing the production, the collected data was necessary in order calculate the lead time. All the data for the current state analysis was collected during the same period, during the months of January and February in 2019 in order to give as reliable an accurate results as possible.

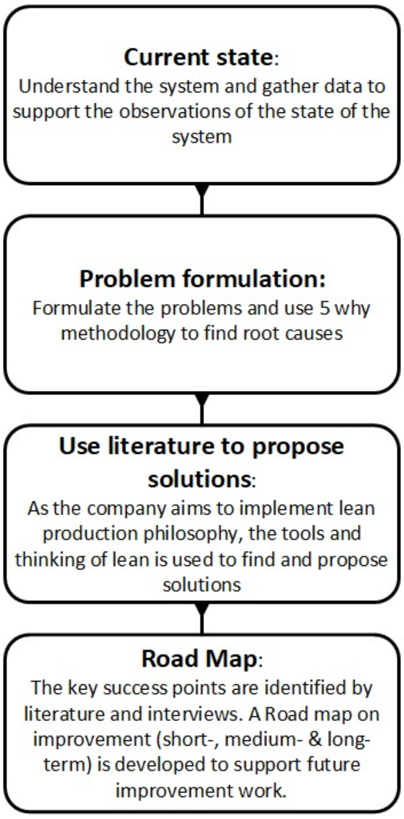

Figure 3.1: The Methodology that was used during the project

The research was designed as mixed methodology, where both qualitative and quantitative data was used. However, the weighting and mixing of the different data was not set as equal. The main focus was on the qualitative data but quantitative data was analyzed to strengthen the findings that was made by analyzing the qualitative data. The approach was based on the chapter 10 of the book "Research Design" by John W. Creswell[37].

When the Current state was defined the value stream map was used to identify wastes, and to go to the bottom to find the root cause to the problems, the 5 why methodology was used to analyze previously identified wastes in the system[33].

When the root causes to the wastes was identified literature was used to find solutions, mainly by lean methodologies because of that the company already use an adapted version of the Toyota production system. A future state map was then constructed based on the solutions that was recommended in the literature.

The last step was to construct a road map, with the purpose to give the company directions on how to proceed in order to amend the identified problems. The first iteration was built on literature and the results from the current state analysis. Before the second iteration was made, interviews with managers on different levels was held in order to find what key aspects which had to be considered to reach the future state. The road map was then modified to better fit the needs of the company.

3.1.1 Deductive and Inductive phases

The problem which this project is based on was open ended, which led to that the project was designed to have two phases.

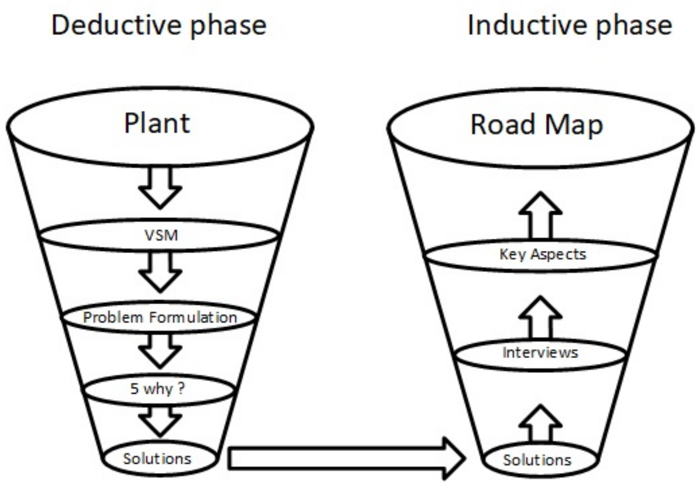

Figure 3.2: Work flow through deductive and inductive phases

Deductive Phase The first phase was the deductive phase in which the production as a whole were considered. The system was gradually understood and the scope were continuously narrowed down to consider the most important factors in which there was potential to improve predictability and control within the production which were the main goal of the project. The last step of the deductive phase was to narrow it down further into solutions which should remedy the production issues. The solutions was mainly from lean production methodology and they were verified to be in line with methods that the company was already applying.

Inductive Phase The second phase was the inductive phase in which the solutions was expanded into a road map. The purpose of the road map was that it was supposed to act as a guide in order to increase the possibility that the solutions would be beneficially implemented. Because of that the company was previously acquainted to the proposed solutions through their production philosophy, the new goal became to identify why they had not been able to implement the solutions, which was done by conducting interviews with involved managers on different levels. The key aspects which was identified to why improvements have not been made is then complementary to the road map in order to raise the chance of successful implementation.

3.2 Current state

In order to base the future improvements on facts, the current state of the production system must be sufficiently understood. To build understanding of the current state a VSM was conducted, which entailed understanding of the dynamics between the production lines, the internal logistics and available supply of components. The results of the mapping was a part of the qualitative data which composed a base for for the rest of the project. There was three product families that was chosen to follow trough the values stream. This because products A and B are mainly produced on assembly 1 and has different characteristics and have some difference in cycle times and order volumes. Product C was chosen due to that is the newest product and have a large order volume at assembly 2. The Value stream map follows both the main two components, PCB and Sensor that have two separated flows and then merged in the assembly lines was chosen in order to get good understanding of the dynamic of the production flow.

3.2.1 Creation of current state map

To get started with the current state map it was recommended to start with empty A3 sheet and a pencil to draw by hand, and map the whole process by yourself in order to get a complete understanding of the flow [27]. The VSM and every improvement in lean thinking starts by clarifying the end customer demand. This was done to avoid to improve the value stream in a way that does not benefit the customer or to provide something other than what the customer wants and is willing to pay for[27].

Step 1 The first step in creating the current state map was to choose a product or a product family to follow through the value stream. When the Product family was chosen the flow was traced, which was done by walking through the factory starting at the warehouse for finished goods and then walking upstream production flow and observing the processes to get a brief understanding of the value stream.

Step 2 The second step was to define the main processes, which was visualized with process boxes. The resolution of the map i.e in what level of detail the processes would be mapped in was decided to be at the line level, in order to get a good picture of the system dynamics in an effective way. As too many processes would have made the map unmanageable, the processes which is directly connected by automation was merged into one process [27].

Step 3 When the main process was defined, production data was collected which included cycle times, changeover times, number of operators, scrap percentage, batch sizes and available working hours. The walks through the production flow also revealed locations of buffers and inventories, which was also included in the map in order to get full understanding of the material flow[27]. Triangles was used to visualize the inventory.

Step 4 The flow of incoming material and outgoing products to end customer was visualized. In order to keep the map manageable only two main components (PCBs & Sensors) of one product group was mapped. Trucks and factory symbols was used to visualize shipping and customer plants as well as supplier plants. Broad arrows was used to show the direction of the material flow.

Step 5 Next the information flows was mapped in order to understand the complexities of the system. There are two main information arrows. Manual information flows was symbolized with straight arrows and electronic information flows was symbolized with arrows modified as a lightning bolt. The mapping of the information flow was relatively complicated, and discussions with controllers and planners had to be conducted to fully understand the information connections. A lot of controlling was done manually by supervisors or production controllers that needs to manually count the inventory and make daily adjustments to the production, these points in the flow was visualized with a symbol of a pair of glasses[27].

Step 6 When the information flow was drawn, the material flow was defined and introduced into the map. If the material was pulled from a previous upstream process or if it was pushed through the processes downstream was determined. Pushed material was visualized with a straight, striped and broad arrow, meanwhile pulled material was visualized with a circled arrow.

Step 7 The last step was to draw the time-line under the main process and calculate the total value-adding time and the total lead time for the product family that was chosen for assessment. In value stream mapping with multiple upstream the longest path should be the used to calculate the lead time[27].

3.3 Data Collection

This section describes how and why the data was collected.

3.3.1 Literature study

The purpose with the literature study was to find relevant information and gain useful knowledge from available research articles and literature about Lean manufacturing, Value stream mapping and related subjects that may be relevant for the project. The primary data bases that was used was Chalmers library, Summon and Google scholar.

3.3.2 Qualitative data

Qualitative data for the current state was gathered by the members of the group by direct observations by spending time in the production observing the processes and taking field notes. Clarifying questions to operators and responsible personnel was asked in order to get a better understanding of certain processes or routines. This approach is what Creswell denominates the natural setting[37]. Daily communication either by e-mail or in person was also held with responsible managers and knowledgeable employees at the factory in order to get an as general picture of the situation as possible.

3.3.3 Quantitative data

The quantitative data which was gathered continuously by the ERP-system was retrieved with the aim to identify and understand production bottlenecks, general behaviour of the production system and recurring disturbances.

3.4 Analysis

This section describes how the data was analyzed and interpreted.

3.4.1 Literature study

The analysis of the literature was made by grouping relevant articles and books after different key words, e.g. VSM, Lean, Continuous flow, TQM, PDCA and ToC. The literature findings was used to get an better understanding of the current state. The literature was also used to propose solutions and strengthen strengthen the findings from both quantitative data and other qualitative data.

3.4.2 Qualitative data

The "Good research guide" by Denscombe recommends to identify themes to analyze qualitative data in order to identify patterns[38]. Therefore was six themes composed and color coded in order to group the wastes and problems that was observed in the production. By identifying and visualizing wastes and problems in the current state map, the problems became more visible and gave an better general picture of the current state situation. Through discussion with managers and observations it was concluded that this six themes was considered as the most critical areas to improve. The six themes was following:

1. Green: Laboursome Management
2. Blue: Quality
3. Yellow: WIP/Material Handling
4. Orange: Flexibility/Lead time
5. Pink: Over production
6. Purple: Limited time and personnel resources

The analysis of the current state map was then conducted by placing color coded arrows on the map where the wastes and problems was observed in the production flow, see Appendix 1.

An interview protocol was constructed following the recommendations from the book "Research design" by Creswell. The questions was divided into two phases. the first phase was to let the respondent to discuss their view of the current state and what was need to improve in order to become better. The second phases was about discussing their view on how a future state production system should be and the main obstacles to reach that future state. To see the full interview protocol see Appendix 2.

To gather qualitative data for the iteration of the road map, semi structured interviews was conducted with managers on different levels and departments within the company. The semi structured interview was recorded and key takeaways from the interviews was written down, as recommended by Creswell in the book "Research design"[37].

The analysis of the interviews was made by grouping the answers from the respondent into the six themes that was used in analyzing the VSM. Every theme got the same color code in order to make it more visible to group the answers correctly to find patterns and interactions in the data.

1. Green: Laboursome Management
2. Blue: Quality
3. Yellow: WIP/Material Handling
4. Orange: Flexibility/Lead time
5. Pink: Over production
6. Purple: Limited time and resources

Due to that relatively few interviews was made, the analysis was chosen to be made manually and that a full transcriptions of the recorded interviews was not considered to be necessary. Therefore, answers was interpreted and key takeaways that was documented from the interviews was color coded, in order to group the answers and get an clear overview over the themes in order to identify patterns. The key findings from the interviews was then used to iterate and improve the road map.

3.4.3 Quantitative data

The analysis of the quantitative data was done by using Pareto charts and line balancing charts in order to to find the few vital problems and the bottlenecks. The primary data was collected during the same period as the qualitative data was collected in order to strengthen the findings of the qualitative data. However, the quantitative data was compared to a larger data set of one year in order to verify that the observed data was not deviating i.e is representative for the production system.

3.5 Problem formulation

By observing the production, asking relevant questions to operators and responsible managers it was possible to interpret the results from the current state map which entailed to that problems, that affect the production flow and throughput in a negative way, was identified and localized.

3.5.1 5 Why analysis

In order to analyze the results of the value stream map and to find the true core to the problem the 5 why methodology was used. The first step was to state and formulate the observed problems at the production lines, then ask the simple question why it happened? or why is it like this? when that was answered the same question was asked again. This was then repeated several times in order to reach the root cause to the problems. The goal was to lift up these problems to the surface and make a road map that points the direction for the company to overcome the core problems.

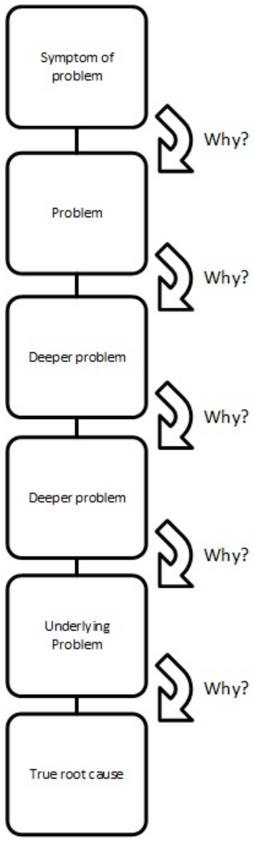

Figure 3.3: The concept of 5 why methodology

3.6 Creation of Future state map

The future state map was constructed according to the value stream mapping methodology that was used for the current state map. The aim with the future state map was to minimize the lead time through the system and reduce waste for example over production which is considered as the main waste according to the lean methodology.

3.7 Creation of Road Map

The road map was created in order to point the direction for the company to reach the future state by implementing identified solutions. In order to make the road map as articulate as possible, the solutions where sorted by which organizational level they did concern and at which time horizon they should be implemented.

The organizational levels used in the road map was identified from observations made at the company, where three different organizational levels chosen to be relevant for implementation of the found solutions. The levels were, day to day operations, middle management and top management. The distinctions between the levels was that day to day management are mainly working with daily operations with responsibility for specific lines. The middle management have a more long term focus on their work and are not responsible for a line but rather an larger area or field. The top management are the managers on a factory or company level.

The road map was constructed to be implemented in three different time spans: 0-1 years, 0-3 years, 0-5 years. These time spans was chosen to fit the organizational levels previously chosen, the longest time horizon was set to 5 years due to that the rapid change of the company would have rendered a longer time span unrealistic. The reason to why the three time spans starts at zero is to that the changes needs to start immediately but here is have different time horizon to succeed with the implementation. E.g. cultural changes takes times to truly implement and it needs to start with small steps and evolves over time.

The road map was constructed in steps, the first step was to make recommendations that was first based on literature. Then the road map was developed and improved by combining the literature with the findings that came from the analysis of the interviews, see section 4.5.1.

4

Results

4.1 Current state

The production system is changing continuously due to increasing production volumes and introduction of new products and production equipment as well as improvements on existing machinery. The current state analysis is mainly based on observations directly at the production lines. Production data from the company's ERP-system was used to identify bottleneck's and to get an accurate picture of the state of the productivity of the lines. The bulk of the observations was made and the production data was gathered between the 11th of January and the 9th of February 2019.

4.1.1 VSM-Current State Map

The Value stream map shows that there are complex material and information flows where the lead time in the worst case is up to 25 days and where the value adding time is 193s for sensor through assembly 1. This implies that there is much waiting time in the production and that there is a large improvement potential[27]. All VSMs are available in Appendix 3.

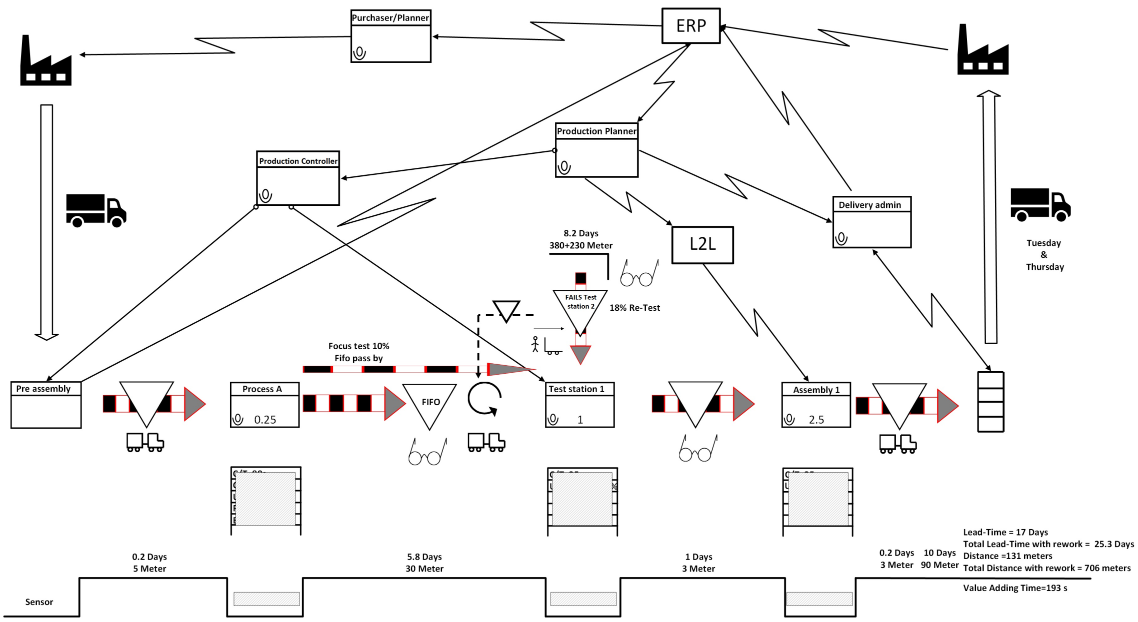

Figure 4.1: Value stream map of Sensor through Assembly 1 with a lead time of 25 days

4.1.2 Overall Equipment Efficiency

During the observed period the Overall Equipment Efficiency (OEE) of the two lines was at an average 55% for both lines which is just above the average for the lines over the last year. However, the logistics department expected 65% respectively 60% when they planned the production of that period. This gives an error of approximate 15% respectively 8%. This results in a gap between the expected throughput and the actual throughput, which entails to that the production planner needs to re-plan and interrupt the production by for example changing the order of production and introducing extra change overs in order to produce most urgent orders. The practise of quick changes within the production planning is believed to contribute to the unpredictable nature of the production system as it results in disturbances of the flow and lowered performance.

The Overall Equipment Efficiency is furthermore a key aspect of the unpredictability and poor flow of the production system. Bottleneck equipment is not utilized to its full potential due to unexpected downtime because of machine breakdowns, Low performance arises due to multiple different inefficiencies of the line as well as machine time spent on products which are later scrapped because of quality issues.

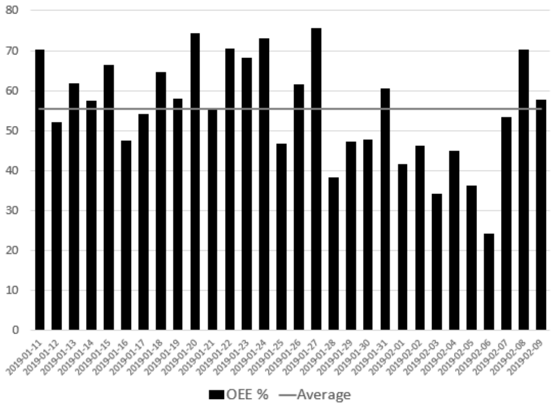

Figure 4.2: OEE for the bottleneck of Assembly 1 during the observation period

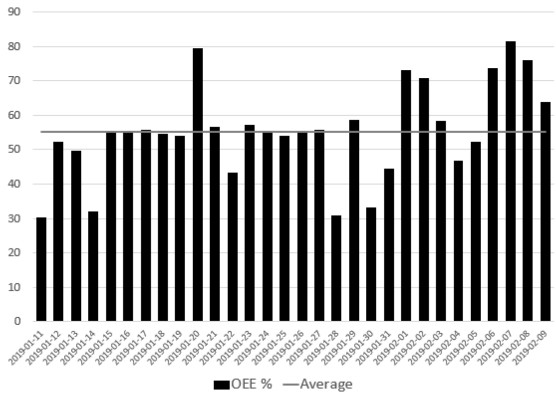

Figure 4.3: OEE for the bottleneck of Assembly 2 during the observation period

4.1.3 Productivity

The relatively low OEE of the assembly lines is attributed to three main factors which are found by analyzing Pareto-charts of breakdowns for the respective stations of the lines. The three main factors which both assembly 1 and 2 have in common is failure of the Final test, screwdrivers and cooling paste dispensing stations at the assembly lines. These factors are found by observations to have a large impact on not only downtime but the performance as well, this is due to that the operators often run the lines at a reduced speed for a while when the problems arise before making the decision to take down the machine and call for a maintenance technician. The screwdrivers are also impacting the yield as problems also translates into quality issues resulting in scrap, on top of the reduced performance and breakdown. These findings from the observations was then confirmed that dispensing and screwdrivers was common failure in the Pareto-charts, see figure 4.4 and 4.5.

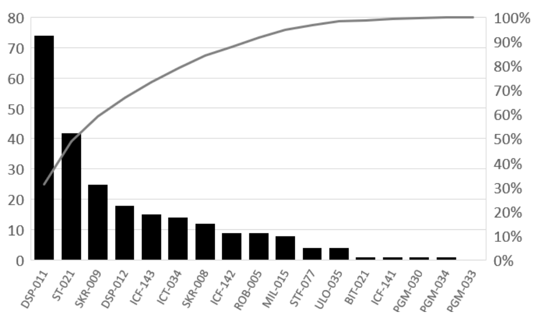

Figure 4.4: Pareto-chart of number of most common break downs at assembly 1 and 2, where DSP-011 stands for dispensing position 11, ST-021 stands for Final test position 21, and SKR-009 stands for screwdrivers position 9

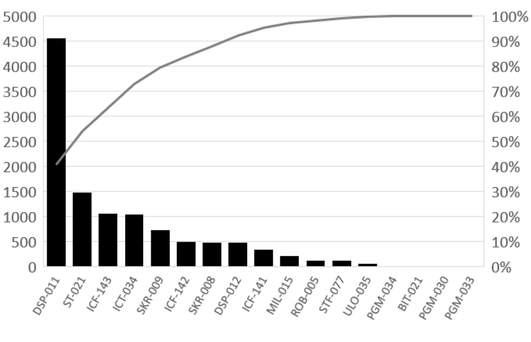

Figure 4.5: Pareto-chart of summarized Down time at assembly 1 and 2, where DSP-011 stands for dispensing position 11, ST-021 stands for Final test position 21, and SKR-009 stands for screwdrivers position 9

The fourth factor is that Process 1 is integrated Assembly 1, the cycle time of that integrated Process 1 is close to the line cycle time. Which entails that stops and delays of the Process 1 directly effects the whole line. When a PCB fails within the Process 1 the whole panel with multiple PCBs needs to be re-tested in the machine multiple times in order to assure that no false negatives results in unnecessary scrap. The practise of multiple re-tests do however affect the OEE as the panel is starving the whole line when tested, as the panel consists of multiple PCBs, the re-test time used may be as much time as 16 times the cycle time. The loss of time due to retest is originating in a quality issue, but the time loss is classified as a performance loss.

4.1.4 Flows of Material

There are two main kinds of material flows in and around the lines, standardized material handling and non-standardized material handling. The standardized material flows are mainly handled by operators on electric trolleys which move trough the production on predetermined trails, picking up components, products and Kanban-cards as well as delivering parts and products previously ordered using the Kanban system. The operators move through their trails 2 times every hour. The non standardized material handling is more unstructured, there are no particular rules on how the operator or controller should handle the material, instead it is up to the individual to make a decision on how and when the material should be moved or processed.

The material flows are standardized and based on work instructions for the most common material flows, i.e. standard products and components. The non-standardized flows are most prevalent among products and components that have been assigned to be analyzed, i.e. have failed to pass quality control. The components and products which fail at the quality control are not necessarily of sub-par quality which entails that they need to be controlled again manually. The products and components which are to be analyzed are placed in special load carriers at the lines which the analysis-operator checks manually when he have time. The analyzed products are either scrapped or returned to the line if the quality is good. At this stage there are no clear routines for when and how the components and products should be re-introduced to the line. Which entails that the most of the products will be stored at the line until a production manager will make the decision to do the rework. Which entails that the components and products may be put on hold for a while, waiting for the opportunity to fit them into the production schedule. Scrapped components may take up production space as well due that scrap is not always immediately removed. One reason to why scrap was not immediately removed was in one case that it was not clear on which production area should be assigned the scrapping cost.

4.1.5 Work in process

The material flows are laboursome to manage because of several reasons, the material handling which is not regulated by standardized work procedures being one.

The largest factor is found to be the WIP in the system. It clutters the lines and creates a lot of labour for operators and managers. Common work caused by the WIP that where observed by the group was operators who had to handle a lot of extra material, managers and planners who had to localize material which was hard to find due to the large amount of other WIP and the extra work to find available load-carriers and boxes which where not already occupied.

The Value stream map shows that a majority of flows are pushed through the system which results in large quantities of WIP. This is a result of large buffers that are put in place due to that the processes are not reliable and that there is a urgency to meet the customer demand. Which is why management is not willing to stop the upstream production which results in that buffers fills up quickly. At some points there is allowance for buffers to grow past their designed size as the urgency to deliver is felt so strong that management is ready to fill the system with even more WIP if that decreases the risks of disturbances related to material shortage.

4.1.6 Standard work instructions

There are work standards for the tasks that are conducted during a majority of the time. However, there is little time for follow up on work or improvements. Which entails to that operators do not follow them.

The lacking routines/work instructions entails to lost opportunities of automating managerial tasks. The handling of reoccurring problems are not automated in a way that the operator knows what to do without needing to consult a manager or engineer. Standard work instructions forms platforms for continuous improvements, which entails that it is hard for the managers and operators to work with continuous improvement in the current milieu as a substantial amount of work is not regulated by any standards.

4.1.7 Production Planning

The logistics department is responsible for planning the production and to deliver the right amount of products to the customer at the right time. The operations department on the other hand is responsible to ensure that the production is producing the quantity that the logistics department has ordered. In order to get this to work the logistic department and the operations department establish a production contract every two weeks with a fixed quantity of produced units of different product types. The production schedule, is then set once a week and adjusted approximately two times per day. The production schedules for the two assembly lines are separate. This is due to disparities between the lines, which results in that all different models are not approved for being produced in the the first line and vice verse.

4.1.8 Quality and testing

The company is struggling with quality issues, which due to the large WIP leads to that problems are hidden. When the problems are discovered it is often to late. This results in a large amount of products needing rework, which affects the performance in a negative way and results in a low delivery precision. Firefighting disturbances becomes laboursome for the management and consume important time that could be used for improvement work, which may become costly for the company in the long run.

A key function within lean production philosophy is that decisions should be based on facts. Thus, it is essential that information is available for managers and workers so that they can make beneficial decisions. At several points within the production, important feedback regarding quality have a long lead time which entails that it is hard to base decisions on facts.

The implications of the lagging feedback is that the faulty products are not discovered until the next shift or even later which entails to that operators handle quality issues which is a result of work that someone else have produced.

4.2 Identified problems

This section will present waste and problems that was identified during observations at the production lines. To see all VSM with identified problems see Appendix 1.

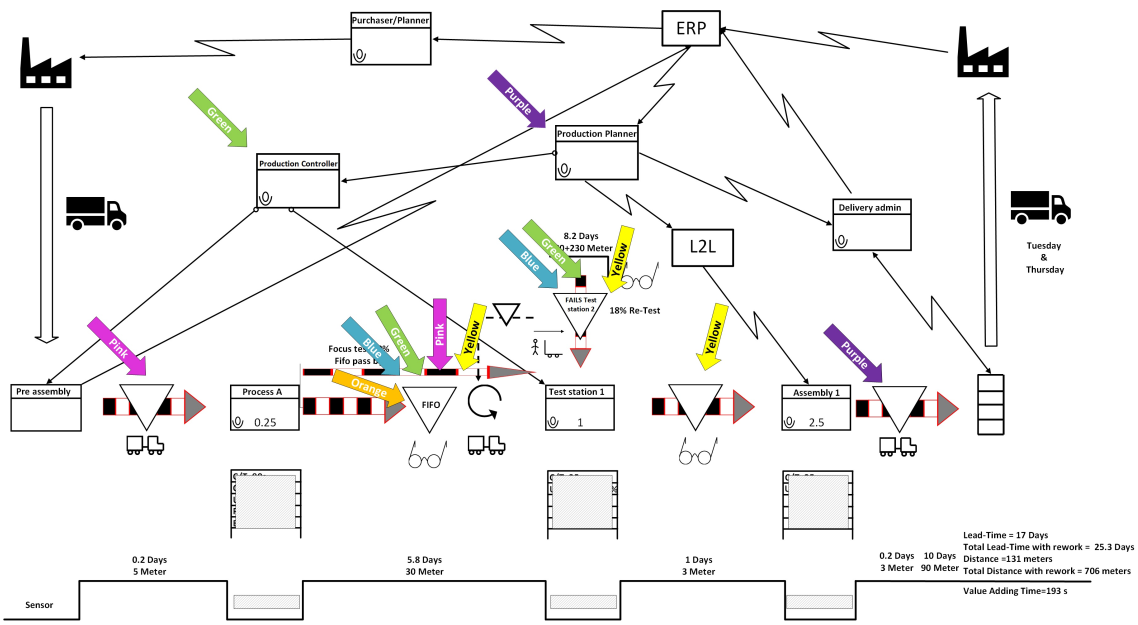

Figure 4.6: Waste and problems that was found during observations

4.2.1 Green: Laboursome management

One of identified reasons to why the performance is not as good as it could be is found to be a shortsightedness in how work is performed. The symptoms of problems are handled rather than the core issues which allows for problems to occur again and again. This is one of the reasons to why the current production is heavily dependent on engineers and managers to keep it operational.

The work is mainly focused on short term solutions and is conducted in a relatively short sighted manner. Problems are handled by implementing solutions which are not documented properly, making knowledge difficult to share. This results in that a problem that is solved is likely to return a couple of weeks later and the work have to be done again. This leads to that the processes are depending on that management and technical personnel are available to solve problems that arise over and over again.

4.2.2 Blue: Quality

From the perspective of value streams and productivity improvement, the main problems with the quality situation in the production lines are that the poor quality and the false negatives of testing are affecting the productivity negatively. Where components and products which become scrap or are to be re-tested occupies valuable machine time at the bottleneck. This leads to an interesting insight, which is that some of the disturbances that are thought of as process-disturbances actually are quality-disturbances in disguise. This entails that the data which is automatically gathered and used to compute disturbances from Quality, Performance and Breakdowns is not to be taken at face value as the Performance factor is confounding quality-disturbances with other kinds of disturbances. Which entails that the consequences of poor quality is larger than what is perceived by just reading the production reports in the ERP-system.

4.2.3 Yellow: WIP/Material Handling

The concept of the Japanese lake is found to be suitable the situation of the plant. According to the Japanese lake theory, inventory is used to disguise a plethora of issues and disturbances, which is assessed to be most likely the case in this context as well. Through observations it is found that the instability of the processes is the main reason to why the inventories are oversized. The reasoning behind the large buffers is that the non-stable key processes must run at all times, and due to that they can not risk to run short on material.

From the reasoning behind the levels of inventory the conclusion is drawn that short term solutions such as increasing inventory is preferred over long term improvements such as taking down the line and implement measures to remedy the core issue. Unknown losses are preferred over known losses, avoiding scrap cost by implementing re-tests was preferred as the cost of the re-tests are hard to quantify as the re-tests entail a lot of utilization of the equipment.

4.2.4 Orange: Flexibility/Lead time

The changeover takes up to 50 minutes to change between different product families and up to 10 minutes to change between products of the same product family in the first assembly line. At the second assembly line it takes approximately 10 minutes for all changeovers. Improvement of the change over time is however something that is not prioritized and there is no active work at the moment to shorten the changeover time.

The logistics department aim for large batches in order to minimize lost production time that is used for change overs. However, due to production disturbances and unreliable processes the production planners often expedite orders in order to finish the most urgent orders in time for delivery. This entails that the operators are forced to make extra change overs which leads to more inefficiencies and lost production time. The increased inefficiencies leads to an even more strained situation in which more scheduling changes needs to be done and the system ends up in a vicious circle. A consequence to the strained delivery situation is that some orders are not delivered in time for the ordinary shipment, which leads to that they are expedited through the system and sent using a expensive special delivery to the customer.

4.2.5 Pink: Over production

As it can be seen in the VSM of the current state there are many push flows throughout the production system. This together with that there is no hard limits on buffers, entails over production. This increases the WIP in the system and leads to several other wastes, E.g. unnecessary movement and the extra attention to manage all the material that is stored all over the production area.

4.2.6 Purple: Limited time and personnel resources

Due to the rapid expansion there has been hard time constraints to meet the customer demand. This has entailed to that industrialization of the production has been done quickly and as soon the line has been able to produce it has been released to serial production. This led to unreliable machines and the re-test flows has not been thoughtfully designed and not fully implemented. This has resulted in that the lines are insufficient for high volume production. Due to limited resources these problems have not been solved and instead of working with the suppliers of the equipment to solve these problems the company has chosen to try other suppliers to deliver machines for the Assembly 2 and the an other suppliers for upcoming lines.

4.3 Root cause

The results from the 5 why analysis of the different wastes that was found in the analysis of the current state is presented in this section. Figure 4.9 shows the 5 why analysis of waste related to Over production, to see the full 5 why-analysis see Appendix 4.

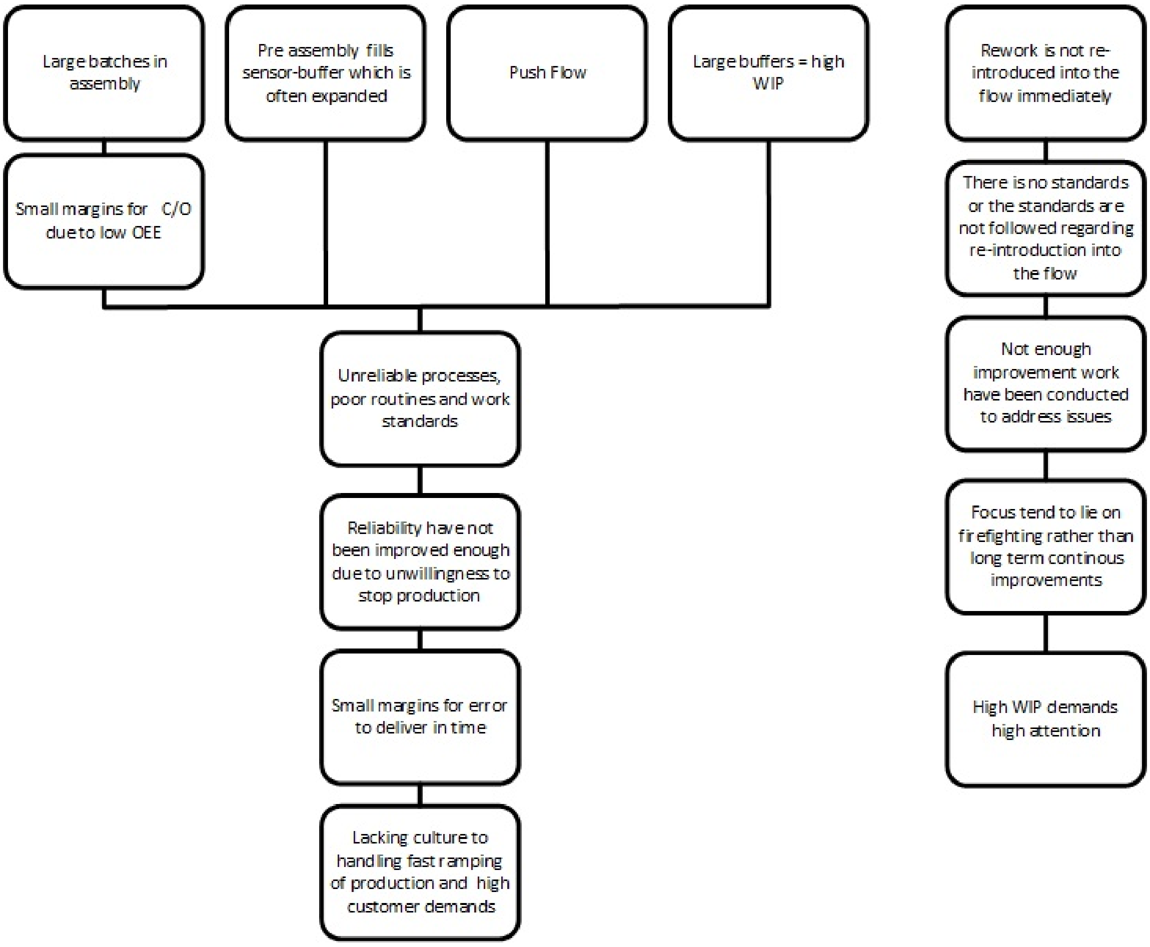

Figure 4.7: 5 Why analysis related to Over production

The root cause related to over production is found to be a vicious circle with two main components, increasing WIP and the extra work related to WIP. Shortsightedness is found to be the cause on a deep level of a majority of the issues which is weighting down the performance of the production. That shortsightedness is in turn a product of the vicious circle in which the heavy workload originating in the large inventories is handled by introducing even more inventory as a short term solution. Which then more often than not becomes a permanent solution, resulting in more WIP and work in the future.

The lacking culture of handling the rapid growth is also a root cause to the problem. The Rapid growth of customer demand has entailed to production lines has been released to quickly and not fully developed to serial production.

The Figure 4.10 shows the attention needed from management in relation to the time buffer, the time buffer meaning how long value adding time is in relation to the lead time through the system. The large WIP and due to that, the long lead time through our plant places the management team at the plant at the far right of the figure.

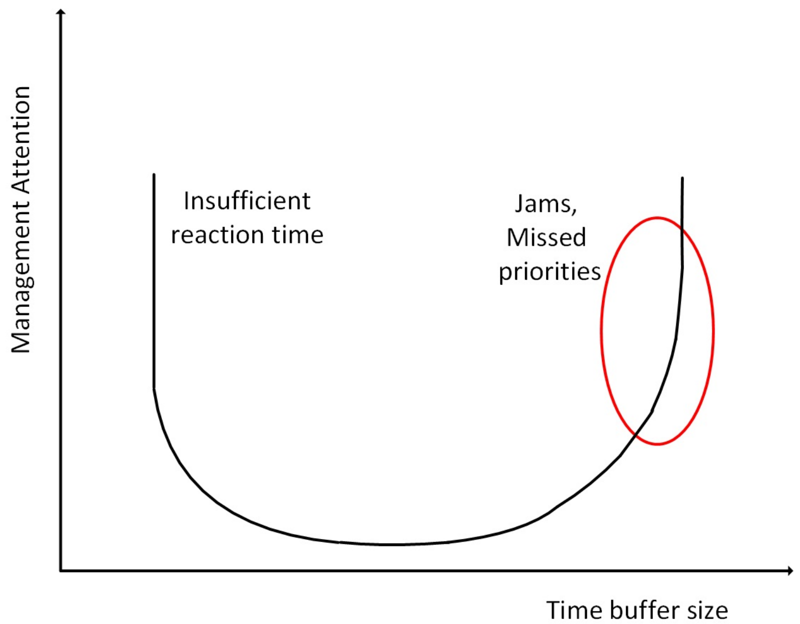

Figure 4.8: Management attention need rises with longer lead times. The circled area points out the area where the company is found to be

The result have become that fulfilling customer orders is a bit of a Sisyphean task, as soon as all difficulties with an expedited order is handled, a new order must be expedited and the same problems arise again and again. This is of course the reason to why shortsighted decisions are made. When becoming overloaded with work just to get products out through the door, the managers do not have time and energy to spare for long term improvements. The mechanism of how the negative downward spiral works is shown in figure 4.11.

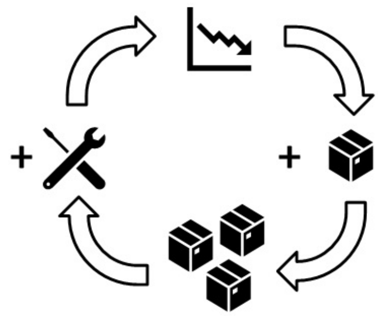

Figure 4.9: Vicious Circle with added WIP the work and attention increases, which leads to decreased performance

4.4 Future State

The future state is based on the theory, and it
should be used as a aim to move towards. The system has only one pacemaker which sets the production pace, and it is placed at the finish goods warehouse. The need of production controllers and planners will be removed, which entails to more work with long term improvements can be performed instead of controlling the production. When the customer makes an order of a product, the product will be shipped to the customer, and at the same time a Kanban signal triggers an upstream assembly line, which then trigger the next upstream process and so on.

Test stations both for the PCB and sensors should be moved closer the upstream process in order to diminishing the risk of find quality issues late in the production. Some buffers will be necessary to even out the production flow making it resistant to fluctuations and disturbances.

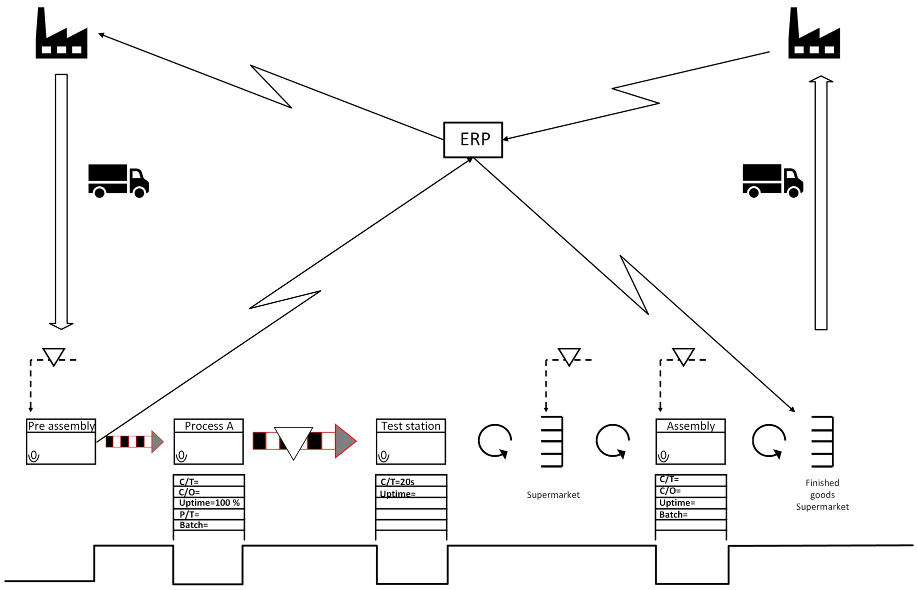

Figure 4.10: Future state production flow for the sensors

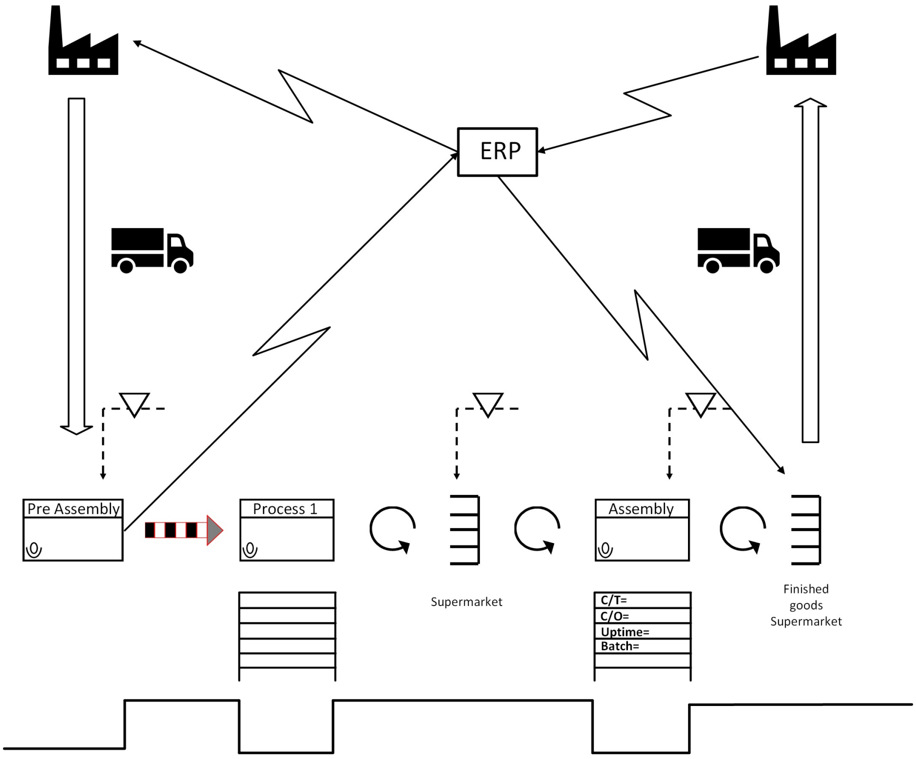

Figure 4.11: Future state production flow for the PCBs

4.4.1 Creating Continuous flow

The main problem in the current state is identified to be overproduction and large inventories. The situation will be improved if the excess material can be removed from the system. The WIP can not be removed too fast, as all disturbances which are hidden by having extra inventory would emerge at once. Using the metaphor of the Japanese lake, one should instead lower the water level (WIP) little by little. So that the rocks (Disturbances) resurfaces one at a time, which allows them to be handled one at a time. As quickly as the disturbances are handled and the flow is smoother, the WIP should be lowered again and the process iterated [5][32]. This would over time lead to less laboursome managerial tasks, freeing up resources to handle long term issues. The concept of the process is shown in figure 4.12.

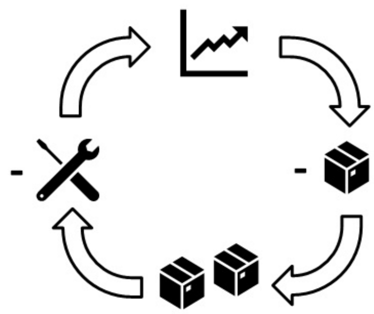

Figure 4.12: Virtuous Circle with removed WIP the work and attention decreases, which leads to increased performance

In order to avoid further over production a function should be put in place that eliminates production which is not needed. This is typically done within lean using Kanban-systems, this will decrease the amount of work the controllers/planners needs to do in order to keep the flow going as well as eliminating the excess inventory production. A model of a future state is shown in figure 4.12 and 4.13 which is a version of the lines where a pull-flow is implemented at most of the flow. This will shorten lead times, improve flexibility and allow the management to focus on long term issues and reducing the need for production planning [27].

4.4.2 Why Standardize work and continuous improvement?

One of the causes to why the performance of the system is not performing at a more pleasing level is found to be that the resources are allocated towards short term firefighting and handling recurring disturbances over and over again.

This issue is solved with one of the core principles within lean, Kaizen. To be able to continuously improve, two mechanisms must be in place. Firstly there must be a standardized way to work so that there is a foundation upon which the continuous improvements build. Secondly there must be a mechanism which is used to change the standard into a better version as soon as one such version is discovered[18].

A key component in Kaizen is the involvement of the operators, they are the ones with the most knowledge of their work and their insights are viewed as incredibly valuable within lean. The standardized way of working does not need to be optimal when first implemented as it at that stage is more of a starting point. Then the process of improving the work is heavily reliant on the operators to improve the process in collaboration with the managers and industrial engineers. Within lean, these mechanisms are utilized to create a virtual circle. When the process is improved to the level that one of the involved operators are not fully needed, the spare time of that operator is used to improve the process further. The increased rate of improvement which follows the improvement work done by the freed up operator results in even more available time for Kaizen[21][22].

4.4.3 Prioritizing improvement work using ToC

The only way to improve the throughput of the system is to improve the throughput of the bottleneck. The bottleneck is found to move between the assembly and the test station depending on the product at line 1. At line 2 it was found to be the assembly line. This was found using balancing charts with data from the ERP-system, see figure 4.13 and 4.14.

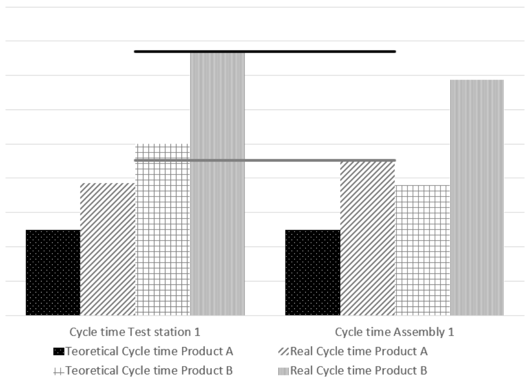

Figure 4.13: Bottleneck detection-chart

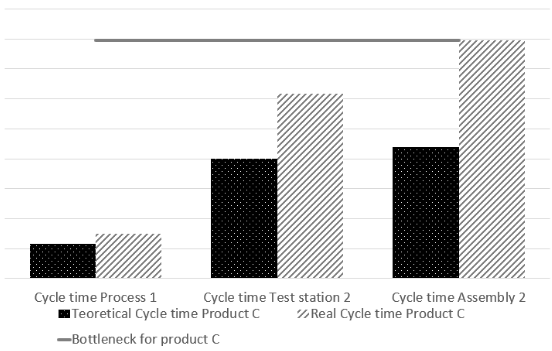

Figure 4.14: Bottleneck detection-chart

As it is discovered that a relatively small number of equipment provides a large contribution of disturbances it is recommended that these vital few factors are handled in order of impact. Improvements of automatic screwdrivers and cooling paste dispensers should be highest priority in order to improve the OEE of the bottlenecks, see figure 4.4 and 4.5.

Using ToC thinking, all available resources should be allocated to improving the throughput of the bottleneck. There is a lot of downtime and machine issues which leads to delays and low OEE, see figure 4.2 and 4.3. Inefficiencies arise when two processes which have to be performed in a certain order are subject to statistical disturbances [25]. On paper, the stations are on average well balanced, the Test station 1 & 2 are outputting an average amount of good quality sensors which is close to the average amount of products that can be assembled at the final assembly lines. The problem arises due to the instability of the Test stations, even if they can produce enough on average, the small buffer between the stations and the Assembly lines are quickly consumed when disturbances happen, leading to that the Assembly lines occasionally becomes starved. Thus, rendering the bottlenecks unable to produce and lowering the throughput.

The above mentioned inefficiencies entail that initial focus should lie on keeping the bottleneck fed with materials so that it is productive at all times possible, i.e direct efforts to improve reliability and output of the control station. The same is true for general material handling, as the bottleneck is sometimes starved due to internal deliveries or missing Kanban orders, efforts should be directed to always keep it supplied. When the bottleneck is well supplied, efforts should be directed to improve OEE of the station by using methods such as preventive maintenance and SMED.

4.5 Findings from interviews

This section presents the findings from the conducted interviews.

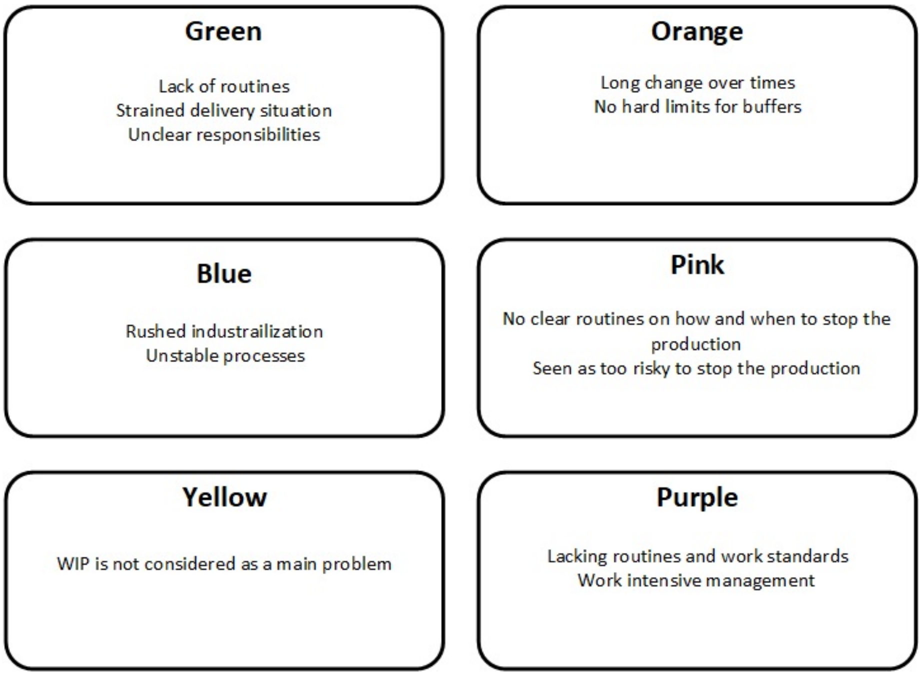

Figure 4.15: Key outcomes from the interviews

4.5.1 Green: Laboursome Management

"..the production is reactive, which is work intensive.." - one of the interviewees

The interviewee's share the picture of that management is spending a lot of time on reactive measures, either to handle quality issues or to push orders through the system in order to be able to deliver the most urgent orders on time. The interviewee's points out that there are often uncertainties regarding where certain responsibilities lie, both on the department level and within the departments. It is unclear who is responsible as most of the routines did not survive when the company was formed from the electronics division of the old company. There are no routines for how or when the operators should stop the production and notify managers when disturbances occur. It was pointed out by one of the managers that information does not transfer well between shifts, which entails to large inefficiencies as the management is not present during all 5 shifts. The large WIP was also pointed out by several of the managers as a problem and that large parts of the material flow is not controlled by the use of rules or routines. Instead it is up to individuals to regulate buffers and rework, which leads to large irregularities in the production. These irregularities forces the management to spend a lot of time in the production just in order to be updated on the current state of the system.

4.5.2 Blue: Quality

"The work needs to be done thoroughly otherwise the problems will come back..." - one of the interviewees

The quality issues are pointed out to be the biggest issue according to the managers responsible for the production. The main reason for the quality issues where identified from the interviews to be that the lines are rushed to start of production. The rushed production start led to that the specifications for the lines that where sent to the supplier of the equipment was not good enough. This results in that the lines have built in disturbances, which then spreads as the factory expands and the design and specifications for the old lines are used when ordering the new ones. The WIP is pointed out as a big factor regarding quality as well. It is easy for the operators to mix up material which leads to quality issues.

4.5.3 Yellow: WIP/Material handling

"The production planner need to go down by himself to just to look and find the boxes that we need to ship to the customer.." - one of the interviewees

The inventory level is identified by all interviewee's as a problem. They spend times on manage and find material. They need also to expedite productions orders sometimes. However, the WIP and material handling was not considered as the main problem. The WIP was more discussed in terms of long lead time.

4.5.4 Orange: Flexibility/Lead time

"We currently plan the production at three points, which makes the production messy and hard to control.." - one of the interviewees

The flexibility is key for the company as the customer orders change continuously, rendering a fixed production schedule impossible. The lead time and the changeovers are too long to provide enough flexibility for a strictly rule based system. Instead the production is planned at several points and production planners must continuously attend to the production and expedite orders through the system. Due to the large amount of WIP, finished goods gets stuck at quality assurance stations for long periods of time, leading to that finished goods that urgently needs to be shipped to the customer is stored within the factory and it could remain there for long stretches of time if the planners are not expediting it through the quality assurance. Other factors that are found to contribute to the cluttering of the lines is that the action to do rework is not rule based, and that there in practise is no hard limit on buffers, implying that it is up to individual managers and operators to decide when to stop the production. This leads to overflowing buffers and large amounts of rework in the flow, as the large amounts of material is accumulates it gets harder and harder to manage.

4.5.5 Pink: Over production

"The predictibility is very low at the moment, So we just produce in order to ensure the delivery our customer.." - one of the interviewees

Over production is found to be one of the underlying factors for all the production related issues that are discussed during the interviews. The over production comes from that there is no clear routines for the operators to stop the upstream processes when buffers are full. There are also no one that are willing to take the risk to stop up stream processes due to the high demand and the critical and strained delivery situation.

4.5.6 Purple: Limited time and personnel resources

"Projects are initiated to late, with too few resources, that comes back and bites you.." - one of the interviewees

Several managers see the lack of work standards as a problem, both among the operators and among the white collar employee's. The full potential of the operators is not utilized as they are not seen as a resource for continuous improvement and their responsibilities are limited. On the white collar side, the routines are lacking and certain competences is only held by few employees. If one of those employees are not available for a longer period, it can affect the operations.

The lack of good routines affect the managerial situation negatively. It becomes very work intensive and everyone have to attend a lot of meetings that in part or fully do not concern them, but they attend due to that there is a lot of uncertainties regarding who is responsible of what.

The delivery situation is straining the production system and there is no buffer of finished goods between the production and the customer to allow some leeway for improvement work. The ambition is to have such a buffer with ten days of inventory, but so far, they have not been able to produce enough to build sufficient amounts of finished goods inventory. This in combination with the rapid growth of orders have led to that development projects are rushed to start of production. As the projects are finished somewhat prematurely in order to continue building the next line, tasks that are related to development of the lines are instead moved to the day to day operations. The problem is that the teams responsible for day to day operations do not have all the competence needed to finish the lines. Entailing fragile processes with a lot of disturbances both in terms of flow and quality.

4.6 Road map

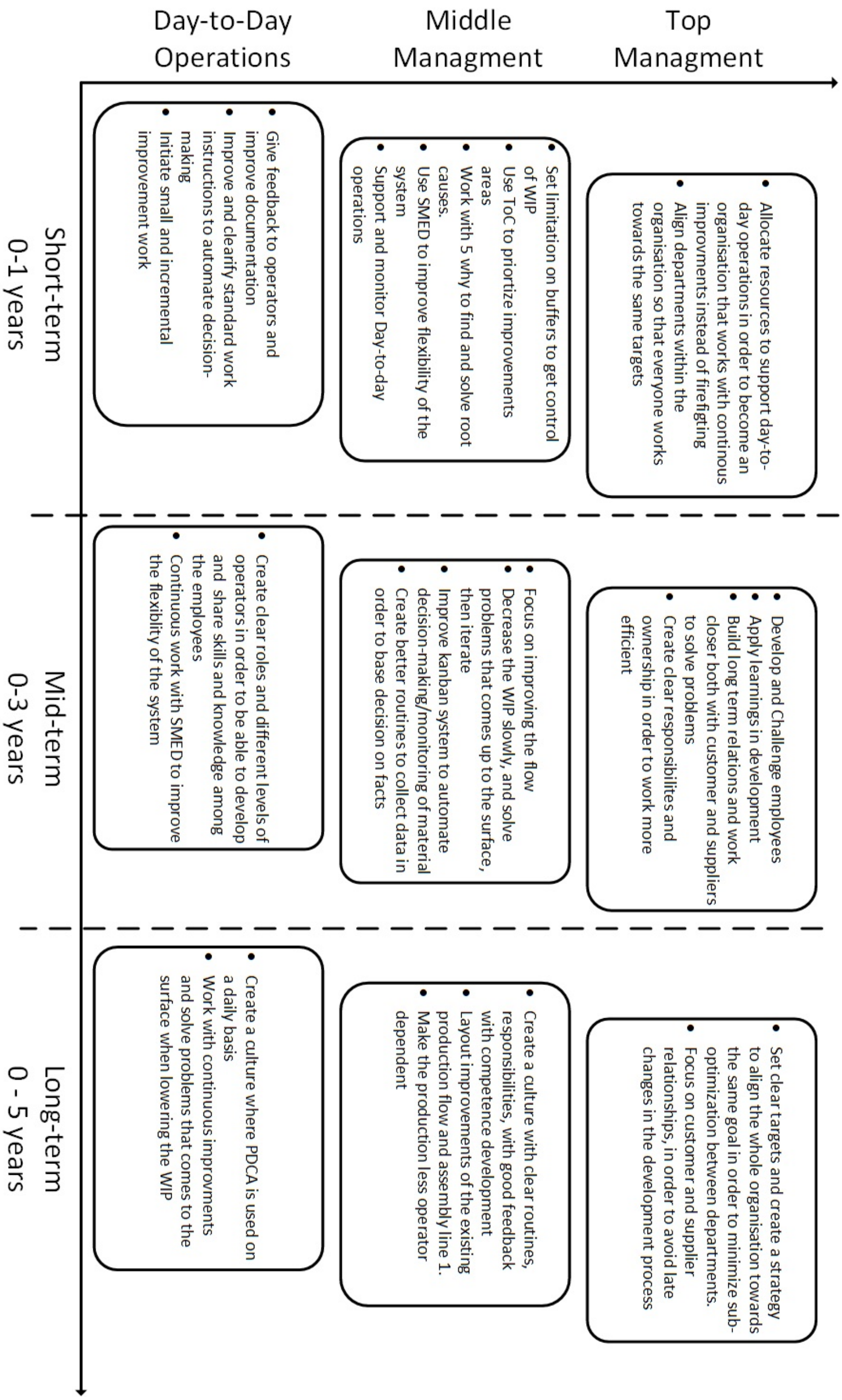

Figure 4.16: Road Map at 3 levels with 3 time spans

4.6.1 Day to day operations

Short-term 0-1 Years. The short term goals do rely on the work of operators, technicians, controllers, planners and managers who handle the day to day production. It is up to them to implement the solutions which will generate fast results and free up resources to focus on the work that will improve performance further down the road. This will be done by immediately starting the work with work instructions and continuous improvements, with the purpose of automating decision making which is currently done by managers. This will be done to improve response time to disturbances and to relieve the managers from unnecessary work.

The habit of immediately stopping production and addressing disturbances as soon as they occur should be implemented, especially on the non-bottleneck stations. Improvements in how and when data is gathered within the ERP-system should also be implemented in order to be able to base future decisions on facts.

The goal is to make the personnel close to the production able to handle as much of the daily disturbances as possible to keep the production going.

Mid-term 0-3 Years It lies in the nature of day to day operations to focus most of it's energy on working and improving the current system. It will however be important to work on cultural improvements regarding quality and priorities. It is essential that every employee knows about the production philosophy and shares the view of the company in regards to quality and knows what to prioritize when disturbances occur.

Long-term 0-5 Years In the long term, focus on the day to day level lies on building competence and motivation among the employees. Investing time and effort to help them becoming as capable as possible, ensuring the long term need of a competent work force. This way, less and less attention will have to be paid by managers on keeping the production going, who will instead be able to invest their time securing the capabilities needed in the future.

4.6.2 Middle management

Short-term 0-1 Years. The core reason to the poor flow is the large level of WIP, thus the middle management level must focus on reducing the WIP and the consequences of the WIP. This should be done by using standard work instructions so that the operators are able to do the best of the situation. At the same time, the WIP should be carefully reduced by setting hard limits on how large the buffers are allowed to be. Whenever a buffer is full, the process that feeds that buffer should immediately be taken down.

A factor regarding the hard limits of buffers found during the interviews was that the production units do not know what to do instead of producing if they have to stop production. Thus, in order for the strategy to work, the management should

define clear tasks for the personnel to work with if they need to stop production due to full buffers.
There is currently enough unused capacity due to the OEE that large investments should not be needed in order to improve the production drastically. It is however crucial to create enough space for the day to day operations to do improvements to access the potential. To do this, short term losses should be taken in order to facilitate for long term gain. This could for example be scrapping some products without re-testing them in order to raise the output enough to create some space for improvements.
As the WIP decreases, disturbances that have been hidden by the WIP should start to emerge and these should be handled in collaboration with the day to day operations before the WIP will be able to be lowered further.

When the situation have stabilized somewhat, the WIP should be further decreased, this time by lowering the limit or completely removing buffers which are not crucial. A buffer such as the supermarket between process 1 and Assembly 2 is a good example of a buffer which do not affect the throughput, as the upstream process have a lot more capacity than the downstream one.

Mid-term 0-3 Years When hard buffer limits are implemented and excess buffers removed more disturbances will become visible which will have to be removed before continuing to lower the WIP.

The disturbances of the value flow in the factory are not solely dependent on the WIP, other factors do also play a role. These factors must also be addressed, so within a 5 year period, the goal is to change the layout so that the lines are arranged so that the flow do not move back and forth between two opposite sides of the factory. Kanban systems are to be implemented at the areas which such systems do not exist today, this will be made possible due to that the lowered WIP improves lead-time and thus removing the need of expediting certain orders.

A system for storing and sharing knowledge should be implemented, this is a key aspect for future success that was found through the interviews. Sharing information and knowledge so that the wheel does not have to be reinvented over and over again is what is known within lean as Yokoten.

Long-term 0-5 Years The long term goal is to arrange the factory as showed in the future state map, where a pull flow will regulate the production in almost the entire value stream. In terms of production layout, it is recommended that the processes are consolidated into one area forming one line with short and clear material flows. Customers should be served from a small inventory of finished goods which should be replenished using an Kanban system. The goal is to reduce change over times using SMED-methodology a way that allows for increased flexibility so that the batch-sizes can be reduced significantly.
Close cooperation with the department which is responsible for designing the future production lines is necessary in order to share knowledge to reduce the risk of expe-

rience the same disturbances on the new lines as the ones which have been removed on the old lines.

4.6.3 Top Management

Short-term 0-1 Years. The top management should focus on strategical long term improvements, this entails that for the short term day to day improvements, they are not key players. Instead their focus should lie on supporting the middle management and those working with day to day operations.

Mid-term 0-3 Years The top management have a good opportunity to facilitate cooperation with customers and suppliers. E.g. the labels of some products are an issue today, where a lot of work needs to be put into assuring the quality of the labels. This is due to high standards from the customer which is hard to reach using their existing equipment. To solve this, the top management could facilitate a cooperation project with the customer who most likely sets equally high demand on themselves and other suppliers, one of whom may have developed a solution which they could share with the company. Doing this would embrace a part of TPS in which customers and especially suppliers are viewed as partners which it is beneficial to cooperate with. A closer collaboration with both customer and suppliers may lead to increased quality which favors all parts, due to Deming's chain reaction, which states that improved quality lead to better economical sustainability.

Long-term 0-5 Years For the long term, the top management should set ambitious goals and align all departments to work towards that same goal. This should be done by creating a common culture which favours cooperation between departments with the sole purpose of achieving the goal set by the top management. This is important to do not only so that employees know how to prioritize their work and how they should make decisions, but also to reduce the risk of sub-optimization at different departments. To create and spread that holistic view on operations is an essential part in order to succeed in becoming better, this is what is known within lean as Hoshin Kanri.

5
Discussion

5.1 Underlying assumptions

The premise for this thesis is that there is a need for improvement of resource utilization and productivity among manufacturers in general and this Swedish electronics manufacturer in particular. That manufacturers in general have potential to improve is clearly shown by the difference in average OEE of 55% in Sweden and the world class OEE of 85% [7][36]. The potential of improvement at the company was verified in several ways, firstly there was a lot of disturbances and poor flow at the bottleneck machines which indicates that the productivity of the whole system could be improved by raising the output of that particular piece of equipment according to Goldratt [25]. The substantial potential for improvement at the electronics manufacturer was verified through observations and interviews at the company. The picture aggregated from observation and the conducted interviews is that there is substantial capacity that can not be utilized due to poor performance and frequent disturbances. Furthermore, the OEE was analyzed for all the equipment within the scope, and was found to be between 50 and 60 percent. This further strengthens the argument that the system contains improvement potential as world class OEE is between 85 percent[8].

The underlying assumption of this thesis is that the potential of the production system can be accessed and utilized by implementation of lean production methodologies and the Theory of Constraints. This assumption is assessed to be reasonable to do as these methodologies have been successful historically when implemented correctly [5] [25]. The assumption is further motivated by that the company's own production philosophy is an adapted version of TPS.

5.2 Analysis & Results

The reasons to why the disturbances and build-up of WIP came to be in the first place was found through interviews to be stress to perform towards customers as well as lacking routines and culture through the whole organization. This was further verified by the previous observations made in the factory. The only factor that was not verified by direct observation was the lacking routines on the white collar side, this is not viewed as a problem as the interviewee's explanations are deemed plausible.

Result-wise, it is the constructed road map which is the main outcome of the project. It is designed to counteract the two main factors which is found to limit the current system and the potential development of the system. The first factor being the large WIP which sets limits of the performance of the current system. The other factor being the organizational culture which through inefficiencies limits the potential improvements of the current system as well as efficient expansion of the system in order to meet future demands. The road map is evaluated to be straightforward in terms of the first factor, i.e on how to handle the problems related to WIP. The solution is heavily inspired by Goldratt who in his article shows that the method is efficient [25].

Regarding the organizational aspect, the road map is deemed to be weaker as it is not as concrete on what to do in order to reach the future state. The goals are more loosely defined as it is hard for the project group as outsiders to concretize exactly what needs to be done in order to develop the culture. The level of understanding of the organization needed to formulate concrete plans on how to move forward was however found to be present among the managers who was interviewed, even though the managers had different perspectives. The road map is evaluated to be valuable in this aspect as well due to that it have the potential to be a catalyst for action as it still points out the broad direction for improving the organization.

The problem analysis in itself is an aspect of the project which also could be valuable from the company's point of view. As the managers work mainly with firefighting, they have had few opportunities to take a couple of steps back and gain a holistic view of the problems at the company. In this way, the problem analysis could be useful in order to gain a broader perspective. The problem analysis is viewed as a complement to the road map, as the managers could gain a more holistic view, which in combination with the road map and their own experience could provide useful insights in how to allocate resources and improve the ways of working in order to improve both predictability and control of the system.

The analysis and results are partly achieved by using established lean literature, mainly from the American lean movement[5][27][17]. Other more scientific literature is used for the more technical aspects. The decision on which literature to use was a trade-off, on one hand gaining the efficiency of using lean literature. And on the other hand, the potential insights of a broader but more time consuming literature study. The bibliography ended up being a compromise, with insights from diverse scientific articles but built on a base of lean management literature. This compromise is deemed to be motivated as we still get a holistic view of the situation.
However this master's thesis will be proven useful and have an real impact at the company or other actors is hard to speculate in. The results are however in line with previous research [7][8][25]. Thus, the found improvement potential in this case could be common as well, entailing that insights in this thesis may serve as valuable inspiration in future improvement projects. As the project aims towards improved productivity and lessened consumption of resources, the improvements should have a positive impact on sustainability. An impact that is hopefully transferable to other

businesses.

5.3 Fulfillment of Aim

The aim of the project was to improve visibility of value flows and wastes in and around the production lines using VSMs. This part of the aim have been reached, it is however important to understand that this will not necessarily entail permanent visibility of flow and wastes, but is instead an iterative process that will have to be updated as the production is continually changing. Furthermore, the aim was to identify the main root causes of the production system, which was successfully done using 5 why. The WIP is found to be one root cause and is relatively straightforward. The cultural part of the root cause is relatively broadly defined and will have to be investigated further by the different departments.

The last part of the aim was to develop a road map at three different levels in order to create preconditions for improvement of the production system. This was also done successfully. Exactly how useful the road map will be is something that the future will tell as it is solely in the hands of the company to realize the plan. There is a risk that the company will not be able to overcome the short term work in order to shift towards long term work due to ever increasing demand of their products and their continuous ramp up of production. If so, then it is deemed likely that they will continue in the old tracks and then the road map will not be of much help. The project group is however optimistic that the contribution in the form of the formulation of the problem and the suggested solutions in this thesis will be enough for the management to gain enough momentum to improve the production flow by increasing predictability & control.

5.4 Methodology

The division of the project into one deductive and one inductive part was motivated by the initially broad problem definition. The result of the deductive phase was that the core problem was honed in using both qualitative data gained from observations and meetings as well as quantitative data gathered from the ERP system of the company. The possible weakness regarding the qualitative data is that it was gathered during daytime by the project group, the day time shift is not necessarily representative for all the work conducted during the week as the management is not available during the night and weekend shifts. A strength of the initial qualitative data is that it was systematically gathered when building the VSM, a method proven effective in similar situations[9][27]. The weakness regarding the quantitative data is that some of the data is not fully automatically gathered but depends on input from the operators. As some routines regarding data gathering is not fully complied to, the data can not be fully trusted. For example, it is possible that the three factors of OEE is confounded with each other. This is not viewed as a limitation for this thesis as no major conclusions are drawn from the data and that the supporting arguments which the data is used for is not dependent on the operators input. It is possible that further conclusions could have been drawn if the quality of the data was better.

The inductive phase meant expanding on the identified problems to find solutions and identifying obstacles within the company in order to avoid them. The methods where qualitative, where solutions was found through literature and the potential of the solutions was evaluated through interviews with managers. The main weakness in this phase is pointed out by Denscombe to be that the interpretation is dependent on the researchers biases and background [38]. This is deemed to be the most relevant weakness in the whole project, and the fact that both participants have a similar background within mechanical & industrial engineering is definitely a factor. However, the project is an industrial engineering project and thus, it is reasonable that the problem is viewed through the eyes of an industrial engineer. A second weakness pointed out by Denscombe is the risk of oversimplifying the results [38]. The risk of oversimplified results is seen as low because of that the conclusions that are drawn are well thought through and backed up by literature and interviews. This is the reason to why the road map is not too specific regarding what needs to be done in order to improve the culture. As it was seen as risking oversimplification if the road map would have been more detailed, it is up to the managers of the company to fill in the blanks.

Using 5 Why methodology and observation the wastes was found and analyzed, the main cause to why the current production is not performing and improving better than it does was found to be the large amounts of WIP in the system. This thesis was verified through observing the work and interviewing the managers as well as through literature [25]. The verification of that WIP is the problem at the current lines indirectly verifies the main solution which is removing WIP in order to create room for long term improvements.

6
Conclusion

The result of this master's thesis is an thorough and holistic investigation of the main problems within the production using VSM and "5 why?". Furthermore, the result includes a road map with solutions designed to improve the productivity and flow of the production system by engaging all parts of the organization. It is designed to amend both cultural issues originating in fast expansion and inefficiency due to over production.

The reason behind the inefficiencies is found to be that the company have undergone large and rapid changes. This have resulted in that the old lean culture have all but vanished. The rapidly increasing volumes and strain on the personnel have resulted in a milieu in which stopping production and amending core problems is seen as risky compared to only doing enough to be able to produce. The same mechanism affects the introduction of new production lines which are not fully finished when delivered to the production department. Furthermore there is a lot of WIP in the production, entailing poor production flows and large amounts of work which is done at the expense of value adding activities. The OEE of the bottleneck processes is low at between 50-55% which is in line with the Swedish average [7]. Consequences of quality issues gets amplified as the feedback from quality assurance is slow. The root cause to the production issues is found to a vicious circle in which disturbances are suppressed using WIP, which is creating work and disturbances which in turn are hidden with more WIP.

There is reason to think that the problem and potential solutions are not unique to this company as others face similar issues[25]. The major findings to what is needed in order to succeed with the implementation of future improvements, is found to be knowledge and knowing what to do. Knowledge meaning that all employees must fully understand the reasoning to why the problem exists and how they should act in order to align their efforts towards a common goal. Knowing what to do is both that there must be a large plan for the whole organization and that employees must know how to escalate an issue, knowing who is responsible and knowing what to do when new situations arise.

The picture of industry and Swedish industry in particular from literature is found to be accurate in this case[7][25].The conclusion of this project is that there is no one single issue which one can amend and expect that all the problems will disappear overnight. There are however several aspects which one can consider in order to improve the system over time. The first factor is the company culture which is currently quite far from where the company wants it to be. The second factor is the rushed industrialization of new lines which is partly a consequence of the culture and partly a consequence of the rapid expand in customer demand. The third factor is the WIP, which is identified as a major consumer of resources without adding value for the customer. These three factors are tightly interconnected which means that poor decision in one area will spill over and have consequences in the other areas. It also means that improvements of for example the WIP could entail in freed up resources which could allow for improvements in culture or some leeway in the industrialization process. If the managers could take advantage of this dynamic, the potential for increasing visibility and predictability is very large, which in turn is expected to improve flow and productivity.

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A

Appendix 1

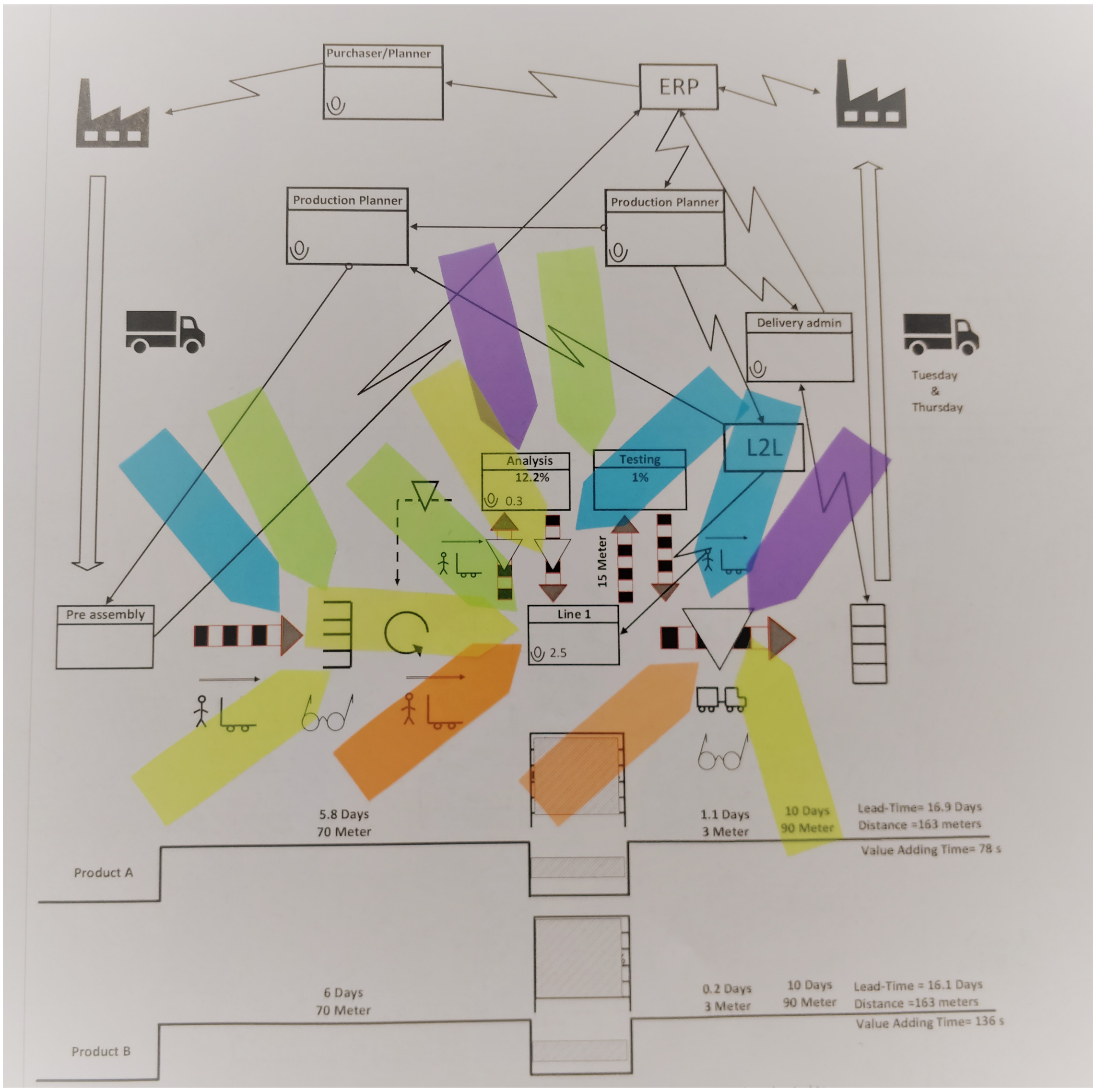


Figure A.1: Identified problems of PCB flow in Assembly 1

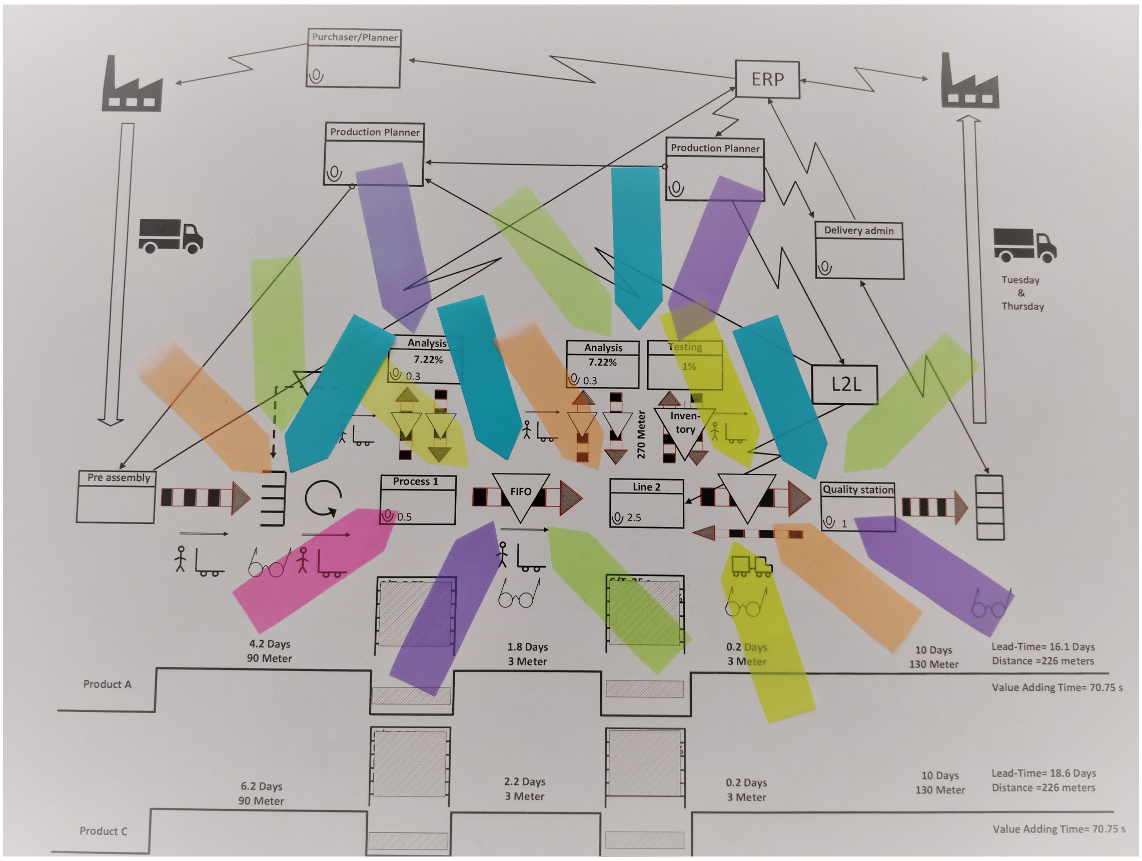


Figure A.2: Identified problems of sensor flow in Assembly 1

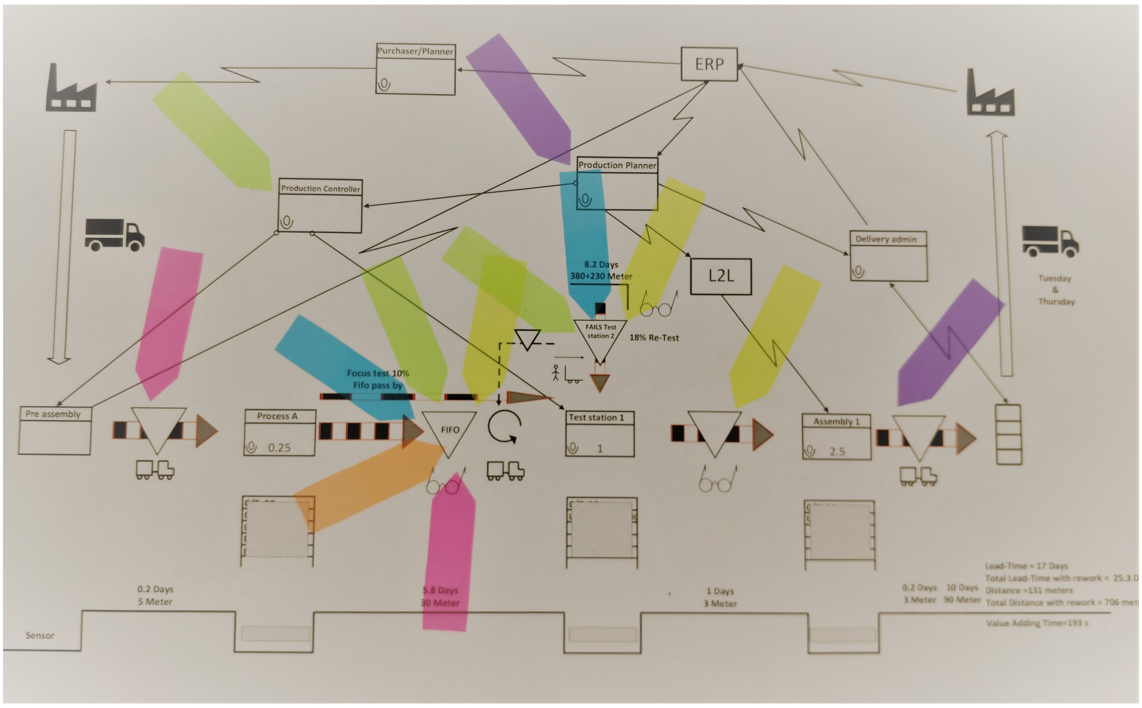


Figure A.3: Identified problems of PCB flow in Assembly 2

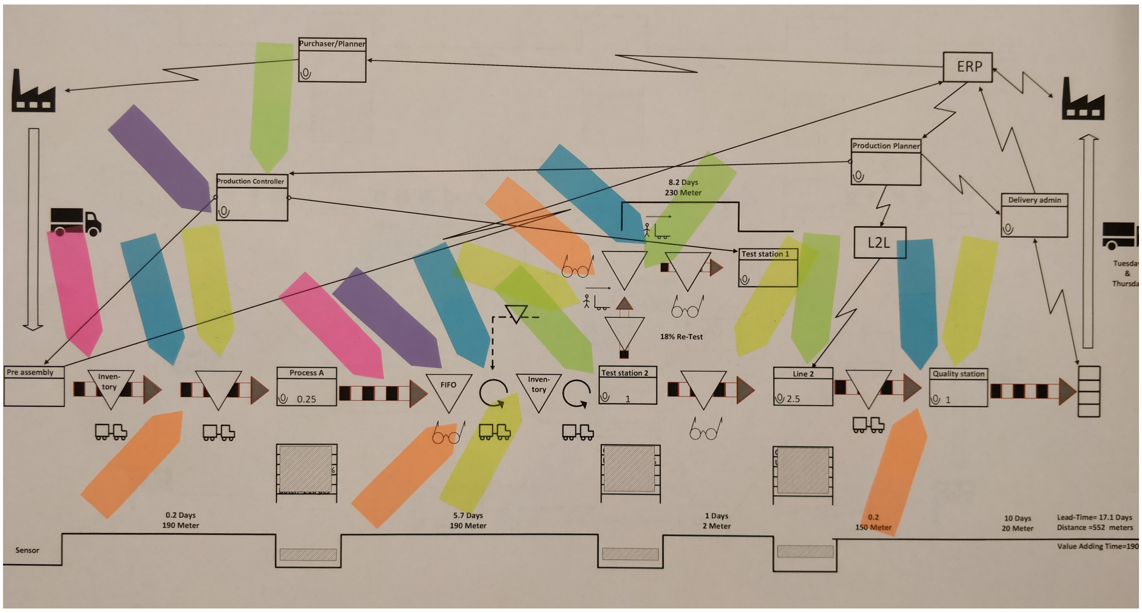


Figure A.4: Identified problems of sensor flow in Assembly 2

B

Appendix 2

Duration: 30 minutes, semi-structured interview with open ended questions which can be followed up on with relevant sub-question in order to facilitate a good discussion. The interview will be recorded, the recording will not be shared with anyone outside the project group. The interview will then be analysed and the results will be anonymized.

General information:

Name:

Position:

Previous working experiences

Questions:

Current state:

What do you think is the biggest issue(s) regarding the production lines as of today?

How do you think one should work in order to manage the previously discussed issues?

What do you think is the biggest obstacle one needs to overcome in order to do that?

How is the current method in order to improve upon flow and performance within the production?

We have made the observation that the daily work is currently composed of a lot of firefighting and handling disturbances as quickly as possible. What are the obstacles in order to make daily work more about long term improvements?

What is the current method of competence development among operators, technicians and managers? Are there clear standardized work instructions and routines which are used to spread knowledge throughout the organization?

Future state:

What do the best possible state of the production look like according to you? What do you want the production to look like 5 years into the future?

Which are the key aspects according to you in order to achieve that best possible scenario?

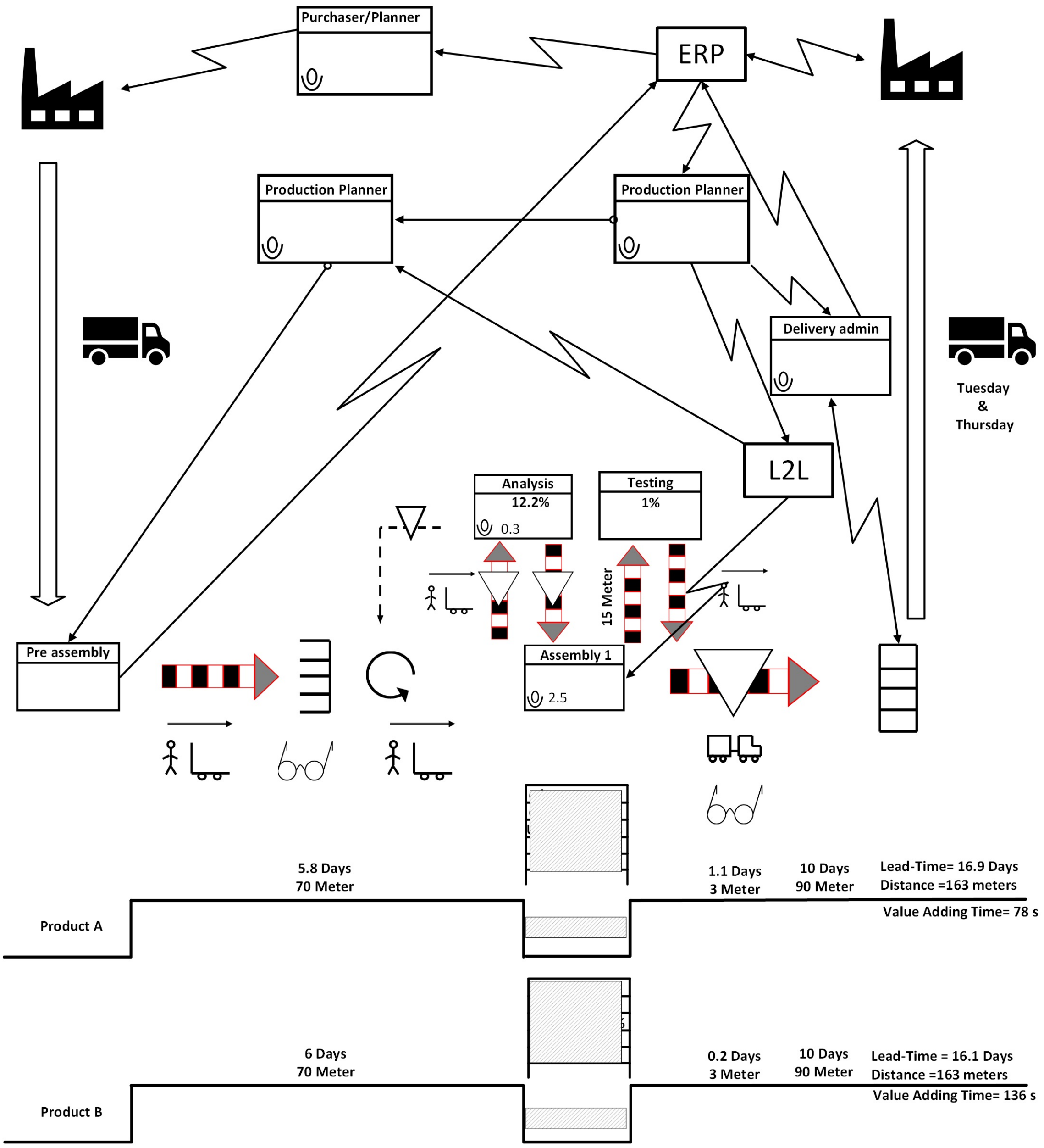
What is the purpose of your interpretation of TPS according to you?

What do you think is the reason to why there is a gap between the real world an the your vision?

What do you think the largest obstacles are in order to implement VES and work according to it in day to day operations?

How do you think the work should be conducted in order to learn from mistakes so they do not reoccur?

C
Appendix 3



The analysis loops are products that have failed in the processess and is reomved and placed on hold. The products are then analysed to see what went wrong with it. Then it is sent back to the production or it is scraped. The time from that products fail and be analysed and return to the production is often long and it can vary a lot.

Changover is estimated to 50 minutes between different products like product A to product B, otherwise it is 10 minutes.

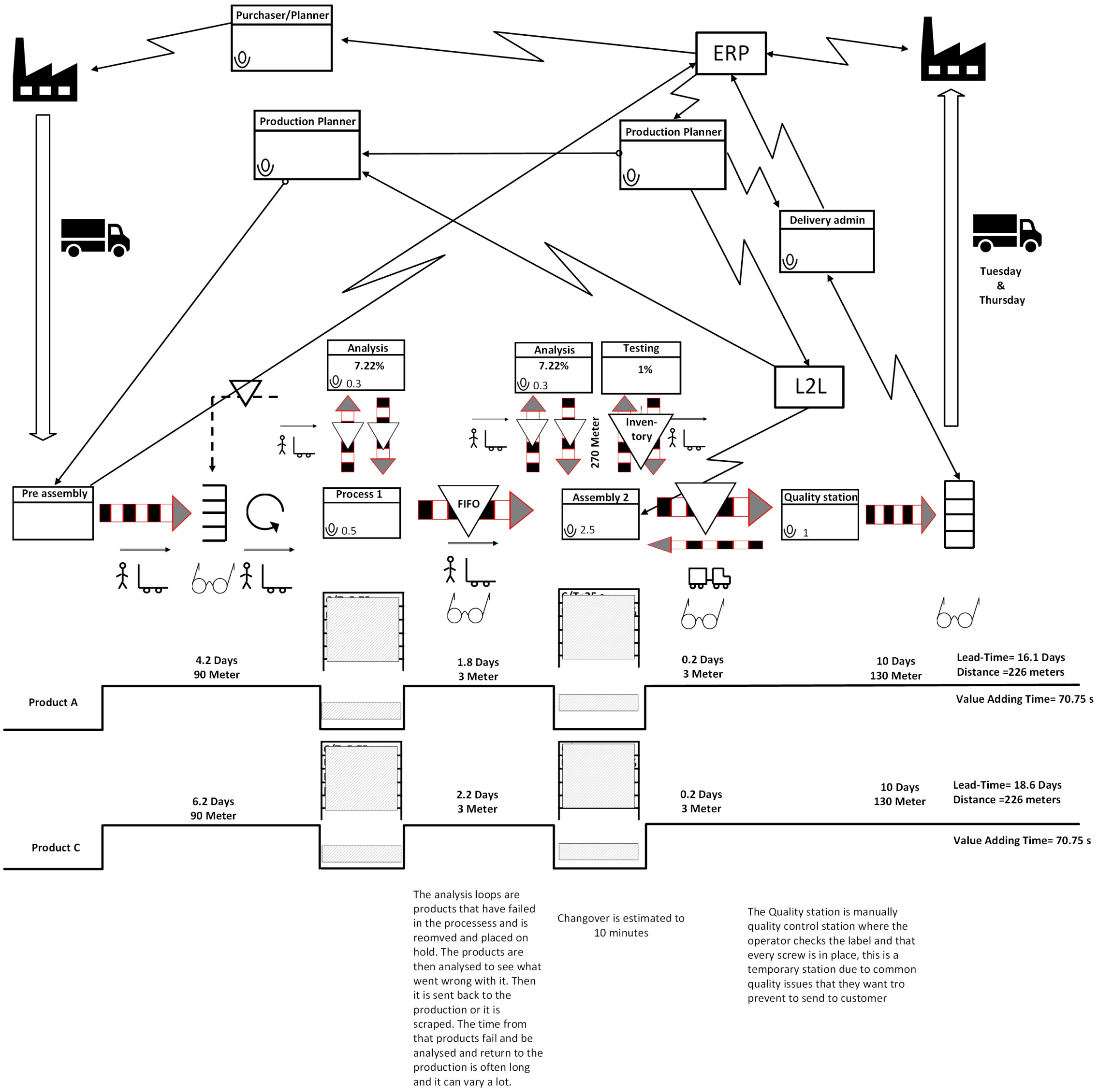


Figure C.2: VSM of Sensor to product A and B in Assembly 1

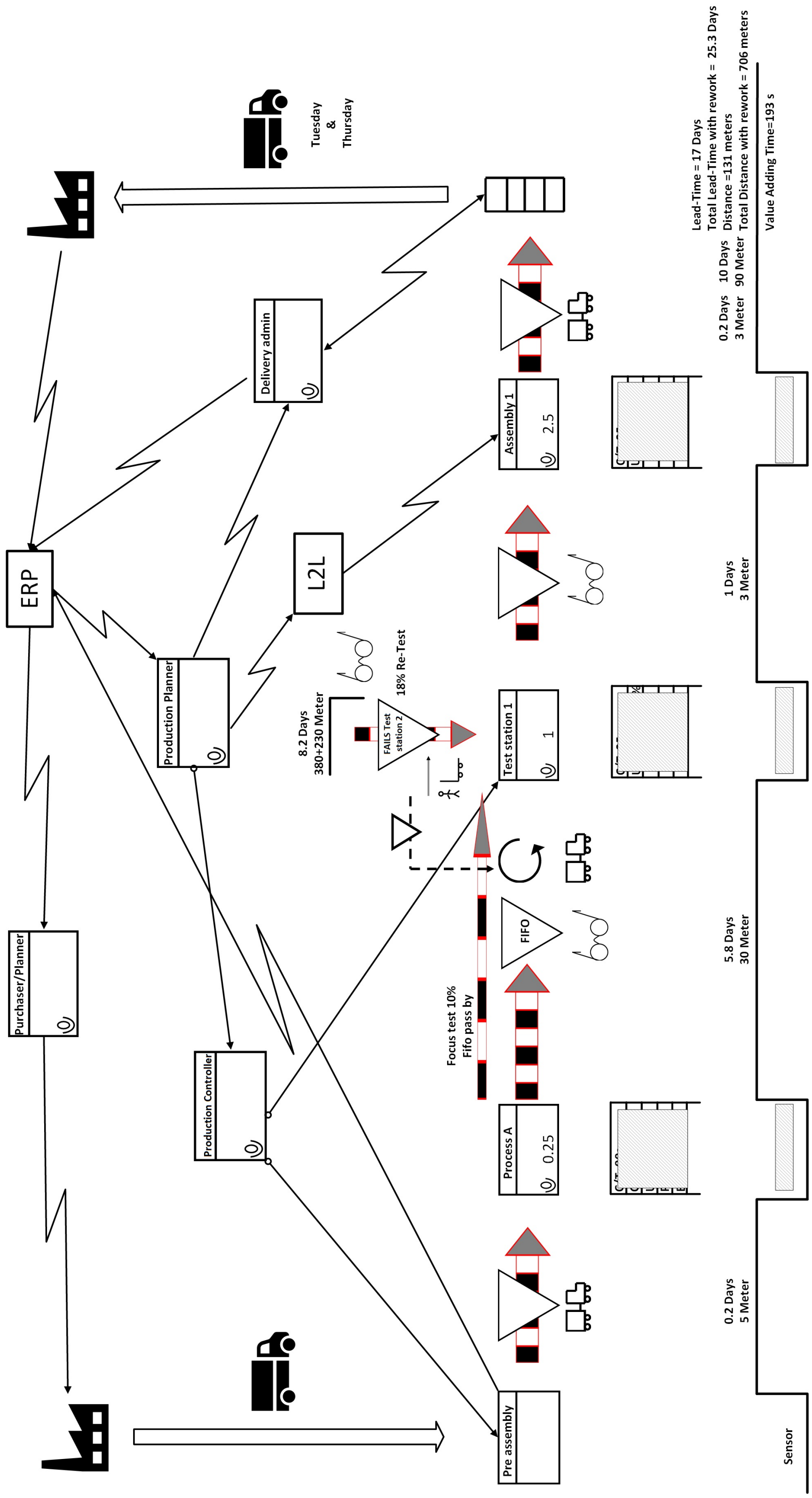


Figure C.3: VSM of PCB to product C in Assembly 2

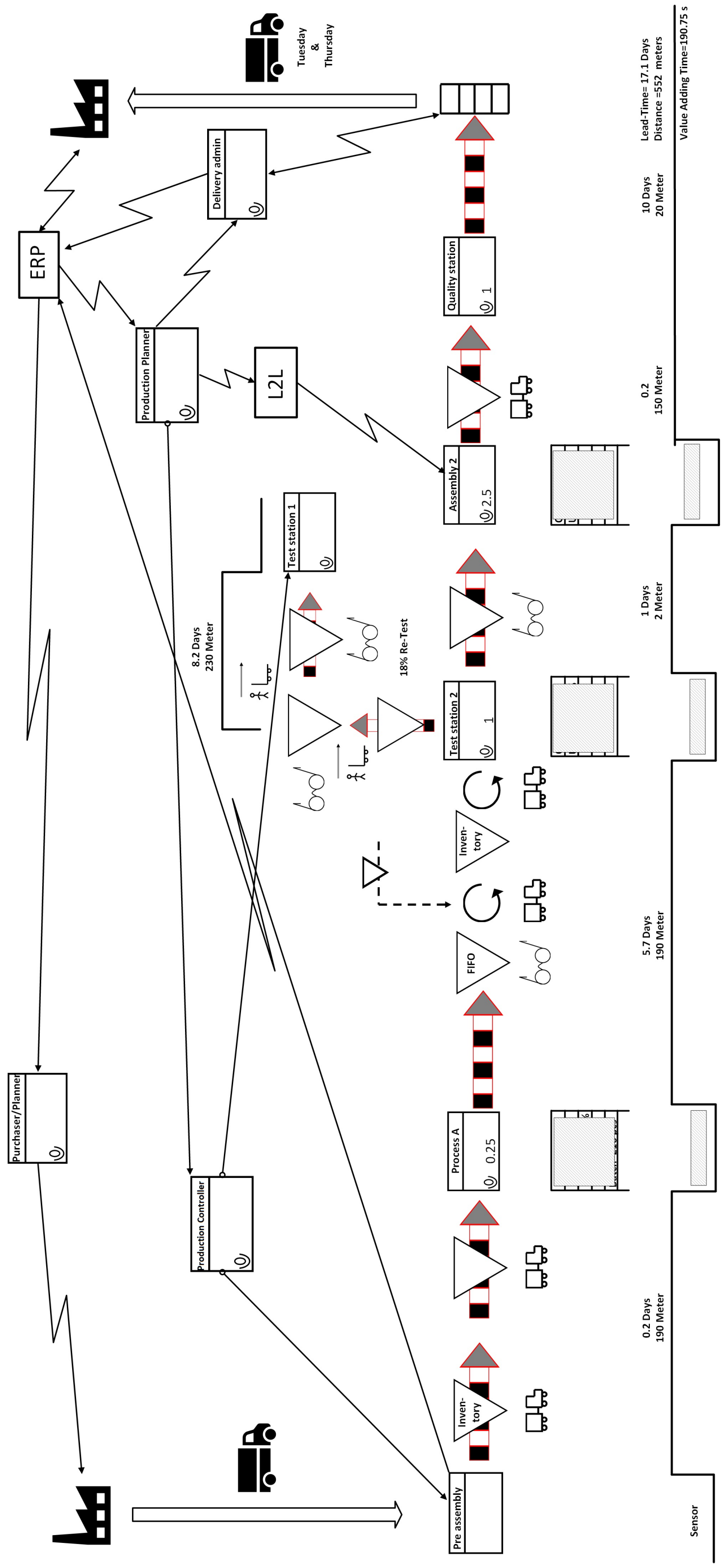


Figure C.4: VSM of sensor to product C in Assembly 2

D
Appendix 4

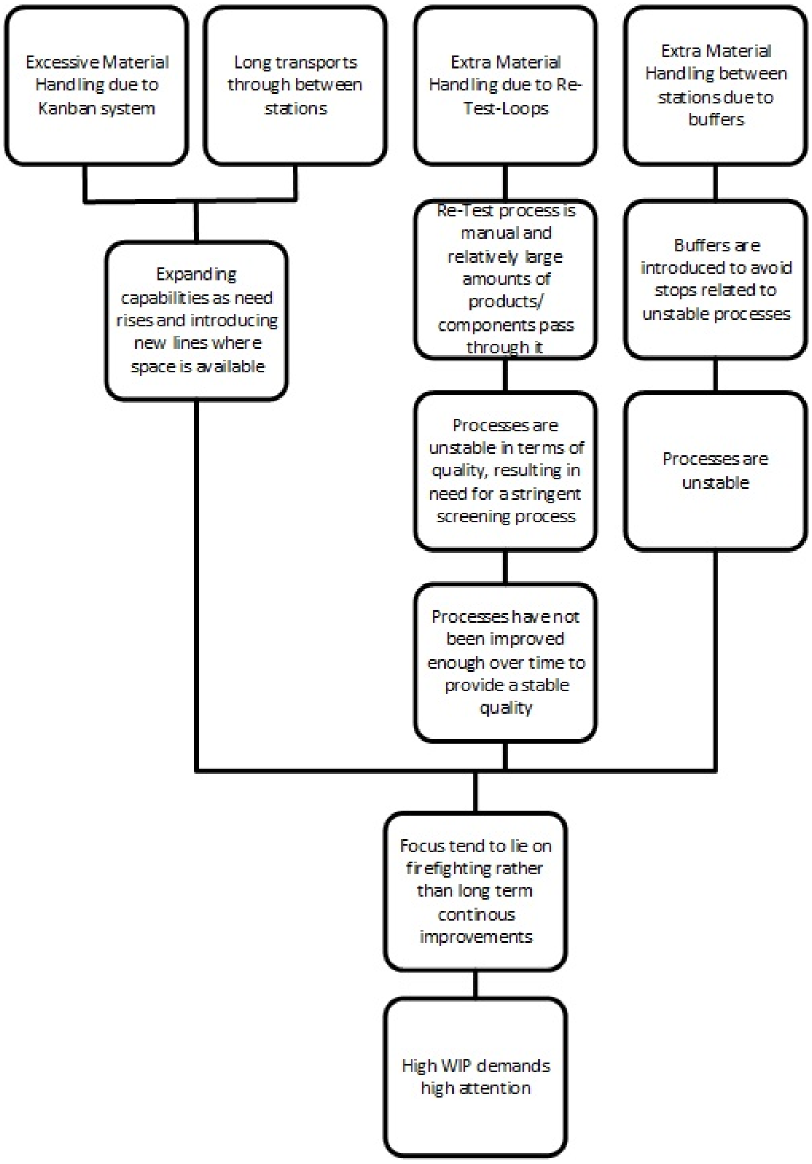


Figure D.1: Root cause to waste related to Material handling

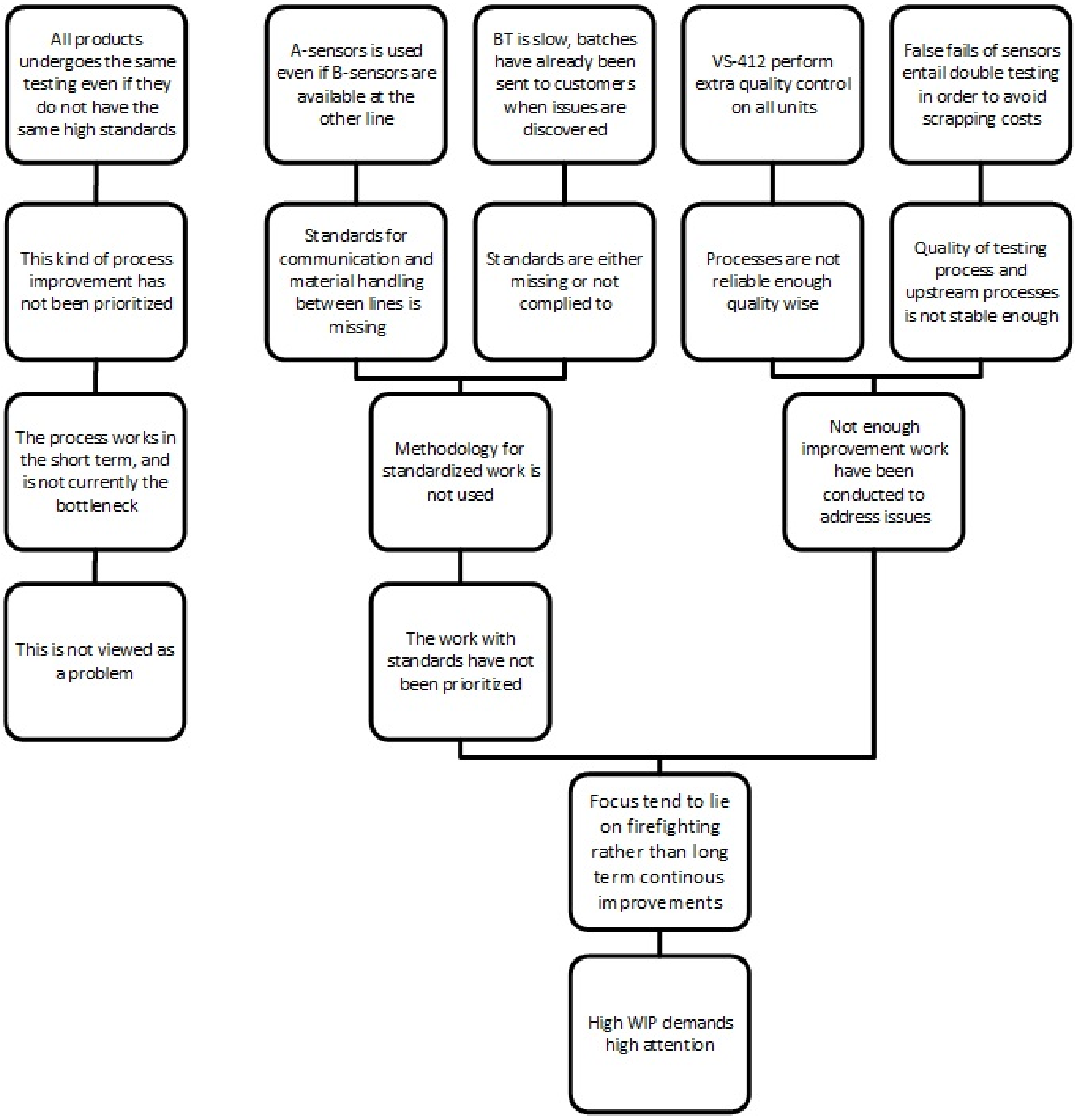


Figure D.2: Root cause to waste related to Over processing

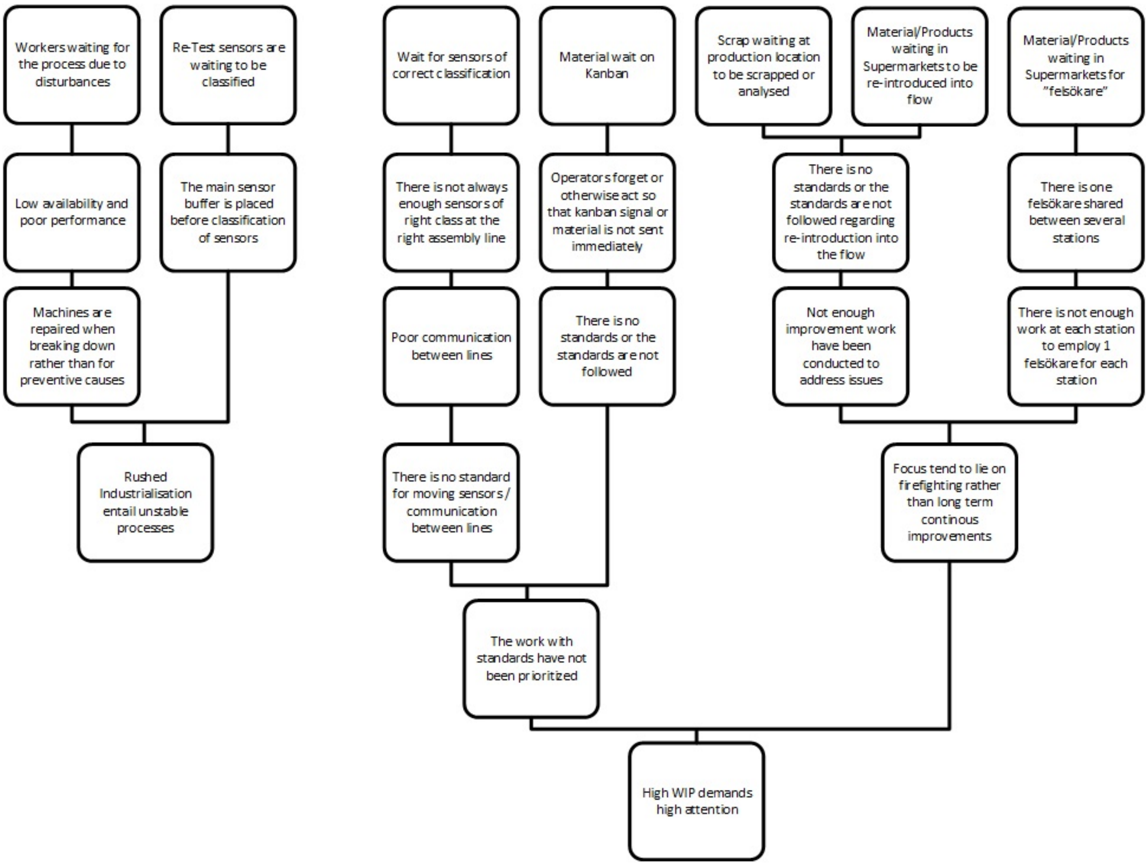


Figure D.3: Root cause to waste related to Waiting

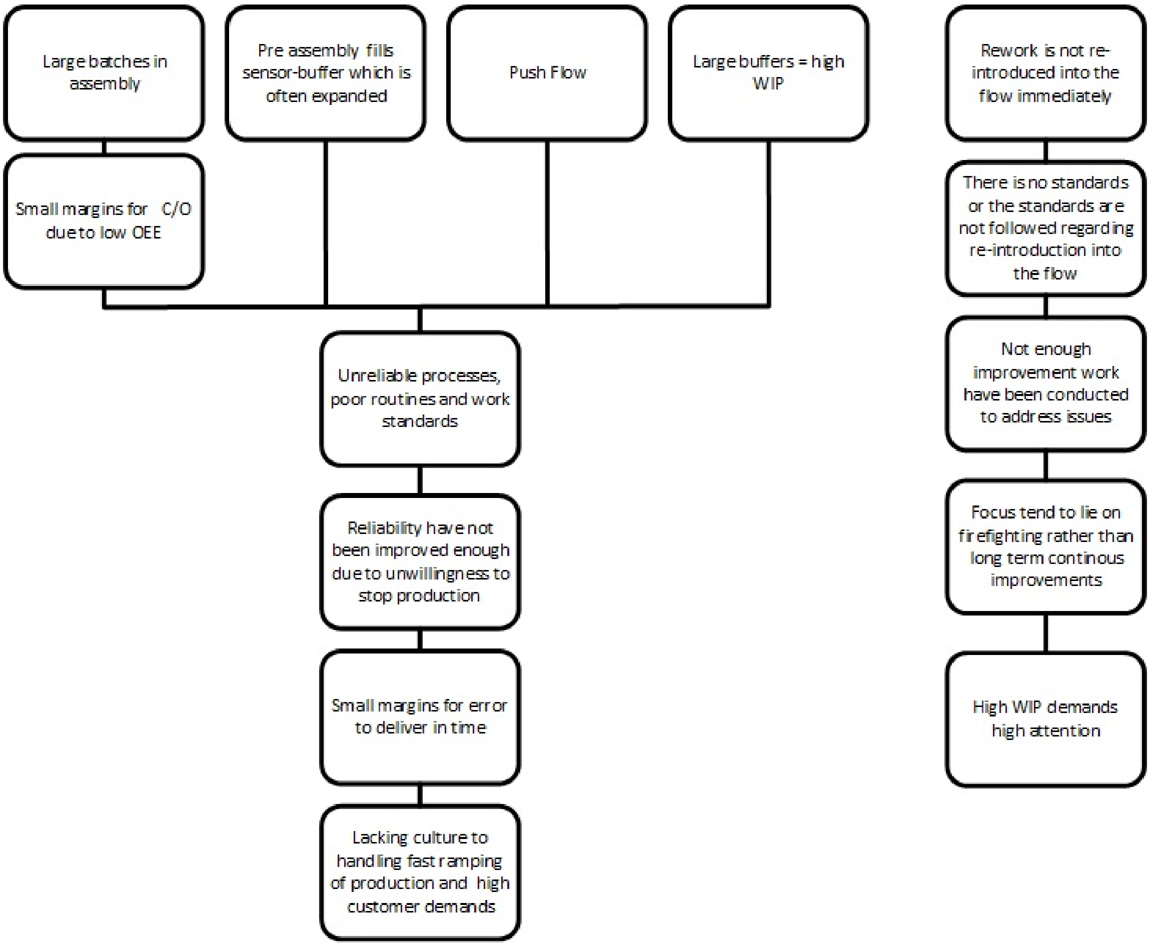


Figure D.4: Root Cause to waste related to Over production

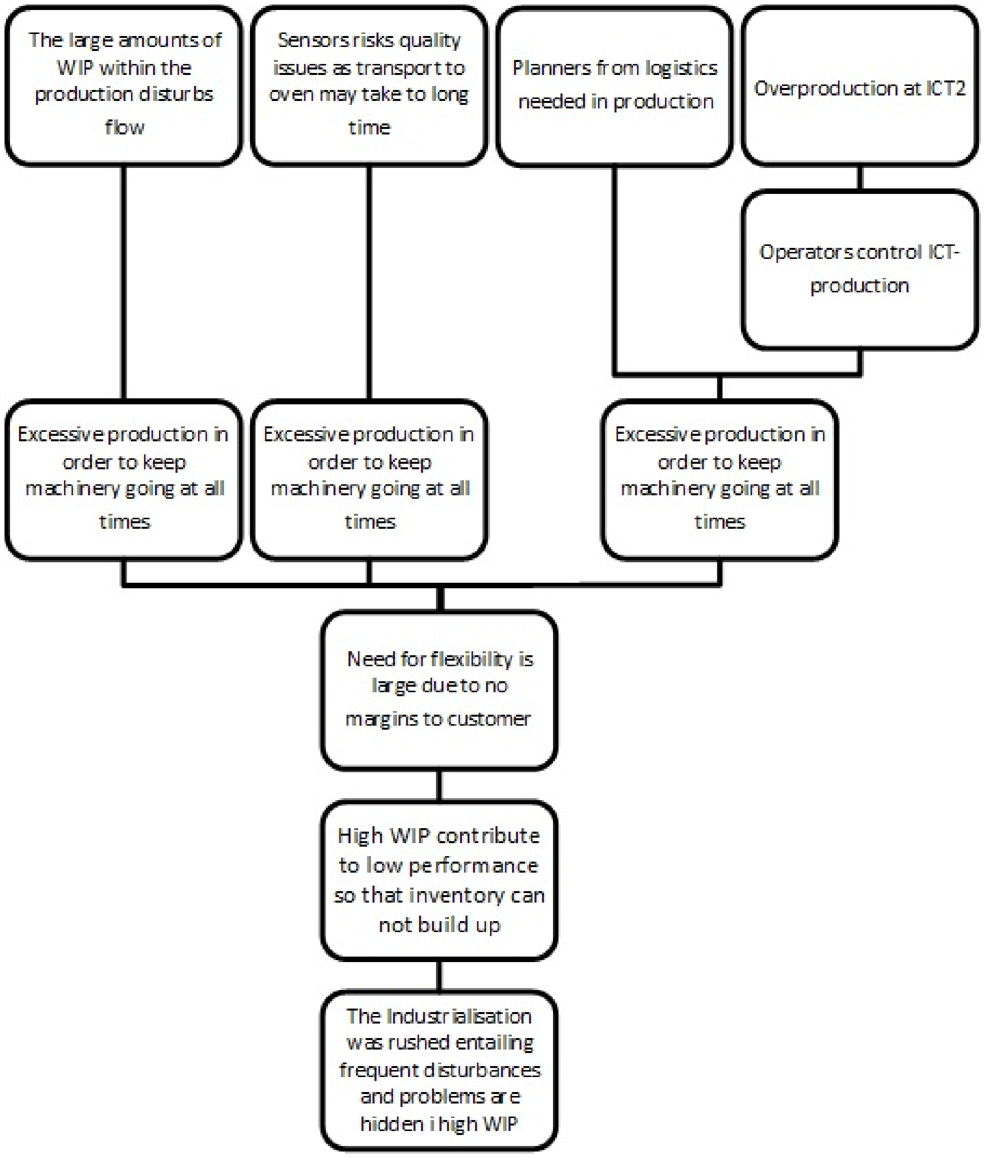


Figure D.5: Root causes related to miscellaneous wastes

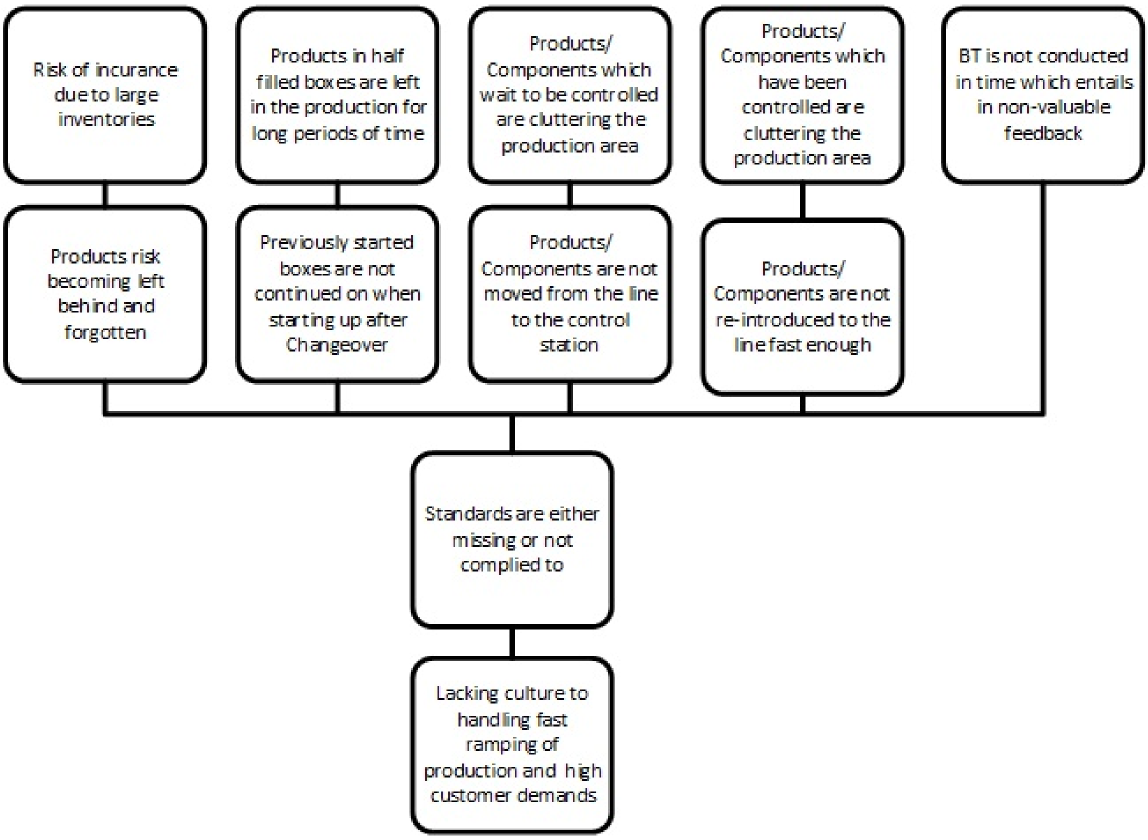


Figure D.6: Root causes related to miscellaneous wastes

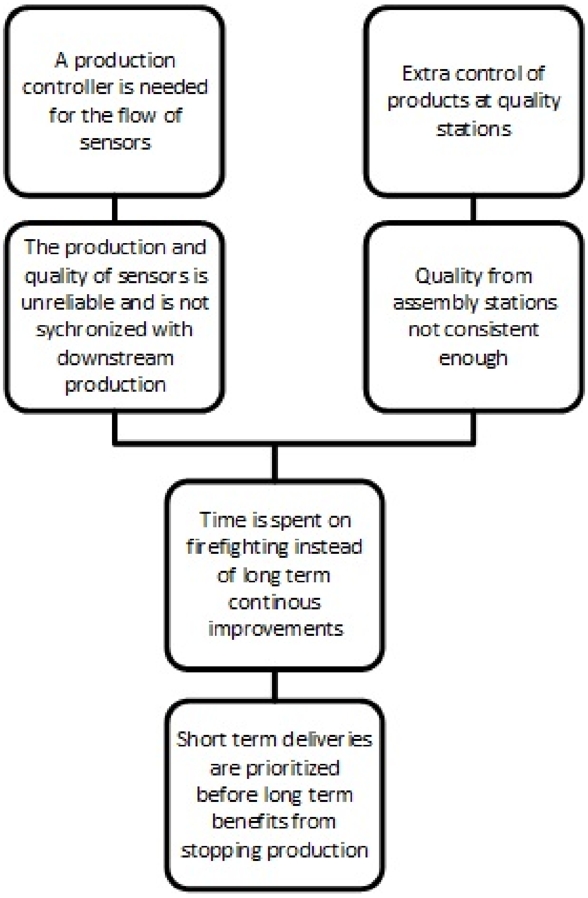


Figure D.7: Root causes related to miscellaneous wastes

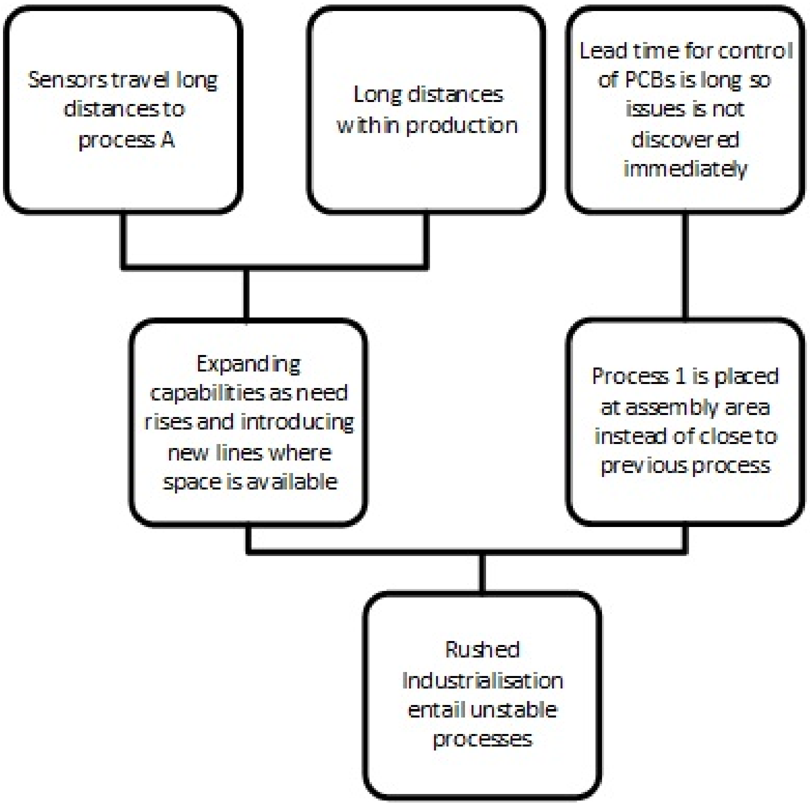


Figure D.8: Root causes related to miscellaneous wastes